DOI: 10.7860/JCDR/2026/88928.23755

Original Article

Anatomy Section

Morphometry of the Foramen Magnum in Relation to Cranial Parameters: Evidence from South Indian Skulls

JE BENILSHA[1], DURGA DEVI GANESAN[2], KRISHNAVENI SHARATH[3]

ABSTRACT

Introduction: The Foramen Magnum (FM) is a critical anatomical region at the craniovertebral junction that transmits vital neurovascular structures and serves as an important landmark in forensic identification and neurosurgical procedures. Variations in dimensions and morphology exhibit population-specific patterns, making regional morphometric data essential for clinical and medico-legal applications.

Aim: To analyse the morphometric characteristics of the FM and its relationship with cranial dimensions in dry adult skulls from South India.

Materials and Methods: A cross-sectional study was conducted on 50 well-preserved adult dry skulls from the Department of Anatomy, Sree Balaji Medical College and Hospital, Chennai, Tamil Nadu, India. In the FM, Anteroposterior (APD) and Transverse Diameters (TD) were measured. The Maximum Cranial Length (MCL) and Maximum Cranial Breadth (MCB) were also measured using standardised osteometric instruments. Standard formulas were used to compute the Foramen Magnum Index (FMI) and the Cephalic Index (CI). Direct visual assessment was used to determine the FM shape. Descriptive statistics, linear regression, and Pearson's correlation were used to evaluate the data, with a significance level of $p<0.05$.

Results: The mean APD and TD of the FM were 33.7±2.02 mm and 27.66±2.42 mm, respectively. The average length and breadth of the skull were 180.37±1.75 mm and 130.65±1.11 mm, respectively. The CI showed that all skulls were dolichocephalic (72.44±0.73). The most prevalent FM morphology was oval (64%), followed by tetragonal (36%). The TD of the FM and cranial breadth were significantly positively correlated (p=0.005). Cranial length and APD showed a slight and non significant correlation (p=0.238).

Conclusion: The sample had an oval FM morphology and a primarily dolichocephalic cranial pattern. While cranial length had little effect on anteroposterior diameter of FM, a coordinated transverse growth pattern was observed between cranial breadth and the TD of the FM. These results offer population-specific information with implications for neurosurgery and forensic anthropology.

Keywords: Anthropometry, Cephalic index, Craniovertebral junction, Forensic anthropology, Osteometry, Skull base

INTRODUCTION

The FM is the largest opening at the base of the skull and represents a critical anatomical gateway between the cranial cavity and vertebral canal. It transmits vital neurovascular structures, including the medulla oblongata, vertebral arteries, spinal accessory nerves, and associated membranes of the skull base. Owing to its strategic location at the craniovertebral junction, variations in the size, shape, and orientation of the FM have significant implications in anatomy, forensic science, and neurosurgical practice [1].

Cranial morphometry plays a pivotal role in understanding population-specific skeletal characteristics of the skull. Parameters such as cranial length, cranial breadth, and CI have long been used in anthropological studies to classify skulls and assess biological variations among different ethnic groups [2]. The CI, in particular, serves as a reliable indicator of cranial shape and has been widely applied in forensic identification, especially when more sexually dimorphic bones are unavailable or are fragmented [2,3].

The FM is considered a relatively robust structure of the skull base and often remains intact, even in cases of severe cranial trauma [4]. This resilience makes it an important anatomical landmark for sex determination and population affinity studies in the field of forensic anthropology [1]. Several studies have demonstrated that FM dimensions exhibit sexual dimorphism and population-specific variability, underscoring the necessity of region-based morphometric standards rather than reliance on generalised global data [2,5].

From a neurosurgical perspective, detailed knowledge of FM morphology is essential for planning surgical approaches to the posterior cranial fossa and the craniovertebral junction. Procedures such as FM decompression, transcondylar approaches, and surgeries for congenital anomalies or tumours require a precise understanding of the dimensions and shape of the FM to minimise the risk of injury to adjacent neurovascular structures [6,7]. Even subtle anatomical variations can influence the surgical corridor and the safety of the procedure [8].

