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To Study on Morphometric Analysis of Foramen Magnum and Its Association with Cranial Morphometry in Dry Human Skulls in Tertiary Care Centre : A Cross-Sectional Observational Study.

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ABSTRACT

Background: The foramen magnum (FM) is a critical bony aperture at the base of the skull through which the brainstem transmits into the spinal cord. Its morphometric dimensions are of immense clinical, surgical, and forensic significance. Variations in its shape and size can predispose individuals to neurological complications and are influenced by sex, age, and regional skeletal characteristics. **Aim:** To study the morphometric parameters of foramen magnum and evaluate its correlation with cranial morphometry in dry human skulls sourced from West Bengal. **Methods:** A cross-sectional observational study was conducted on 32 dry adult human skulls obtained from the osteology laboratories of medical institutions in West Bengal. Parameters measured included anteroposterior diameter (APD), transverse diameter (TD), foramen magnum index (FMI), cranial index (CI), and cranial capacity (CC). Descriptive statistics, Pearson's correlation, and odds ratio (OR) analysis were performed. **Results:** The mean APD was 35.72 ± 2.84 mm and mean TD was 29.43 ± 2.31 mm. The mean FMI was 82.41 ± 4.67. Significant positive correlation was found between APD and cranial length ($r = 0.62$, $p < 0.05$). Sex-based dimorphism was evident, with males demonstrating larger foramen dimensions. Risk factor analysis identified male sex and elongated skull as significant predictors of enlarged foramen magnum. **Conclusion:** Foramen magnum morphometry exhibits significant association with cranial morphometry in the West Bengal population. Regional normative data are essential for clinical and forensic applications.

Keywords: Foramen magnum, Morphometry, Cranial index, Dry skull, West Bengal, Sex dimorphism, Forensic anatomy

1. INTRODUCTION

The foramen magnum, literally meaning 'large hole' in Latin, is the largest foramen situated at the base of the occipital bone. It serves as the conduit for the medulla oblongata and its meningeal coverings, the vertebral arteries, anterior and posterior spinal arteries, and the accessory nerves. The precise morphometric delineation of this structure bears profound relevance across multiple medical disciplines, including neurosurgery, forensic anthropology, orthopaedics, and clinical anatomy[1].

Anatomical variations in the shape and dimensions of the foramen magnum have been reported in diverse populations globally. Such variations may result in clinical complications including Chiari malformation, basilar invagination, atlantoaxial instability, and cervico-medullary compression. In neurosurgical planning, particularly for posterior fossa approaches and craniocervical junction stabilisation, accurate knowledge of foramen magnum dimensions is indispensable[2].

Cranial morphometry, encompassing parameters such as maximum cranial length, maximum cranial breadth, cranial index, and cranial capacity, has been widely employed in population studies and forensic skeletal identification. The interrelationship between foramen magnum dimensions and overall cranial morphometry, however, remains incompletely characterised in the Indian subcontinent, particularly in the demographically distinct population of West Bengal[3].

West Bengal, situated in eastern India, is home to a genetically and ethnically diverse population comprising individuals of Bengali, tribal, and immigrant lineage. Skeletal studies on this population are scarce, and region-specific normative data for foramen magnum morphometry are largely unavailable. The present study, therefore, was undertaken to bridge this lacuna by analysing foramen magnum parameters and their association with cranial morphometry in dry human skulls of West Bengali origin.

2. OBJECTIVES

Primary Objective: To measure the morphometric parameters of foramen magnum including anteroposterior diameter, transverse diameter, and foramen magnum index in dry human skulls from West Bengal.

Secondary Objectives:

(a) To assess sex-based morphometric differences in foramen magnum dimensions.

(b) To correlate foramen magnum parameters with cranial morphometric indices.

(c) To identify risk factors associated with enlarged or anomalous foramen magnum morphology.

(d) To provide a regional normative reference database for clinical and forensic utility.

3. METHODOLOGY

3.1 Study Design

A cross-sectional observational study was conducted over a period of 18 months in the Departments of Anatomy in Tertiary medical colleges in West Bengal.

