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ORIGINAL ARTICLE

Morphometric Analysis of Foramen Magnum and Occipital Condyles for Sexual Dimorphism: Exploring Reliability Through Computed Tomography Investigation

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Abstract:

Anatomical differences between males and females, has been of significant interest in various scientific fields. This study aims to investigate sexual dimorphism in North Indian population by analyzing the dimensions of the foramen magnum, a critical opening at the base of the skull and occipital condyles utilizing computed tomography (CT) imaging. Furthermore, variations in the shape of the foramen magnum are noted and classified into seven distinct types. CT scans of 299 individuals aged between 18 and 87 years underwent precise measurements of the foramen magnum dimensions. Eleven parameters were scrutinized, including foramen magnum length, width, the length and width of the right and left occipital condyles, minimum and maximum intercondylar distance, foramen magnum index, and foramen magnum area calculated using both the Teixeira and Radinsky formulas. Intraobserver and interobserver tests were conducted to assess measurement reliability. Statistical analyses were applied to investigate potential variations in these measurements based on sex. With the exception of the minimum intercondylar distance, all measurements were significantly greater in males. The most common shape of the foramen magnum was oval, while the least common was the pentagonal shape. However, it was found that the shape of the foramen magnum was not a reliable parameter for determining sex. Sexing accuracy, calculated through binary logistic regression and ROC curve analysis, indicated an accuracy of 68.2% for foramen magnum length (FML), 65.8% for foramen magnum width (FMW), and 75.2% and 74.9% accuracy for foramen magnum area when calculated using the Teixeira and Radinsky formulas, respectively, signifying their reliability in distinguishing gender. A multivariate analysis incorporating all eleven parameters demonstrated an overall accuracy of 73.6%. The foramen magnum and occipital condyles do not serve as strong determinants for sexual dimorphism. Nonetheless, this study suggests potential applications in forensic anthropology, paleontology, and medical fields where determining sex from fragmented skeletal remains is essential.

Keywords: Foramen magnum; Occipital condyle; CT imaging; Sexual dimorphism.

Introduction:

The skull has proven to be the second best indicator of sex of an individual. Krogmann claims that sexing of adult skeletal remains can be done with 92% accuracy using skull alone. However often in mass disasters, ballistic injuries, high velocity road and rail traffic accidents it is difficult to extract an intact skull. The base of the skull in such instances is often well preserved from physical aggression due to its protected positioning and relative thickness. The foramen magnum is one such important feature of the base of the skull. It is a large opening in the posterior cranial fossa allowing the passage of the spinal cord and its membranes, the anterior and posterior spinal arteries, vertebral arteries, the tectorial membranes, alar ligaments and the accessory nerve. Thus, it forms an integral part of the craniovertebral junction. The position and location of the foramen magnum has been long researched by anthropologists to study evolution of bipedal species. Human evolutionists have also noted sexual dimorphism in the positioning of the foramen magnum with a more anteriorly positioned foramen magnum in females as compared to males. The size of the foramen magnum provides important information pertaining to species. Humans have a larger foramen magnum to support their erect postures as opposed to other primates. The size of the foramen magnum also varies with age, infants having a smaller size than adults. The foramen magnum area has also been proposed as indicative of relative brain size as studied in different species There are also clinicopathological causes which can be interpreted from the size of foramen magnum. A smaller sized foramen magnum is indicative of conditions like skeletal dysplasia (Achondroplasia), sclerosis of skull, while a larger size can be associated with raised intracranial pressure as seen in Arnold-Chiari malformation. The shape of the foramen magnum can also hint towards craniovertebral anomalies like premature synostosis and hydrolethalus syndrome. Hence, it also assists the autopsy surgeon in arriving at a cause of death, be it of traumatic or pathological origin.[1,2]

The foramen magnum holds distinct merit for the forensic anthropologist in accomplishing the principal objective of