Previous morphometric studies have reported variations in the shape of the FM, including oval, round, tetragonal, pentagonal, and irregular forms, with differing prevalence across populations [2-4]. The number of shapes identified in a particular sample will be specific to that population and will depend on the classifying principles adopted [2,3]. However, limited data are available correlating FM dimensions with overall cranial morphometry in South Indian populations [8]. Establishing such correlations can provide valuable insights into coordinated cranial growth patterns and enhance the applicability of morphometric data in forensic and clinical settings.

Therefore, the present study was undertaken to analyse the morphometry and shape of the FM and to evaluate its relationship with cranial dimensions in dry skulls of adult human in South Indian origin. We hypothesise that FM dimensions correlate significantly with cranial morphometry particularly in the transverse axis. The present study aimed to contribute region-specific anatomical data that may aid in forensic identification and support neurosurgical planning involving the craniovertebral junction.

MATERIALS AND METHODS

A cross-sectional study was conducted in the Department of Anatomy, Sree Balaji Medical College and Hospital, Chennai, Tamil

Nadu, India using dry adult human skulls of South Indian origin during the period of August to December 2025. Since the study was exclusively conducted on dry osteological specimens from the collections in the department, representing individuals of unknown gender and age, the study was exempted from Institutional Ethical Committee approval.

Inclusion and Exclusion criteria: Only well-preserved adult skulls with complete ossification of the cranial sutures were considered eligible for inclusion. Skulls exhibiting fractures, deformities, congenital anomalies, pathological lesions, or any form of damage affecting the cranial vault, cranial base, or FM were excluded. This ensured the accuracy of the measurements and minimised potential sources of error related to postmortem damage or pathological alterations.

Sample size calculation: Sample size adequacy was determined using a standard statistical formula to ensure sufficient power to detect meaningful associations.

$n=Z^2\times\sigma^2/d^2$ [9,10].

Where, Z represents the standard normal deviate at a 95% confidence level (1.96), σ denotes the estimated standard deviation of FMI (3.26mm), and d indicates the allowable error which is taken as 1mm [11]. The allowable error of 1 mm was chosen considering earlier researches about morphometry of the FM, in which very small millimetric variations were described [2,3,11]. For descriptive investigations with continuous variables, this formula is recommended by Charan J and Biswas T (2013) and Daniel WW (1999) [9,10]. This computation indicated that a minimum sample size of 41 was needed; however, in order to increase accuracy and statistical reliability, 50 adult skulls were added.

Study Procedure

All measurements were performed using standardised osteometric instruments, including a spreading caliper and a digital vernier caliper with a least count of 0.01 mm to ensure precision and reproducibility. Measurements were carefully taken along clearly defined anatomical landmarks following established anthropometric protocols. The shapes were categorised twice, by the same individual, with any unclear categories determined by another individual and categorised by consensus, based on existing morphological protocols [2,3].

The following parameters were recorded for each skull [Table/Fig-1-3]:

- Maximum Cranial Length (MCL): measured as the linear distance from the glabella to the opisthocranion [2,4].
- Maximum Cranial Breadth (MCB): measured as the maximum transverse distance between the two euryons [2,4].
- Anteroposterior diameter of the FM: measured from the basion to the opisthion [2,4].
- Transverse Diameter (TD) of the FM: measured as the maximum width between the lateral margins of the FM [2,4].

All measurements were recorded in mm. In order to reduce intra-observer variability, all readings were made three times by the same rater, and the average reading was used for further analysis.

Cephalic Index (CI) and Foramen Magnum (FM) Morphology:

The CI was calculated for each skull using the standard formula:

$$\text{Cephalic Index} = \frac{\text{Maximum Cranial Breadth}}{\text{Maximum Cranial Length}} \times 100$$

Based on the calculated CI values, the skulls were categorised as dolichocephalic, mesaticephalic and brachycephalic. CI is also called as cranial index.

The shape of the FM was assessed by direct visual inspection and classified into distinct morphological categories. There were five different types of morphology such as oval, tetragonal round, pentagonal and irregular [2,3].

