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Morphological And Morphometrical Study Of Foramen Magnum: An NCCT Based Study

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Abstract
Background: *The foramen magnum (FM) is a critical anatomical structure at the cranial base, transmitting the medulla oblongata, vertebral arteries, meninges, and spinal roots of the accessory nerve. Its anatomical characteristics are clinically and anthropologically significant due to its location at the craniovertebral junction. The morphometric knowledge of the FM is necessary to rule out malformation, herniation, achondroplasia and any compressions to the vital structures passing through it.*
Objectives: *To assess the morphological and morphometrical study of foramen magnum by using cranial NCCT scans.*
Materials and methods: *The study was conducted on High quality Cranial NCCT of 261 images at the department of Radiodiagnosis, RIMS, Imphal, without any artifacts, blurry and malformation images. The images obtained were examined visually to analyse the variations in the shape of the FM. Measurements included the anteroposterior, transverse diameters, area and index of all the foramina were taken of both sexes (158 males and 103 females).*
Result: *The overall shape of the foramen magnum in the study were oval (45.6%), circular (17.2%), hexagonal (14.2%), tetragonal (9.2%), egg (5.4%), pentagonal (4.2%), and irregular (4.2%). The average anteroposterior diameter was 36.70±3.33 mm and transverse diameter was 31.48±2.93mm. The mean index was 86.09±7.73 and the area was 859.06±131.81mm^2.*
Conclusion: *The present study demonstrates sexual dimorphism in FM morphometry with males generally exhibiting larger dimensions. Variations in FM size and shape have implications for proper radiological diagnosis, neurosurgical approaches, forensic identification, and anthropological studies.*
Keywords: *Foramen magnum, morphometry, herniation, achondroplasia*

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I. Introduction

The foramen magnum (FM) occupies the central area of the floor.[1] It lies in an anteromedian position and leads into the posterior cranial fossa. It contains the lower end of the medulla oblongata, meninges, cerebrospinal fluid, vertebral arteries and veins, and the accessory nerves; the apical ligament of the dens and the tectorial membrane pass through it to attach to the internal basi occiput. It is oval and wider behind, with its greatest diameter being anteroposterior.[2] One-third of the FM lies in front and two-thirds behind a line joining the tips of the mastoid processes.[3] When the lower part of the cerebellum, the tonsils, descend abnormally through the FM, they may cause compression of the medulla at the level of the FM, a condition called tonsillar herniation or Chiari malformation.[2]

Structural configurations are known to vary racially and regionally. Understanding these ethno-regional differences enables personalized surgical approaches, improved preoperative planning, and encourages further research into region-specific neurological conditions.[4] Moreover, FM morphometry seems to be affected by several factors including various ethnical group or different population, sample size, sexual dimorphism and types of population, genetic, environment and socio-economic factors.[5] Gender determination in missing or damaged skeletal remains is a major problem in forensic medicine. To this end, numerous anatomic parameters, such as shape and dimensions of the FM, should be taken into consideration to solve this problem.[6]

Many authors have classified the shapes of the FM such as oval, circular, tetragonal, pentagonal, hexagonal and irregular. Variations in the shape of foramen magnum are important because of its effects on the vital structures which passes through it, can compress these structures.[7,8] These variations have become significant because of newer imaging techniques such as computed tomography and magnetic resonance imaging in the field of diagnostic medicine.[7] Radiologically, the skull is one of the most useful bones for accurate morphometric determination of sex. The use of radiological methods such as X-ray, computed tomography (CT) and magnetic resonance imaging, is striking and provides data that is consistent with measurements derived through using calipers in estimation of dry skull diameters.[9]

Significant sexual dimorphism was observed, with males generally having larger FM dimensions of the anteroposterior (APD) and transverse (TD) diameters.[10] In regard to the diameters of the foramen magnum, it is reported that the values are highly concordant with previous results. Of the two diameters, the anteroposterior diameter to be significantly greater in length than the TD.[11]

Thus, the present study of morphological and morphometric analysis of FM will be helpful not only in diagnosis, but also in planning of better operative procedures and to avoid complications of surgeries involving the skull base. Further, this study examines the morphometric parameters and shape variations of the FM in Manipuri population and compares the findings with previously published data from diverse populations.