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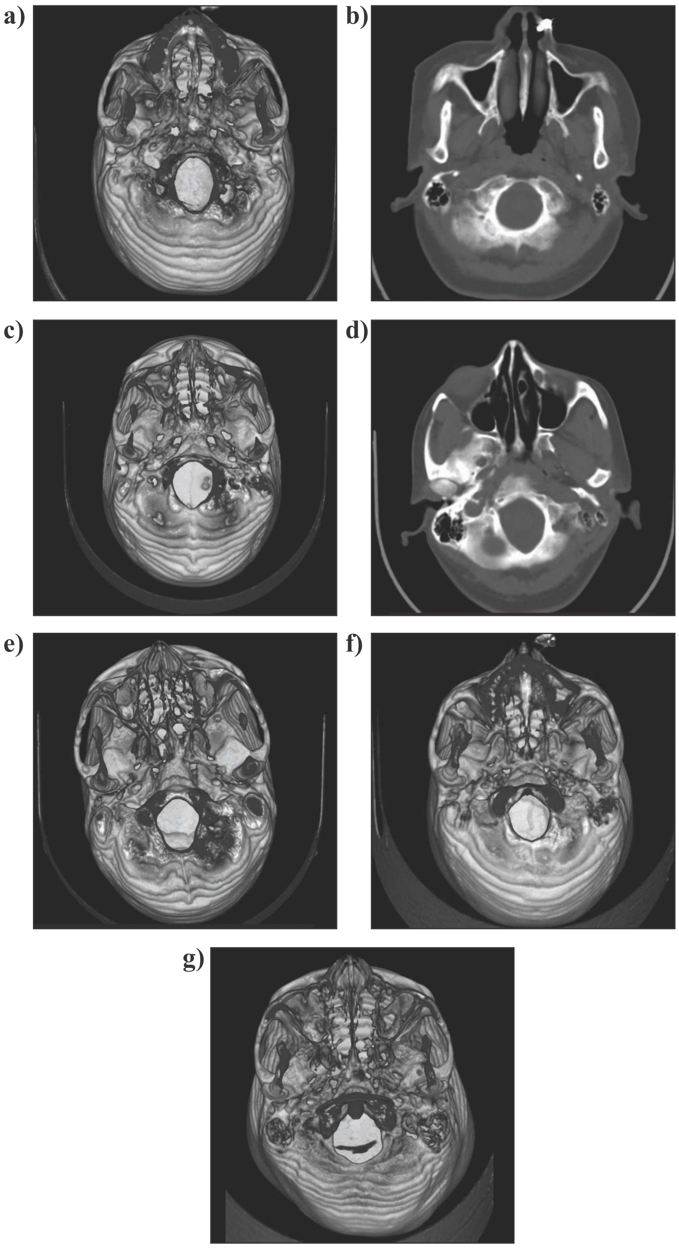


Figure 1: CT Images of different shapes of foramen magnum a) oval, b) round, c) egg, d) tetragonal, e) pentagonal, f) hexagonal, g) irregular.

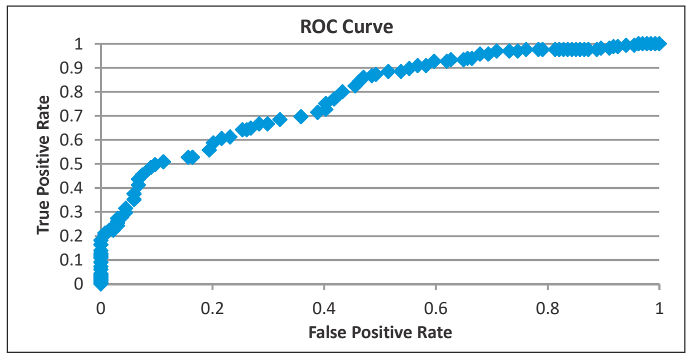
Table 19. Cumulative table of male.

Values	FML	FMW	LR OC	WR OC	LL OC	WL OC	MnI CD	MxI CD	FMI
Mean	3.66	2.99	2.27	1.20	2.27	1.23	1.35	3.27	81.97
SD	0.23	0.20	0.30	0.20	0.25	0.19	0.41	0.33	6.93
Range	1.30	1.16	1.26	1.15	1.16	1.06	2.99	2.16	40.69
Minimum	3.00	2.57	1.70	0.76	1.74	0.70	0.41	2.36	60.23
Maximum	4.30	3.73	2.96	1.91	2.90	1.76	3.40	4.52	100.92
p50	3.68	2.99	2.25	1.18	2.22	1.22	1.40	3.25	81.36