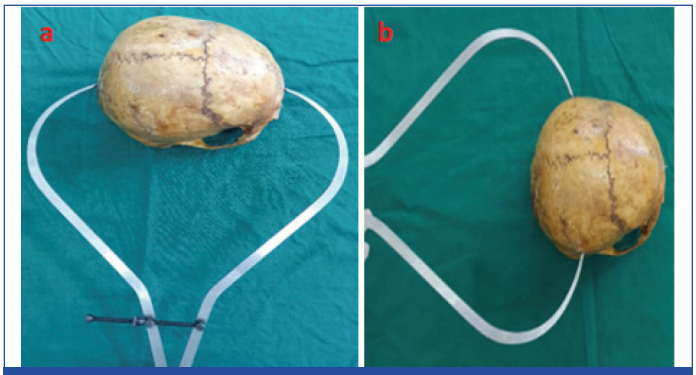
The FMI was calculated using the formula: FMI = (TD/AD) × 100.

STATISTICAL ANALYSIS

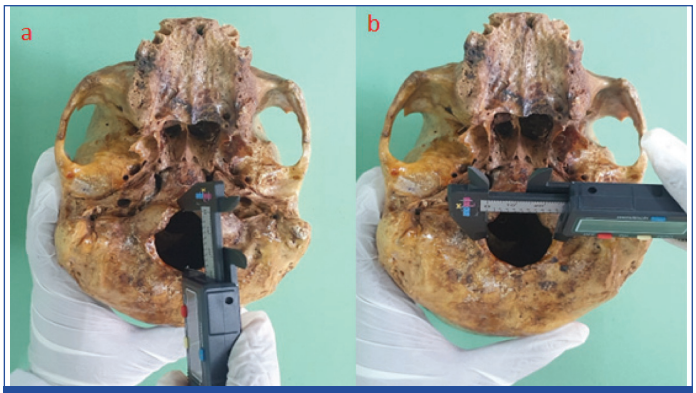
The collected data were entered into a statistical software Statistical Package for the Social Sciences (SPSS) version 27.0 for analysis. Descriptive statistics, including the mean and standard deviation, were computed for all measured parameters. Linear regression analysis was employed to evaluate the relationship between cranial dimensions and corresponding FM measurements. Statistical significance was set at p-value of less than 0.05.

RESULTS

A total of 50 adult dry human skulls of South Indian origin were included in the morphometric analysis. Cranial measurements and FM parameters were recorded using standardised osteometric techniques [Table/Fig-1,2], and the results were summarised.



[Table/Fig-1]: (a) Maximum Cranial Length (MCL) measured from glabella to opisthocranion; (b) Maximum Cranial Breadth (MCB) measured between euryons. Digital vernier caliper shown for scale.



[Table/Fig-2]: a) Anteroposterior diameter of FM measured from basion to opisthion; b) Transverse Diameter (TD) of Foramen Magnum (FM) measured between lateral margins. Digital vernier caliper shown for scale.

Morphometric Measurements

The descriptive statistics for all of the morphometric characteristics has been depicted in [Table/Fig-3]. The cranial index value of 72.44 indicates that the majority of the studied skulls fall within the

Variables	Mean±Standard Deviation N=50
Foramen Magnum (FM)	
Foramen Magnum (FM) Anteroposterior diameter	33.7±2.02 mm
Foramen Magnum (FM) Transverse Diameter (TD)	27.66±2.42 mm
Foramen Magnum Index (FMI)	82.28±8.05
Cranium	
Maximum Cranial Length (MCL)	180.37±1.75 mm
Maximum Cranial Breadth (MCB)	130.65±1.11 mm
Cranial Index	72.44±0.73

[Table/Fig-3]: Mean and standard deviation of various parameters.

dolichocephalic category, reflecting a relatively longer cranial shape in the examined population. This uniformity in dolichocephalic traits, with SD of 0.73 being quite low, may be attributed more to the homogeneity of the osteological sample than actual uniformity in morphological characteristics within the population at large. This almost perfect uniformity needs to be looked into carefully, since it may be biased sampling on account of being limited to one particular departmental collection.