II. Material And Methods

The study is a Cross-sectional study which was conducted at the Regional Institute of Medical Sciences (RIMS), Imphal, Manipur, in collaboration with the Departments of Anatomy and Radiodiagnosis. 261 cranial NCCT images of both sexes ranging from 18-75 years of age were taken for the study.

Study Design: Cross-sectional study

Study Location: Departments of Anatomy, Regional Institute of Medical Sciences (RIMS), Imphal, Manipur-795004, India.

Study Duration: September 2025 to December 2025

Sample size: 261 persons

Sample size calculation:

Based on the study conducted by Muhammad F et al[12] in 2023, Sample size was be calculated using the standard formula as follows:

$$n = \frac{Z^2_{1-\frac{\alpha}{2}} P(1-p)}{d^2}$$

Where;

- n = minimum sample size
- z = standard normal deviation, which is 1·96 at 95% confidence interval
- p = proportion in the target population, given as 33.3% (maximum proportion taken from oval shape foramen magnum)
- d = allowable error, given as 6%
- By substituting these values into the formula, we get :-
- n = $(1.96)^2$ x0.333x0.667/0.0036
- n = 237
- By taking 10% Nonresponse rate, Sample size will be (237+24) =261.

Subjects & selection method: The work comprised of the analysis of 261 cranial NCCT images of both sexes ranging from 18-75 years of age. Purposive Random sampling was done. They were enrolled with patients' records and were randomly collected from the database registered at the Radiology department according to inclusion and exclusion criterias. The study variables were:

- Independent variables: Age, Sex, Race.
- Dependent variables: Shape, anteroposterior and transverse diameters, area and index

Inclusion criteria:

- a) Normal human cranial NCCT scans (from 18-75 years of both sexes) for those who had computed tomography for various diagnostic reasons.
- b) High quality NCCT images.

Exclusion criteria:

- a) Low quality blurred images or artifacts.
- b) Scans of subjects with history of trauma, surgery or any other pathological abnormalities.
- c) Scans with congenital, acquired, focal brain lesions or deformities in the skull base.
- d) Scans without the proper extent of the foramen magnum.

Ethical Issue:

Ethical approval was obtained from the Research Ethics Board, Regional Institute of Medical Sciences, Imphal, Manipur, prior to commencement of the study (approval date: 10/09/2025 and approval number: A/206/REB/Prop(Sp)265/57/2025).

Procedure methodology:

Prior to the commencement of the study, ethical clearance was obtained from the Research Ethics Board (REB) of Regional Institute of Medical Sciences (RIMS). High quality Cranial NCCT images were collected from the department of Radiodiagnosis, RIMS, Imphal, without any artifacts, blurry and malformation images were used for the study through proper channel. The study tool used was Siemens Somota CT-SCAN 128 Dual Slice . The images obtained were examined visually to analyse the variations in the shape of the FM. Then, measurements included the anteroposterior, transverse diameters, area and index of all the foramina will be taken based on the H. M. Abo El-Atta et al[13] in 2020 (as shown in Figure no 1A).

- Measurement of the antero-posterior diameter (APD) of the foramen magnum (optimally viewed on sagittal section) – a line drawn from the basion to the opisthion.
- Measurement of the transverse diameter (TD) (optimally viewed on axial section) – a line drawn to connect both lateral margins of the foramen magnum at its greatest curvature.
- Foramen magnum area (FMA) was determined automatically using electronic calliper tool on the NCCT images. The cross-sectional area of foramen magnum was obtained after tracing its whole inner circumference on the images (as shown in Figure no 1B) based on Wani HA et al[14] in 2019.
- Foramen magnum index (FMI) was measured using the formula based on the H. M. Abo El-Atta et al[13]: [TD/APD].100