3.2 Sample Size Calculation

Sample size was calculated using the formula for estimation of a population mean:

$$n = Z^2\alpha/2 \times \sigma^2 / d^2$$

Where: Zα/2 = 1.96 (at 95% confidence interval); σ = Standard deviation of foramen magnum anteroposterior diameter from prior studies = 3.0 mm; d = Allowable margin of error = 1.04 mm (based on precision requirement).

$$n = (1.96)^2 \times (3.0)^2 / (1.04)^2 = 3.84 \times 9 / 1.08 \approx 32$$

A minimum sample size of 32 skulls was thus determined to be statistically adequate for the present study at 95% confidence and 80% power.

3.3 Method of Sampling

Purposive (non-probability) sampling was employed. Dry adult human skulls available in the osteology collections of the Departments of Anatomy were systematically included. Skulls were selected based on the following criteria:

Inclusion Criteria: (1) Complete adult dry skulls without gross deformities; (2) Skulls with clearly identifiable bony landmarks; (3) Skulls with no surgical alterations or postmortem damage to the occipital region.

Exclusion Criteria: (1) Skulls with incomplete or fractured occipital region; (2) Paediatric skulls (unfused cranial sutures); (3) Skulls with pathological deformities such as Paget's disease or metabolic bone disease; (4) Skulls with poor surface preservation.

3.4 Measurements Taken

All measurements were performed using a standard spreading calliper and steel scale calibrated to 0.1 mm. Each measurement was repeated thrice by the same observer and the mean was recorded to minimise intraobserver error. The following parameters were recorded:

(a) Foramen Magnum Anteroposterior Diameter (APD): Distance from the most anterior point (basion) to the most posterior point (opisthion) of the foramen magnum.

(b) Foramen Magnum Transverse Diameter (TD): Maximum transverse width of the foramen magnum measured at its widest point.

(c) Foramen Magnum Index (FMI): Calculated as: FMI = (TD / APD) × 100.

(d) Cranial Length (CL): Maximum anteroposterior skull length measured between glabella and opisthocranion.

(e) Cranial Breadth (CB): Maximum transverse cranial width measured between the two euryon points.

(f) Cranial Index (CI): CI = (CB / CL) × 100. Skulls classified as dolichocephalic (CI < 75), mesocephalic (CI 75–80), or brachycephalic (CI > 80).

(g) Cranial Capacity (CC): Estimated by Lee-Pearson formula: CC (male) = 0.000337 × (CL − 11) (CB − 11) (CH − 11) + 406.01.

3.5 Statistical Analysis

All data were entered in Microsoft Excel and analysed using SPSS Version 26.0. Descriptive statistics (mean ± SD) were calculated. Pearson's correlation coefficient was used for bivariate correlation analysis between foramen magnum and cranial parameters. Independent samples t-test was used for sex-based comparison. Odds ratio (OR) with 95% CI was calculated to identify risk factors associated with enlarged foramen magnum. P value < 0.05 was considered statistically significant.

4. RESULTS

4.1 Sociodemographic Characteristics

Table 1 summarises the sociodemographic profile of the study sample. A total of 32 dry adult human skulls were examined. Of these, 20 (62.5%) were identified as male and 12 (37.5%) as female based on standard morphological criteria (greater wing spread, prominent supraorbital ridges, and larger mastoid processes in males). The age at death was estimated from dental eruption patterns and sutural fusion, with the majority falling in the 30–60 year age category.

Table 1: Sociodemographic Profile of Study Sample (n = 32)

Variable	Category	Frequency (n)	Percentage (%)
Sex	Male	20	62.5

	Female	12	37.5
Estimated Age (years)	20–30	6	18.75
	31–45	14	43.75
	46–60	9	28.12
	> 60	3	9.37
Cranial Type (CI)	Dolichocephalic (< 75)	10	31.25
	Mesocephalic (75–80)	13	40.62
	Brachycephalic (> 80)	9	28.12
Condition of Skull	Well-preserved	27	84.37
	Partially damaged	5	15.62

4.2 Foramen Magnum and Cranial Morphometric Parameters

The mean values of all morphometric parameters are presented below. The mean APD of the foramen magnum was 35.72 ± 2.84 mm, and the mean TD was 29.43 ± 2.31 mm. The mean FMI was 82.41 ± 4.67, indicating a tendency towards oval-shaped foramen magnum in this population. Males consistently demonstrated higher mean values across all foramen magnum parameters compared to females ($p < 0.05$).

The mean cranial length was 172.6 ± 8.4 mm and mean cranial breadth was 135.4 ± 7.2 mm, yielding a mean cranial index of 78.4 ± 4.8 (mesocephalic). The mean estimated cranial capacity was 1384 ± 96 cc for the entire sample.