Correlation and Regression Analysis between Cranial Morphometry and Parameters of Foramen Magnum (FM)

Pearson's correlation analysis was performed to assess the relationship between FM dimensions and cranial morphometry. A weak positive correlation was observed between the anteroposterior diameter of the FM and MCL (r=0.170), which was not statistically significant (p=0.238). A moderate positive correlation was found between the TD of the FM and MCB (r=0.392), which was statistically significant (p=0.005). The correlation between the FMI and cranial index showed a weak positive correlation (r=0.310), but this association was not statistically significant (p=0.112).

The regression results showed a β coefficient of 0.86 (95% CI: 0.27-1.44; p=0.005; R^2=0.154), suggesting that cranial breadth accounts for about 15.4% of the variation in the TD of the FM. In contrast, the relationship between cranial length and the anteroposterior diameter of the FM was not statistically significant (β=0.15; 95% CI: -0.10 to 0.39; p=0.238; R^2=0.021). This indicates that cranial length explains only around 2.1% of the variation in the anteroposterior diameter.

This describes a coordinated transverse growth pattern between the cranial vault and the cranial base, while longitudinal cranial growth appears to have limited influence on the anteroposterior dimension of the FM. This differential pattern of association is of particular relevance in forensic identification and neurosurgical approaches involving the posterior cranial fossa and craniovertebral junction [Table/Fig-4].

Variables	Pearson's r value	p-value (Correlation)	Beta Coefficient	95% CI	R square	p-value (Regression)
Foramen Magnum (FM) Anteroposterior diameter vs Maximum Cranial Length (MCL)	0.170	0.238	0.15	(-0.10-0.39)	0.021	0.238
Foramen Magnum (FM) TD Vs Maximum Cranial Breadth (MCB)	0.392	0.005	0.86	(0.27-1.44)	0.154	0.005*
Foramen Magnum Index (FMI) vs cranial index	0.310	0.112	NA			

[Table/Fig-4]: Correlation and regression analysis between cranial morphometry and parameters of Foramen Magnum (FM).
*Regression not performed due to non significant correlation (p=0.112)

Evaluation of the CI demonstrated a uniform cranial pattern within the study sample. As shown in [Table/Fig-5], all examined skulls (100%) were classified as dolichocephalic, with CI values ≤75. No skulls were categorised as mesaticephalic (76-80) or brachycephalic (>80). This consistent predominance of the dolichocephalic cranial type indicates minimal variability in overall cranial shape within the studied South Indian population.

Cephalic Index (CI) range	Category	Number of skulls N (%)
75 or less	Dolichocephalic	50 (100)
76-80	Mesaticephalic	0
More than 80	Brachycephalic	0

[Table/Fig-5]: Classification of skulls according to Cephalic Index (CI) values (n=50).

Morphology of the Foramen Magnum (FM)

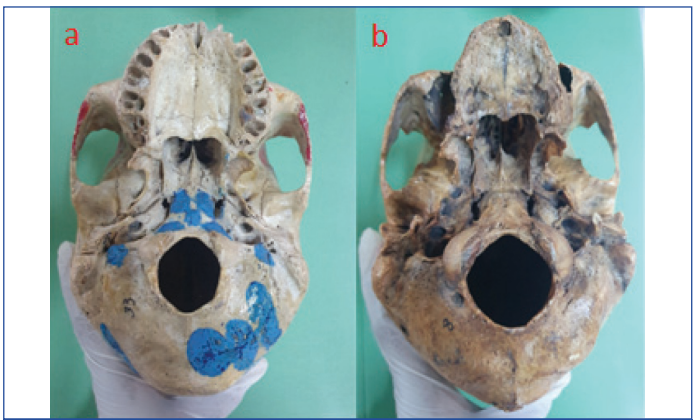
Morphological assessment of the FM revealed two distinct shapes in the studied skulls [Table/Fig-6,7]. The oval shape was the most frequently observed configuration, present in 32 skulls (64%), followed by the tetragonal shape, which was identified in 18 skulls (36%). No irregular or atypical shapes were noted. The predominance of the oval FM suggests it represents the characteristic morphology in this population, while the presence of tetragonal forms reflects normal anatomical variation relevant to both forensic classification and surgical planning at the craniovertebral junction. No round, pentagonal, or irregularly shaped FM were observed in this sample.