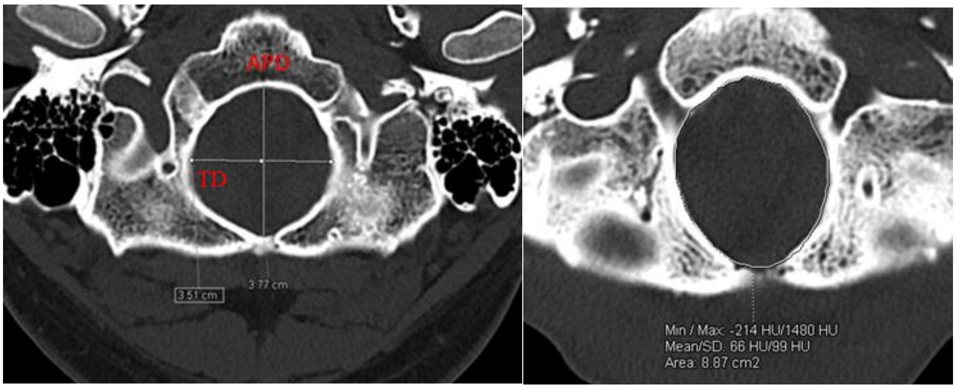

Figure no 1: Measurement of foramen magnum parameters on computed tomographic images. (A) Antero-posterior diameter (APD) and transverse diameter (TD). (B) Area.

Statistical analysis:

Data collected were checked for consistency and completeness. The data were entered into MS- Excel and will be analyzed by transferring into SPSS software, version 27.0 (IBM Inc., Armonk, NY, USA). Descriptive statistics like Mean, standard deviation and percentage were used to summarize continuous variables such as anteroposterior, transverse diameters, area and index. Analytical statistics like independent t-test and Pearson Correlation-coefficient were used. A p-value of <0.01 is considered as statistically significant.

III. Result

Male dominance is evident in every age group except 21–30 years, where females (12) slightly outnumber males (10). The highest male count is in the 61–70 years group (43), followed by 41–50 years (31). The highest female count is in the 51–60 and 61–70 years groups (24 each) as shown in (Table no 1 & Figure no 2).

Table no 1: Age and Sex Distribution

Age Group	Female	Percent	Male	Percent	Total	Percent
Upto 20 years	01	1.0	05	3.2	06	2.3
21 to 30 years	12	11.7	10	6.3	22	8.4
31 to 40 years	17	16.5	22	13.9	39	14.9
41 to 50 years	16	15.5	31	19.6	47	18.0
51 to 60 years	24	23.3	27	17.1	51	19.5
61 to 70 years	24	23.3	43	27.2	67	25.7
71 years and Above	09	8.7	20	12.7	29	11.1
Total	**103**	**100.0**	**158**	**100.0**	**261**	**100.0**