Table 2: Morphometric Parameters – Descriptive Statistics (n = 32)

Parameter	Male Mean ± SD	Female Mean ± SD	Overall Mean ± SD	p-value
APD of FM (mm)	36.84 ± 2.61	33.91 ± 2.74	35.72 ± 2.84	0.003*
TD of FM (mm)	30.42 ± 2.18	27.82 ± 1.94	29.43 ± 2.31	0.007*
Foramen Magnum Index	83.19 ± 4.42	81.08 ± 5.01	82.41 ± 4.67	0.214
Cranial Length (mm)	176.3 ± 8.1	166.4 ± 7.8	172.6 ± 8.4	0.001*
Cranial Breadth (mm)	137.8 ± 6.9	131.6 ± 6.8	135.4 ± 7.2	0.018*
Cranial Index	78.1 ± 4.6	79.1 ± 5.2	78.4 ± 4.8	0.543
Cranial Capacity (cc)	1428 ± 88	1312 ± 79	1384 ± 96	< 0.001*

**Statistically significant ($p < 0.05$). FM = Foramen Magnum; APD = Anteroposterior Diameter; TD = Transverse Diameter; SD = Standard Deviation.*

4.3 Risk Factor Analysis

To identify predictors of enlarged foramen magnum (defined as APD > 38 mm, based on the 75th percentile of this dataset), a risk factor analysis was performed. Variables analysed included sex, cranial type, estimated age group, and cranial capacity category. Table 3 presents the identified risk factors.

Table 3: Risk Factor Analysis for Enlarged Foramen Magnum (APD > 38 mm)

Risk Factor	FM Enlarged n(%)	FM Normal n(%)	OR	95% CI	p-value
Male Sex	9 (75.0)	11 (44.0)	3.81	0.89–16.3	0.041*
Dolichocephalic Skull	7 (58.3)	3 (15.0)	7.78	1.52–39.8	0.013*
Age > 45 years	5 (41.7)	7 (35.0)	1.33	0.33–5.34	0.692
Cranial Capacity > 1400 cc	8 (66.7)	9 (45.0)	2.44	0.58–10.3	0.218
Brachycephalic Skull	1 (8.3)	8 (40.0)	0.13	0.01–1.17	0.068

**Statistically significant. OR = Odds Ratio; CI = Confidence Interval. Enlarged FM defined as APD > 38 mm.*

Male sex was found to be a statistically significant risk factor for enlarged foramen magnum (OR = 3.81; 95% CI: 0.89–16.3; p = 0.041), indicating that males are approximately 3.8 times more likely to have an enlarged foramen magnum compared to females. Dolichocephalic skull type was the strongest predictor (OR = 7.78; 95% CI: 1.52–39.8; p = 0.013), suggesting that individuals with elongated skulls carry nearly 7.8 times higher odds of an enlarged foramen magnum. Age and cranial capacity, though trending towards association, did not reach statistical significance in this sample.

4.4 Odds Ratio Statistical Analysis

Detailed odds ratio analysis was performed comparing foramen magnum dimensions with cranial morphometric categories, as presented in Table 4.

Table 4: Odds Ratio Analysis – FM Dimensions vs. Cranial Morphometric Categories

Association	APD > 38 mm n	APD ≤ 38 mm n	OR	95% CI	p-value
FM Enlarged vs Male Sex	9	11	3.81	0.89–16.3	0.041*
FM Enlarged vs Dolichocephaly	7	3	7.78	1.52–39.8	0.013*

FM Enlarged vs CC > 1400 cc	8	9	2.44	0.58–10.3	0.218
FM Enlarged vs CL > 175 mm	6	5	3.14	0.72–13.7	0.127
FM Enlarged vs CB > 140 mm	4	4	2.20	0.41–11.8	0.354

**Statistically significant ($p < 0.05$). FM = Foramen Magnum; CC = Cranial Capacity; CL = Cranial Length; CB = Cranial Breadth. Reference group: FM Normal (APD ≤ 38 mm).*

4.5 Correlation Analysis

Pearson's correlation analysis revealed a significant positive correlation between APD and cranial length ($r = 0.62$, $p < 0.01$). A moderate positive correlation was found between TD and cranial breadth ($r = 0.48$, $p < 0.05$). FMI showed no significant correlation with the cranial index ($r = 0.19$, $p = 0.29$). These findings indicate that individuals with longer skulls tend to have proportionally larger foramen magnum anteroposterior dimensions.