DISCUSSION

In present morphometric study of 50 adult dry skulls of South Indian origin, standardised measurements of the FM and cranial vault were recorded to explore their anatomical relationships and population characteristics. The mean FM APD (33.7±2.02 mm) and TD (27.66±2.42 mm) fell within the ranges reported in recent Indian morphometric studies, closely matching regional datasets and contributing to the growing body of population-specific normative measures [1,4-6]. Such consistency with prior data supports the reliability of osteometric protocols and highlights subtle inter-population variability in cranial-base dimensions.

The calculated FM index (82.28±8.05) and predominance of the dolichocephalic cranial type (100% in this sample) underscore a relatively uniform cranial structure in this cohort. Similar dolichocephalic predominance has been noted previously in South Indian samples, emphasising regional cranial morphology patterns that are potentially influenced by genetic and environmental factors [7,11]. Although some studies have documented a broader distribution of cranial types, population-specific analyses remain fundamental for forensic and anthropological applications [4,11].

Morphological classification revealed that the oval FM shape was the most frequent (64%), followed by the tetragonal shape (36%). Comparable shape distributions have been reported in contemporary skull studies, reinforcing the notion that the oval configuration is frequently encountered in adult crania across diverse geographic groups [4,8]. These morphological insights are valuable for neurosurgical planning, particularly when approaching lesions at the craniovertebral junction, where FM anatomy directly influences the surgical corridors.



[Table/Fig-6]: (a) Oval shaped FM; (b) Tetragonal shaped FM.

Shape	n (%)
Oval	32 (64)
Tetragonal	18 (36)
Total	50 (100)

[Table/Fig-7]: Shapes of Foramen Magnum (FM).

Study	Modality	Population	Key statistical findings	Comparative interpretation
Uthman AT et al., 2012 [12]	Helical Computed Tomography (CT) morphometry	Iraqi population	Sex estimation accuracy ~65-70% using FM parameters	Demonstrated moderate predictive value of FM metrics; did not assess cranial vault-FM growth relationship
Sadakat A and Pankaj K, 2024 [11]	Dry skull morphometry	North Indian population	Cranial–FM correlation coefficients < 0.40	Reported weak-to-moderate proportional association; no statistically significant transverse growth linkage highlighted
Misra D and Bateja S 2024 [19]	Conical Beam Computed Tomography (CBCT) morphometry	Indian radiologic cohort	Significant transverse FM differences ($p<0.05$)	Imaging-based sex differentiation emphasis; limited focus on cranial growth coordination
Dereli AK et al., 2025 [18]	3D CT morphometry	Turkish population	Significant sex differences in FM area and intracranial volume ($p<0.001$)	Multivariate radiologic analysis; population-specific imaging dataset
Present study (2026)	Direct osteometric (dry skull) analysis	South Indian adult skulls (n=50)	Significant correlation between cranial breadth and transverse FM diameter ($r=0.392$; $p=0.005$); non significant longitudinal correlation ($r=0.170$; $p=0.238$); 100% dolichocephalic	Demonstrates coordinated transverse cranial vault–base growth pattern in a homogeneous South Indian osteological cohort; provides region-specific normative baseline data

[Table/Fig-8]: Comparative overview of the present study with contemporary morphometric studies [11,12,18,19].

Correlation analyses indicated a weak, statistically non significant relationship between MCL and FM APD, suggesting a limited influence of longitudinal cranial growth on FM APD. This aligns with recent observations from a correlated morphometric study of dry skulls, which also reported weak or non significant longitudinal associations [9-11]. Conversely, a moderate and statistically significant positive correlation was observed between the MCB and FM TD. These findings demonstrate a coordinated transverse growth pattern between the cranial vault width and FM transverse dimension, indicating that lateral cranial expansion may contribute more directly to FM transverse dimension than expansion of FM Anteroposterior diameter [12-14].