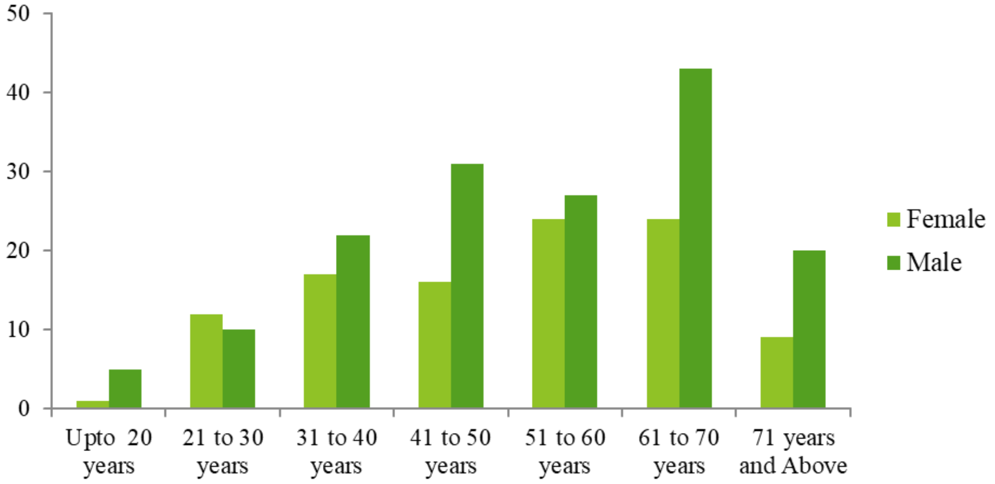

Figure no 2: Age and Sex Distribution Bar Graph

Table no 2. summarizes the anteroposterior diameter (APD) of the FM consistently higher mean values in males than females across all age groups. In the total sample, the mean APD was 36.21 ± 3.49 mm in females and 37.02 ± 3.19 mm in males, with an overall mean of 36.70 ± 3.33 mm. The greatest sex difference (4.72 mm) was observed in individuals up to 20 years of age.

The transverse diameter (TD) similarly demonstrated higher mean values in males in all age groups. The total mean TD was 30.78 ± 3.28 mm in females and 31.93 ± 2.58 mm in males, yielding an overall mean of 31.48 ± 2.93 mm.

Across age groups, males consistently exhibited greater FM area, with peak mean values observed in the 21–30 year age group. The total mean area was 826.04 ± 136.21 mm² in females and 880.58 ± 124.64 mm² in males, with an overall mean of 859.06 ± 131.81 mm². The highest mean areas were observed in the 21–30 year age group for both sexes, after which a gradual decline was noted with advancing age.

The FM index demonstrated comparatively smaller differences between sexes. The overall mean FM index was 85.31±7.96 mm in females and 86.60±7.56 mm in males, with a combined mean of 86.09±7.73 mm. Across age groups, the FM index showed a tendency to decrease from younger adulthood to middle age, followed by a slight increase in older individuals.

Table no 2: Mean and Standard Deviation (SD) for Foramen Magnum Indices by Age and Sex

FM Indices / Age Group	Anteroposterior (mm) Mean ± SD			Transverse (mm) Mean ± SD			Area (mm²) Mean ± SD			FM Index Mean ± SD		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
Upto 20 years	31.60±0.00	36.32±2.12	35.53±2.71	27.90±0.00	32.72±1.94	31.91±2.62	661.00±0.00	886.80±86.73	849.17±120.48	88.29±0.00	90.09±1.66	89.79±1.66
21 to 30 years	37.17±3.99	38.64±2.43	37.84±3.38	32.61±4.00	32.62±2.56	32.61±3.35	904.67±173.54	926.80±115.75	914.73±147.12	87.74±5.43	84.53±5.98	86.28±5.78
31 to 40 years	35.91±3.73	37.51±3.14	36.82±3.46	30.29±2.25	32.26±2.60	31.40±2.62	810.41±95.80	901.14±111.60	861.59±113.24	84.95±8.56	86.28±6.84	85.70±7.56
41 to 50 years	35.91±3.15	36.33±2.12	36.19±2.49	29.91±2.47	31.26±2.22	30.80±2.37	797.50±109.99	848.42±107.69	831.09±110.02	83.40±3.78	86.17±6.07	85.25±5.52
51 to 60 years	36.64±3.12	37.58±3.90	37.14±3.55	30.62±3.28	32.27±2.63	31.49±3.04	833.79±128.71	892.30±121.34	864.76±127.07	83.93±9.71	86.66±10.91	85.38±10.35
61 to 70 years	36.33±3.76	36.53±3.45	36.46±3.54	31.06±3.65	32.14±3.07	31.76±3.30	825.21±155.97	880.70±148.06	860.82±152.14	85.78±8.36	88.26±7.16	87.37±7.64
71 years and Above	35.06±3.37	37.19±3.42	36.53±3.49	30.86±3.94	31.13±1.87	31.04±2.62	801.33±144.42	867.10±126.75	846.69±133.49	88.27±9.37	84.16±7.10	85.43±7.94
Total	36.21±3.49	37.02±3.19	36.70±3.33	30.78±3.28	31.93±2.58	31.48±2.93	826.04±136.21	880.58±124.64	859.06±131.81	85.31±7.96	86.60±7.56	86.09±7.73

FM Oval shape dominates, accounting for nearly half of all cases (45.6%). Females (55.3%) are predominant over male (39.2%) in this study. Round shape is balanced across sexes (~17%) as compared to other shapes. Oval, Hexagonal and Round FM shapes together account for ~77% of all cases, showing these are the dominant FM shapes in this sample. Pentagonal and irregular shapes are least common overall (Figure no 3,4 & Table no 3).