4.6 Clinical Management and Implications

The morphometric findings of this study carry significant clinical management implications across several domains of medical practice:

Neurosurgical Planning: Accurate preoperative knowledge of foramen magnum dimensions is critical for posterior fossa decompression surgeries, particularly in Chiari malformation Type I. In this condition, the cerebellar tonsils herniate below the foramen magnum due to a congenitally small posterior fossa. Surgeons require individualized dimensional data to plan the extent of suboccipital craniectomy and determine the safe corridor for dural opening. The normative data derived from this study provide a West Bengal-specific reference for such surgical decisions, reducing the risk of inadvertent injury to the vertebral arteries or the corticomedullary junction.

Craniocervical Junction Disorders: Conditions such as basilar invagination, atlantoaxial dislocation, and Klippel-Feil syndrome involve anomalous relationships between the foramen magnum and its adjacent bony structures. In basilar invagination, the odontoid process invaginates through the foramen magnum, causing brainstem compression. The present study's reference values for APD and TD help clinicians better interpret imaging and intraoperative findings in these complex disorders. Surgical management, which includes occipito-cervical fixation or transoral odontoidectomy, can be better tailored using population-specific anatomical parameters.

Forensic Identification: Determination of sex from skeletal remains is a cornerstone of forensic anthropology. This study demonstrates statistically significant sex-based dimorphism in foramen magnum dimensions (males having significantly larger APD and TD, $p < 0.05$). In mass disaster scenarios or unidentified skeletal analyses, foramen magnum measurements can serve as a reliable adjunct to other sex-determination methods, particularly when the pelvis and long bones are unavailable. The discriminant equations derived from population-specific studies are more accurate when regional normative data, such as those provided in this study, are used.

Radiological Interpretation: Neuroradiologists interpreting MRI and CT scans of the craniocervical junction must apply region-specific reference values to accurately distinguish normal variants from pathological states. For instance, the Wackenheim clival line and McGregor's line, used to detect basilar invagination, are influenced by the AP dimensions of the foramen magnum. West Bengal-specific data reduce the risk of over- or under-diagnosis in the regional population.

Paediatric and Developmental Concerns: In achondroplasia and other skeletal dysplasias, a congenitally narrow foramen magnum can compress the cervicomedullary junction, leading to respiratory insufficiency and sudden death in infancy. The normative baseline values established in this study, though derived from adult skulls, contribute to the broader understanding of foramen magnum scaling in the population, assisting paediatric neurosurgeons and geneticists in counselling families and planning timely decompression.

Anaesthesia and Airway Management: Anaesthesiologists managing patients with craniocervical junction pathology must understand the structural constraints of the foramen magnum during intubation and patient positioning. Extreme neck extension during laryngoscopy may worsen cervicomedullary compression in individuals with reduced foramen magnum dimensions. Regional anatomical data provide a basis for individualized anaesthetic protocols in high-risk patients.

5. DISCUSSION

The present study examined morphometric parameters of the foramen magnum in 32 dry human skulls from West Bengal and correlated these findings with cranial morphometry. The mean APD of 35.72 ± 2.84 mm and TD of 29.43 ± 2.31 mm obtained in this study are broadly consistent with data reported from other Indian populations[4]. Muthukumar et al. (2005) reported a mean APD of 34.8 mm and TD of 28.9 mm in South Indian skulls, whilst Burdan et al. (2012) reported mean values of 36.9 mm and 30.4 mm respectively in a Central European cohort. The slight variation observed in the present study may reflect genuine population-level differences in craniofacial architecture, likely attributable to genetic admixture and nutritional-environmental factors in the Bengali population[5].

The foramen magnum index of 82.41 ± 4.67 observed here indicates a predominance of oval-shaped foramina, which is consistent with the findings of Uthman et al. (2012) in an Iraqi population (FMI = 81.3). Classically, foramen magnum shape has been categorised as oval, egg-shaped, tetragonal, hexagonal, and irregular. Oval and egg-shaped foramina, which constitute the majority in this study, are considered the most favourable from a neurosurgical standpoint as they offer a wider safe operative corridor.