The morphometric findings of present study revealed a statistically significant association between cranial breadth and FM TD, while longitudinal parameters showed no significant correlation. The following discussion focuses on the interpretation and clinical relevance of these findings. Sadakat A and Pankaj K found low-to-moderate cranial-FM correlations ($r<0.40$), indicating limited proportional prediction, which is consistent with the weak, non significant correlation between the FMI and CI [11]. Similarly, Uthman AT et al., used CT morphometry and reported reasonable sex estimation accuracy (about 65-70%) based on FM parameters [12]. This further supports the idea that anthropometric discrimination is supported by FM measures alone rather than conclusive. Dimensions of the FM are very important when performing surgical interventions, especially in cases of neurosurgery, where knowing the exact dimensions of the FM can help avoid complications [15]. Although there is enough research on FM dimensions and correlations, it cannot be denied that some investigators have proposed that FM dimensions may not be universally applicable across populations [16,17].

On the other hand, when multivariate factors are used, imaging-based studies show greater statistical distinction. Dereli AK et al., found highly significant gender-related variation in FM area and intracranial volume ($p<0.001$) using 3D CT analysis, while Misra D and Bateja S revealed substantial TD variations ($p<0.05$) using cone beam computed tomography scan [18,19]. Similarly, Kattimani A et al., found significant differences in FM measurements ($p<0.001$) among a sample of 200 individuals [20]. Comparative overview of the present study with contemporary morphometric studies have been done in [Table/Fig-8] [11,12,18,19].

The unique nature of the correlations found between transversely-oriented measurements of the cranial vault and the cranial base can possibly be attributed to the embryological basis of the processes involved. The growth of the base, which includes the FM, takes place via endochondral ossification, during which the precursors of bone are cartilage cells that are subsequently transformed into bone through the process of ossification in a well-regulated fashion. However, the vault, on the other hand, grows intramembraneously, meaning bone formation occurs directly through differentiation of mesenchymal tissue without an intervening cartilage stage. The FM as part of the base is more closely associated, thus, with the cranial growth that takes place endochondrally along the transverse plane rather than along the longitudinal axis of the cranium. This would account for the high positive correlation coefficient found between cranial breadth and the TD of the FM ($r=0.392$; $p=0.005$), as cranial breadth is influenced by intramembranous ossification at sutures, while FM develops endochondrally-hence the correlation may reflect coordinated but not identical growth mechanisms. The low positive coefficient found between the two longitudinally oriented measurements, on the other hand ($r=0.170$; $p=0.238$), indicates that FM development does not take place due to growth along the cranial suture planes in the sagittal plane, since longitudinal growth in the cranial vault happens intramembraneously [21].

From the standpoint of neurosurgery, these morphometric measurements directly correlate with surgical procedures performed at the craniovertebral junction. In cases where transcondylar access is used for lesions located on the ventral aspect of the brain stem and upper cervical cord, knowledge of the size of the FM and its anatomical relation to surrounding structures is essential. An increased TD of the FM found in crania with a broader skull shape could facilitate the surgical procedure by avoiding excessive resection of the condyle and thus decreasing the risk of developing atlantoaxial instability. For procedures such as decompression of the FM, e.g., in cases of Chiari malformation type I, it is necessary to measure the anteroposterior and transverse sizes of the FM beforehand in order to assess the degree of bone removal needed to relieve pressure on the structures inside [22]. Given the dominant oval shape of the FM among the examined South Indian population (64%), and its mean transverse dimension of 27.66±2.42 mm, these measurements constitute normative data specific to this population, which could be used by surgeons operating in this region as a reference point.

Overall, present study's results contribute valuable anthropometric data for the South Indian population and highlight specific correlations between cranial breadth and FM transverse dimensions. These insights have direct applicability in forensic identification protocols and surgical strategies involving the craniovertebral junction.