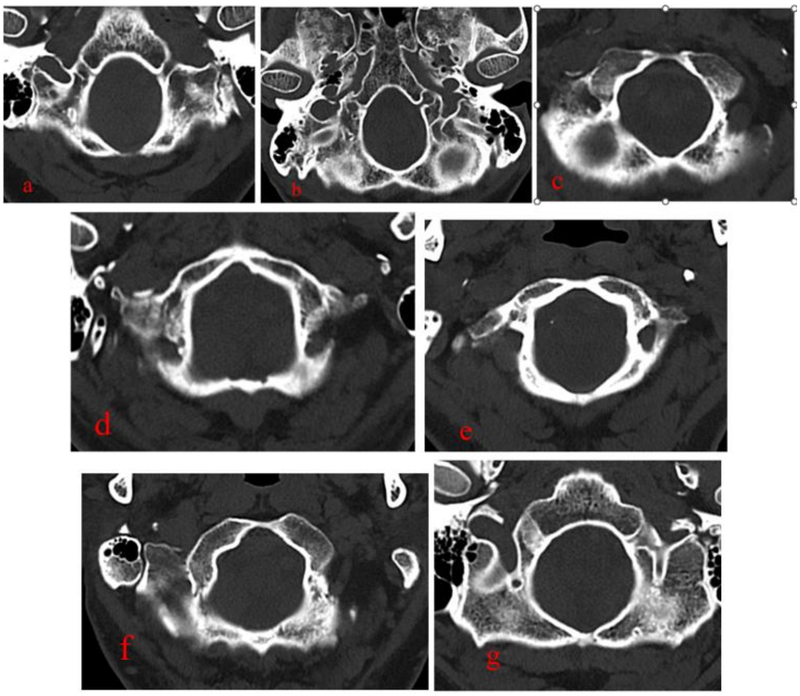

Figure 3: Different shapes of the foramen magnum (a) Oval, (b) Egg, (c) Tetragonal, (d) Pentagonal, (e) hexagonal, (f) Irregular, and (g) Round

Table no 3: FM Shape and Sex Distribution

FM Shape	Female	Percent	Male	Percent	Total	Percent
Oval	57	55.3	62	39.2	119	45.6
Egg	03	2.9	11	7.0	14	5.4
Tetragonal	09	8.7	15	9.5	24	9.2
Pentagonal	03	2.9	08	5.1	11	4.2
Hexagonal	12	11.7	25	15.8	37	14.2
Irregular	02	1.9	09	5.7	11	4.2
Round	17	16.5	28	17.7	45	17.2
Total	**103**	**100.0**	**158**	**100.0**	**261**	**100.0**