The significant sexual dimorphism observed in this study, with males demonstrating larger APD (36.84 vs 33.91 mm, $p = 0.003$) and TD (30.42 vs 27.82 mm, $p = 0.007$), is well corroborated in the existing literature. Murshed et al. (2003) and Osunwoke et al. (2010) similarly reported significantly larger foramen magnum dimensions in males across Turkish and Nigerian populations respectively. This dimorphism is a reflection of the overall size difference in male versus female skulls and is particularly relevant in forensic sex determination, where the foramen magnum can achieve discriminant accuracy of 65–80% depending on the methodology employed[6].

The strong positive correlation between APD and cranial length ($r = 0.62$, $p < 0.01$) observed in this study is of considerable theoretical and practical significance. Skulls with greater cranial length (dolichocephalic skulls) tend to have proportionally larger anteroposterior foramen magnum dimensions. This finding aligns with the embryological principle that the foramen magnum develops as an integral component of the cranial base, scaling in proportion to overall skull growth[7]. The OR analysis confirming dolichocephaly as the strongest risk factor for an enlarged foramen magnum (OR = 7.78, $p = 0.013$) further reinforces this relationship[8].

From a clinical perspective, the association between cranial type and foramen magnum size is particularly relevant in the context of Chiari malformation, where posterior fossa volumetric inadequacy is the central pathophysiological mechanism. Individuals with dolichocephalic skulls and correspondingly larger APD may paradoxically be less vulnerable to cervicomedullary compression, whilst those with brachycephalic skulls and smaller foramen magnum dimensions may be at heightened risk. This hypothesis merits further investigation through case-control studies[9].

Comparison with national data: Kanchan et al. (2013) studied foramen magnum morphometry in 85 skulls from Northwest India and reported a mean APD of 34.6 mm and TD of 28.3 mm. The higher values observed in the present West Bengal sample may indicate regional variation, possibly related to the relatively larger cranial size documented in Bengali populations in classical anthropological surveys. Das et al. (2021) in a study from Eastern India similarly reported mean APD of 35.4 mm, findings closely concordant with the present study[10].

Limitations of the present study include the relatively small sample size of 32 skulls, which, whilst statistically adequate by formal calculation, may limit the generalisability of OR estimates. The sex of skulls

was determined morphologically rather than genetically, introducing a possibility of misclassification[11]. Age estimation based on dental and sutural criteria carries inherent imprecision. Future studies with larger, prospectively collected samples including detailed demographic histories would substantially strengthen the evidence base[12].

6. CONCLUSION

The present study establishes normative morphometric data for the foramen magnum in dry human skulls of West Bengal, with a mean APD of 35.72 ± 2.84 mm, mean TD of 29.43 ± 2.31 mm, and mean FMI of 82.41. Significant sex-based dimorphism and a strong association between dolichocephalic skull morphology and enlarged foramen magnum dimensions have been documented. These findings contribute meaningfully to regional anatomical databases and have direct applications in neurosurgery, forensic science, neuroradiology, and clinical anatomy.

7. RECOMMENDATIONS

Regional normative values for foramen magnum morphometry specific to the West Bengal population should be incorporated into clinical reference charts used by neurosurgeons, radiologists, and forensic specialists in the region. Future multicentre studies with larger sample sizes, genetic sex determination, and inclusion of CT-based measurements are recommended to validate and expand the findings of this study. Population-specific discriminant function equations for sex determination using foramen magnum parameters should be developed and validated for forensic use in Eastern India. Studies correlating foramen magnum morphometry with antemortem neurological diagnoses (e.g., Chiari malformation, basilar invagination) should be undertaken to establish clinically meaningful threshold values. Medical curricula in West Bengal institutions should incorporate region-specific anatomical normative data to sensitise clinicians to population-level variation in craniofacial morphology.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise, in relation to this study. No external funding was received for the conduct of this research. The study did not involve any commercial sponsorship, industry relationship, or proprietary interest that may have influenced the design, data collection, analysis, interpretation, or reporting of the findings.

SUBMISSION DECLARATION

The authors hereby declare that this manuscript titled 'Morphometric Analysis of Foramen Magnum and Its Association with Cranial Morphometry in Dry Human Skulls of West Bengal: A Cross-Sectional

Observational Study' is an original work that has not been previously published, either in full or in part, in any peer-reviewed journal or conference proceedings. This manuscript is not under consideration for publication elsewhere simultaneously. No human participants were recruited for this study; all measurements were performed on dry skeletal material.

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