Limitation(s)

It is important to recognise the limitations of present study. The results may not be as broadly applicable as sample size is only of 50 dried adult human skulls. Gender and age differences in the samples could not be established since this study was based on unidentified osteological specimens from the department. This makes stratified morphometry impossible, and future researchers should consider using identifiable specimens or imagery-based data with established demographic characteristics. In addition, the

nearly uniform dolichocephalic pattern of the skull (CI=72.44±0.73; 100% dolichocephalic) might be due to sample bias arising from using a sample only from one department's collection of skulls, not because of any actual morphological variation in the population. ICC measurement to assess inter-rater reliability among the observers, which is one of the methods to enhance reliability, was not conducted in present study, and thus is considered as a study weakness.

Future studies should include such analysis involving at least two independent observers. Wider population comparisons were limited by the study's restriction to a specific regional population. Manual osteometric tools were used to take the measurements, which could increase observer-related variability. Furthermore, the cross-sectional design limits the ability to evaluate cranial growth trends causally. To improve clinical and forensic usefulness, future research should include radiological imaging methods and bigger, sex-differentiated samples.

CONCLUSION(S)

The present study provides population-specific morphometric data on the FM and cranial dimensions in South Indian dry skulls. The mean anteroposterior and TDs were consistent with previously reported Indian studies. Oval shape was the predominant FM morphology, followed by the tetragonal type. All skulls were classified as dolichocephalic, indicating uniform cranial morphology in the sample. A weak, non significant correlation was observed between cranial length and the anteroposterior diameter of the FM. In contrast, cranial breadth showed a statistically significant positive correlation with the TD of the FM. These findings suggest coordinated transverse growth between the cranial vault and cranial base. The results have relevance in forensic identification and anthropological research. They also hold clinical importance in surgical approaches to the craniovertebral junction. Further studies with larger and sex-differentiated samples are recommended to enhance applicability. Based on the low R^2 values of the two regression models, (R^2=0.021 and R^2=0.154), it is evident that cranial dimensions alone have little predictive capacity when estimating FM dimensions. The inclusion of more cranial factors in future investigations, using multiple regression models, could yield interesting results.

Acknowledgement

All authors have contributed equally to the conception, data analysis, and drafting of the manuscript and all have approved and reviewed the final version of the manuscript for publication.