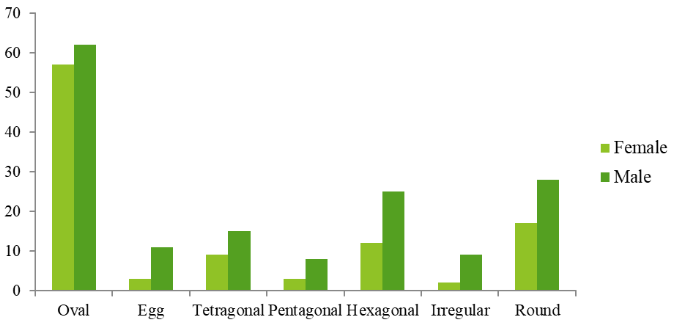

Figure no 4 : FM Shape and Sex Distribution Bar Graph

FM Indices / Shape of FM	Anteroposterior (mm)			Transverse (mm)			Area (mm ^{2})			FMI		
	Mean ± SD			Mean ± SD			Mean ± SD			Mean ± SD		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
Oval	36.75±3.68	37.80±3.42	37.30±3.57	29.64±2.44	31.07±2.44	30.38±2.53	801.32±126.99	871.02±126.22	837.63±130.81	81.03±6.40	82.62±8.10	81.86±7.35
Egg	33.63±2.47	35.35±3.53	34.99±3.32	30.37±0.81	30.55±2.90	30.51±2.57	794.33±51.00	813.09±144.25	809.07±128.33	90.58±6.23	86.75±7.44	87.57±7.15
Tetragonal	37.79±2.31	35.91±3.10	36.62±2.93	34.90±4.08	32.74±2.08	33.55±3.09	937.78±134.64	844.93±120.70	879.75±131.46	92.25±7.93	91.56±7.22	91.82±7.33
Pentagonal	34.10±3.40	36.73±2.13	36.01±2.64	31.57±2.80	32.18±1.47	32.01±1.78	791.00±129.46	894.13±78.16	866.00±99.74	92.95±9.43	87.80±5.15	89.20±6.49
Hexagonal	34.67±3.11	36.52±2.29	35.92±2.69	30.29±3.34	32.25±2.69	31.62±3.02	807.67±124.15	883.04±121.37	858.59±125.73	87.35±5.00	88.32±4.70	88.00±4.75
Irregular	36.65±1.63	36.76±4.60	36.74±4.15	33.00±3.25	33.49±3.28	33.40±3.11	840.50±202.94	950.56±165.89	930.55±167.68	89.93±4.88	91.42±4.55	91.15±4.39
Round	35.44±3.37	37.14±2.77	36.49±3.09	32.47±3.42	33.07±2.17	32.84±2.69	872.82±157.98	918.82±101.35	901.44±126.04	91.73±6.02	89.29±5.69	90.21±6.03
Total	36.21±3.49	37.02±3.19	36.70±3.33	30.78±3.28	31.93±2.58	31.48±2.93	826.04±136.21	880.58±124.64	859.06±131.81	85.31±7.96	86.60±7.56	86.09±7.73

Table no 4: Mean and Standard Deviation (SD) for Foramen Magnum Indices by Shape and Sex

Table no 4. showed the males anteroposterior diameter (APD) had higher mean diameters than females across most shapes except in tetragonal shape. Tetragonal-shaped foramina exhibited the highest mean APD in females (37.79 ± 2.31 mm), whereas oval-shaped foramina showed the highest values in males (37.80 ± 3.42 mm). Egg-shaped foramina demonstrated the lowest anteroposterior dimensions in both sexes.

Transverse diameter (TD) also differed according to FM shape, with tetragonal and irregular shapes showing the highest mean values. Females with tetragonal-shaped foramina demonstrated the greatest TD (34.90 ± 4.08 mm), while males showed maximum values in irregular-shaped foramina (33.49 ± 3.28 mm).

FM area varied markedly across different shapes, with tetragonal and irregular shapes demonstrating the largest mean areas. The highest mean area was observed in irregular-shaped foramina in males (950.56 ± 165.89 mm²), followed by round and pentagonal shapes. However, the highest mean area was observed in tetragonal-shaped foramina in females (937.78±134.64). Egg (809.07±128.33) and oval shapes exhibited comparatively smaller areas.

The FM index showed significant variation across different shapes. Pentagonal-shaped foramina demonstrated the highest mean FMI in females (92.95 ± 9.43), while tetragonal-shaped foramina showed the highest values in males (91.56±7.22). Oval-shaped foramina exhibited the lowest FMI values in both sexes.

Table no 5 : Mean, SD, SEM, Range, t and p values for FM Indices by Sex

FM Indices	Female (n = 103)				Male (n = 158)				t	p
	Range	Mean	SD	SEM	Range	Mean	SD	SEM		
Anteroposterior	28.60 – 45.50	36.21	3.49	0.34	27.40 – 47.20	37.02	3.19	0.25	1.89	0.06
Transverse	25.70 – 40.90	30.78	3.28	0.32	26.20 – 39.40	31.93	2.58	0.21	2.99	0.00
Area	588.00 – 1272.00	826.04	136.21	13.42	535.00 – 1268.00	880.58	124.64	9.92	3.27	0.00
FMI	63.74 – 105.14	85.31	7.96	0.78	69.04 – 124.09	86.60	7.56	0.60	1.31	0.19