REFERENCES

[1] Rogers TL. Determining the sex of human remains through cranial morphology. J Forensic Sci. 2005;50(3):493-500.
[2] Tubbs RS, Griessenauer CJ, Loukas M, Shoja MM, Cohen-Gadol AA. Morphometric analysis of the foramen magnum: An anatomic study. Neurosurgery. 2010;66(2):385-88; discussion 388. Doi: 10.1227/01.NEU.0000363407.78399.BA. PMID: 20087140.
[3] Chethan P, Prakash KG, Murlimanju BV, Prashanth KU, Prabhu LV, Saralaya VV, et al. Morphological analysis and morphometry of the foramen magnum: An anatomical investigation. Turk Neurosurg. 2012;22(4):416-19. Doi: 10.5137/1019-5149.JTN.4297-11.1. PMID: 22843456.
[4] Muthukumar N, Swaminathan R, Venkatesh G, Bhanumathy SP. A morphometric analysis of the foramen magnum region as it relates to the transcondylar approach. Acta Neurochir (Wien). 2005;147(8):889-95. Doi: 10.1007/s00701-005-0555-x. Epub 2005 Jun 9. PMID: 15924208.
[5] Raghavendra Babu YP, Kanchan T, Attiku Y, Dixit PN, Kotian MS. Sex estimation from foramen magnum dimensions in an Indian population. J Forensic Leg Med. 2012;19(3):162-67.
[6] Şeker A, Rhoton AL. The Anatomy of the Posterior Cranial Fossa. In: Özek M, Cinalli G, Maixner W, Sainte-Rose C. (eds). Posterior Fossa Tumors in Children. Cham: Springer; 2015. Pp.75-99. Available from: https://doi.org/10.1007/978-3-319-11274-9_3.
[7] Menezes AH. Craniovertebral junction anomalies: Diagnosis and management. Semin Pediatr Neurol. 1997;4(3):209-23.
[8] Govsa F, Ozer MA, Celik S, Ozmutaf NM. Three-dimensional anatomic landmarks of the foramen magnum for the craniovertebral junction. J Craniofac Surg. 2011;22(3):1073-76.
[9] Charan J, Biswas T. How to calculate sample size for different study designs in medical research? Indian J Psychol Med. 2013;35(2):121-26. Doi: 10.4103/0253-7176.116232.
[10] Daniel WW. Biostatistics: A foundation for analysis in the health sciences. 9th ed. New York: Wiley; 2009.
[11] Sadakat A, Pankaj K. Morphometric study of foramen magnum and its correlation with cranial morphometry in dry human skulls of North India. Indian J Clin Anat Physiol. 2024;11(3):178-82.
[12] Uthman AT, Al-Rawi NH, Al-Timimi JF. Evaluation of foramen magnum in gender determination using helical CT scanning. Dentomaxillofac Radiol. 2012;41(3):197-202.
[13] Murshed KA, Çiçekcibaşi AE, Tuncer I. Morphometric evaluation of the foramen magnum and variations in its shape: A study on computerized tomographic images of normal adults. Turk J Med Sci. 2003;33(5):301-06.
[14] Jain SK, Choudhary AK, Mishra P. Morphometric evaluation of foramen magnum for sex determination in a documented North Indian sample. J Evol Med Dent Sci. 2013;2(42):8093-98.
[15] Raveena S, Verma S, Arti, Vipin K. Morphometric and morphological study of foramen magnum. J Popul Ther Clin Pharmacol. 2024;31(6):1685-89.
[16] Kalambe YM, Bhadage CJ, Bhoosreddy AR, Virkar VV, Santan RS, Shahakar MS. Forensic prospect in maxillofacial radiology: A condensed review. AIJFR. 2025;6(6).
[17] Gupta AK, Shah GJ, Chaudhary A, Prasad RJ. Foramen magnum: A morphometric study in dried human skulls. NJHS. 2022; 2(1):01-06.
[18] Dereli AK, Sağtaş E, Akça A, Özgül HA, Şenol H, Acar K. Sex estimation by morphometric analysis of intracranial volume and foramen magnum using 3D CT. Pamukkale Med J. 2025;18(2):244-53.
[19] Misra D, Bateja S. Analyzing morphometry of foramen magnum using CBCT: A forensic radiology study. J Indian Acad Oral Med Radiol. 2024;36(4):442-46.
[20] Kattimani A, Swetha K, Bhayya H, Kardalkar SB. Foramen magnum as a tool for sexual dimorphism: A computed tomography study. J Indian Acad Oral Med Radiol. 2023;35:130-33.
[21] Lieberman DE, Pearson OM, Mowbray KM. Basicranial influence on overall cranial shape. J Hum Evol. 2000;38(2):291-315.
[22] Menezes AH, Traynelis VC. Anatomy and biomechanics of normal cranio-vertebral junction and biomechanics of stabilization. Childs Nerv Syst. 2008;24(10):1091-100.

PARTICULARS OF CONTRIBUTORS:
1. Postgraduate Student, Department of Anatomy, Sree Balaji Medical College and Hospital, Chennai, Tamil Nadu, India.
2. Professor and Head, Department of Anatomy, Sree Balaji Medical College and Hospital, Chennai, Tamil Nadu, India.
3. Professor, Department of Anatomy, Sree Balaji Medical College and Hospital, Chennai, Tamil Nadu, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. JE Benilsha,
Postgraduate Student, Anatomy, Sree Balaji Medical College and Hospital,
Chennai-600044, Tamil Nadu, India.
E-mail: benilsha1996@gmail.com

PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Mar 19, 2026
- Manual Googling: Apr 23, 2026
- iThenticate Software: Apr 25, 2026 (9%)

ETYMOLOGY: Author Origin

EMENDATIONS: 7

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? No
- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Mar 11, 2026**
Date of Peer Review: **Apr 02, 2026**
Date of Acceptance: **Apr 27, 2026**
Date of Publishing: **Jul 01, 2026**