Males demonstrated higher mean values than females across all measured parameters (Table no 5). The mean APD was slightly greater in males (37.02 ± 3.19) than in females (36.21 ± 3.49); however, this difference did not reach statistical significance ($t = 1.89$, $p = 0.06$). In contrast, the TD was significantly larger in males (31.93 ± 2.58) compared to females (30.78 ± 3.28), with a statistically significant difference ($t = 2.99$, $p < 0.01$). Similarly, the FM area was significantly greater in males (880.58 ± 124.64) than in females (826.04 ± 136.21) ($t = 3.27$, $p < 0.01$). Although the FM index (FMI) showed a slightly higher mean in males (86.60 ± 7.56) than females (85.31 ± 7.96), the difference was not statistically significant ($t = 1.31$, $p = 0.19$). Overall, statistically significant sex differences were observed for the TD and area, whereas APD and FMI did not differ significantly between sexes.

Table no 6 : Correlation Matrix of FM Indices and their p-values

	Transverse	Area	FMI
Anteroposterior	.531**	.786**	-.463**
p-value	.000	.000	.000
Transverse		.844**	.498**
p-value		.000	.000
Area			.072
p-value			.246

**. Correlation is significant at the 0.01 level.

A moderate positive correlation was observed between the APD and TD ($r = 0.531$, $p < 0.001$), indicating that increases in one dimension are associated with increases in the other (Table no 6). The APD also demonstrated a strong positive correlation with FM area ($r = 0.786$, $p < 0.001$), reflecting its substantial contribution to overall FM size. In addition, a moderate negative correlation was found between the APD and FMI ($r = −0.463$, $p < 0.001$), suggesting that greater APD is associated with lower FMI values.

The TD showed a strong positive correlation with FM area ($r = 0.844$, $p < 0.001$), indicating that transverse dimension plays a major role in determining FM area. It was also moderately positively correlated with FMI ($r = 0.498$, $p < 0.001$), suggesting that increases in transverse diameter are associated with higher FMI values.

No statistically significant correlation was observed between FM area and FMI ($r = 0.072$, $p = 0.246$), indicating that overall FM size does not directly influence FM shape as expressed by the index.

Overall, these findings suggest that FM area is strongly dependent on both anteroposterior and transverse dimensions.

IV. Discussion

Table no 7: Comparison of the APD, TD and Area of various studies

Study	Population	APD Male (mm)	APD Female (mm)	TD Male (mm)	TD Female (mm)	Area Male (mm²)	Area Female (mm²)
Present study	Manipur, India	37.02	36.21	31.93	30.78	880.58	826.04

Espinoza et al. [15]	Chile	37.4	35.6	31.9	30.1	877	798
Catalina-Herrera [16]	Spain	36.2	34.3	31.1	29.6	888.41	801
Macaluso A[17]	France	35.38	34.90	30.72	29.40	860.27	815.13
Gapert et al.[18]	UK	35.91	34.71	30.51	29.36	868.95	808.14
Burdan et al. [19]	Eastern Europe	37.06	35.47	32.98	30.95	877.40	781.57
Murshed et al. [20]	Turkey	37.2	34.6	31.6	29.3	931.71	795.0

Table no 8 : Comparison of the mean Foramen magnum index (FMI) with various authors

Author	Year	Country	FMI Male	FMI Female
Present study	2026	India, Manipur	86.60 ± 7.56	85.31 ± 7.96
Madadin et al. [21]	2017	Saudi Arabia	85.22 ± 6.35	84.96 ± 6.39
Abo El-Atta et al. [13]	2020	Egypt	117.45 ± 10.35	119.85 ± 9.38
Vidisha et al. [22]	2019	India	88.17 ± 6.33	88.09 ± 5.79
Gobbur et al. [23]	2013	India	90.95 ± 0.09	88.98 ± 0.08

In this study, most FM dimensions were larger in males, consistent with the presence of sexual dimorphism. Statistical analysis revealed significant sex differences in TD and FM area, whereas APD and FM index did not differ significantly between sexes (Table no 7 & 8).

These findings are supported by previous studies. Muhammad G et al[24] reported higher FM dimensions in males, with strong correlations between FM and occipital condyle measurements. Similarly, H. M. Abo El-Atta et al[13] observed significant sexual dimorphism in the Egyptian population, identifying FM length and width as reliable predictors of sex. Murshed et al[20] also documented larger sagittal and transverse diameters and FM area in males. However, other studies have reported minimal sex differences. Wani MR et al[25] found non-significant differences in FM area between sexes, while D.E. Ogolo et al [4] reported slightly larger FM areas in females, also without statistical significance. Such discrepancies may reflect population-specific traits, sample size, and methodological differences.

Comparison with international populations indicates that the FM dimensions observed in this study fall within the ranges reported worldwide (Table no 7 & 8). Previous studies have reported APD values between 34–37 mm and TD between 29–32 mm, while FM area typically ranges from 780–930 mm².[15-18] These similarities suggest relative consistency of FM morphometry across populations, with minor regional variations.

Age-wise analysis revealed that FM dimensions were slightly higher in younger adults (21–30 years), with minimal reduction in older age groups, indicating that FM size remains relatively stable after adulthood. Bahşi I et al[26]. and Öksüzler et al[5]. similarly reported no significant correlation between FM dimensions and age in adult populations.

Regarding FM shape, the oval configuration was most common, followed by round, hexagonal, and tetragonal shapes. Less frequent forms included egg-shaped, pentagonal, and irregular types. These findings align with previous reports indicating the predominance of the oval shape.[5,26] Nevertheless, some studies describe variations in shape distribution. de Lucena et al[6] observed that pentagonal FM was more frequent in males, while biconvex shapes predominated in females.[27] Murshed et al[20] reported diverse FM shapes, including oval, round, egg-shaped, tetragonal, pentagonal, hexagonal, and irregular forms. Such morphological variability likely reflects genetic, environmental, and developmental influences on cranial base formation.

Embryologically, the four occipital sclerotomes, which surround the notochord and contribute to the basioccipital, exoccipital, and supraoccipital sections of the occipital bone, fuse to form the foramen magnum. These centers go through chondrification during the embryonic stage, and the cartilaginous predecessors of the FM are formed by the 12th week of pregnancy.[2,28] The three enchondral components of the basiocciput, exocciput, and supraocciput, as well as the basi-exoccipital and exo-supraoccipital synchondroses, are the main factors that determine the size and area of the foramen magnum. The foramen magnum and associated structures have irregular geometry as a result of abnormalities and malformations of the occipital sclerotomes.[5,29] Environmental, social, and genetic factors play a significant part in the population-specific sexual dimorphism in FM dimensions.

Conditions such basilar invagination, Chiari malformations, or condylar dysplasia, in which anomalous ossification or fusion alters FM dimensions and impacts craniovertebral stability, can result from developmental anomalies.[2,28] The observed sexual and demographic differences in FM size, shape, and index are functionally explained by these developmental insights, which supplement morphometric data.

Clinically, detailed knowledge of FM morphology is crucial for neurosurgical procedures at the craniovertebral junction. Approaches such as far-lateral and transcondylar surgeries require precise understanding of FM dimensions and surrounding structures to optimize exposure and minimize complications.[30,31]

V. Conclusion

The anatomy of foramen magnum is quite important for every clinician as many vital structures pass through this foramen. The present study demonstrates sexual dimorphism in FM morphometry in the Manipuri population, with males generally exhibiting larger dimensions. The oval FM shape predominated, and the morphometric values observed are comparable with global data. These findings provide valuable morphometric information for anthropological, forensic, and neurosurgical applications. Identification of sex or race from any human skeletal remains can be done which is a necessary step in archaeological and forensic department including in detection of crime. Knowing its proper variation, it will be helpful in radiodiagnosis such as in new imaging techniques like computed tomography and magnetic resonance imaging, etc.

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