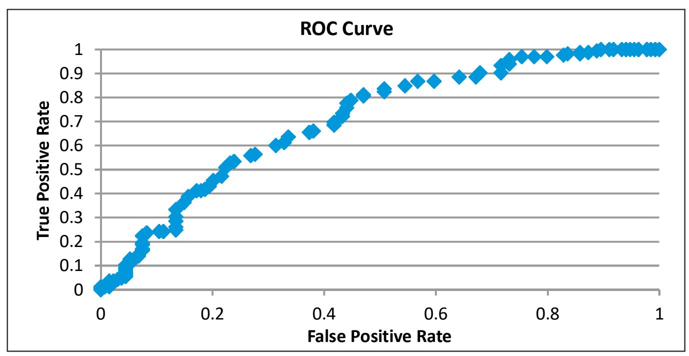
identification especially in fragmented, advanced decomposition and commingled cases. The measurements can be recorded either by the conventional method of metric measurements using spreading callipers on dry bones or radiographically which has been favoured in recent times. With focus shifting from traditional autopsy techniques to virtopsy, post mortem skeletal imaging can be used for comparative data analysis with the antemortem film images of the same individual. CT imaging other than its primary application in cranial, oral and maxillofacial surgeries and studies can be used concurrently for the purpose of identification, bite-mark analysis, anthropology and expanding the database on sexual dimorphism.

The following will be the objectives of the study:

1. To measure the different metric and descriptive parameters to ascertain whether there is any anthropologically significant sexual dimorphism.
2. If there is , the exact metric range of the parameter in male and



Graph 1. FML - ROC Curve with AUC of 0.8135.



Graph 2. FMW- ROC Curve with AUC of 0.7118.

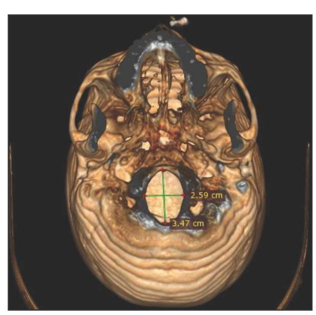


Figure 2A. CT Scan image showing measurements of foramen magnum length (FML) and breadth (FMW).

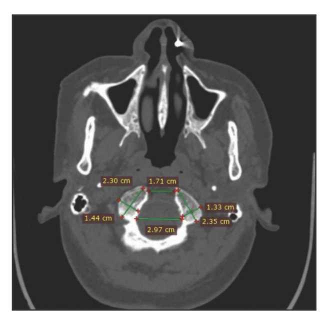


Figure 2B. CT Scan image showing measurements of length and breadth of right and left occipital condyles (LROC, WROC, LLOC,WLOC), minimum intercondylar distance (MnICD), maximum intercondylar distance (MxICD).

female skulls.

3. To study the shape of the foramen magnum and ascertain if there are variations to the classical "circle"/ "oval" shape which determines the formula for calculation of area of foramen magnum.
4. To compare and study the difference in mean areas achieved from the two formulas (Radinsky & Teixeira) popularly used to calculate the foramen magnum area.
5. To determine whether different measurements computed from occipital condyles provide supplemental data for gender determination.

Materials and methods:

The study design is a retrospective observational study on cranial CT scan images obtained from the department of Radio - Diagnosis Imaging, BHU, Varanasi. In accordance with the National Ethical Guidelines For Biomedical And Health Research Involving Human Participants by ICMR 2017, the scans were anonymized by the principal investigator, retaining only age and sex while recording data. Research ethics approval was obtained from the Institute Ethical Committee. Cranial CT Scans of male and female from North Indian population belonging to the age group 18 -87 years were included.

High quality scans displaying the entire extent of foramen magnum and occipital condyles were only included whilst excluding scans which were of poor quality, displaying artefacts, with history of trauma, surgery or displaying pathology affecting the skull base. Thus, after screening, out of a total of 468 Scans, 299 scans from North Indian population were studied for six months which comprised of 165 males and 134 females belonging to the age group of 18-87 years. The scans were obtained using GE Light speed VCT 128 slice CT scanner and axial scanogram settings of 300 mA, 120 kV, slice thickness of 5mm, with reconstructed images of same slice thickness. All measurements were done using an inbuilt electronic calliper in the RadiAnt DICOM (Digital Image Communication in Medicine viewer) 2022. 1 (64bit) software. The reconstructed images were analysed by two independent observers (by department of Forensic Medicine and department of Radio - Diagnosis Imaging, BHU) to exclude observer bias. All images were viewed on HP Laptop Intel Core i5(11TH generation) Screen 15.5" LED full HD, UHD Graphic (Hewlett Packard Company, 71004 Boeblingen, Germany) done in axial cross

Table 1. Basic metric measurements.

Variable	Mean	SD	Minimum	Maximum
FML	3.55	0.27	2.68	4.3
FMW	2.92	0.23	2.35	3.7
LROC	2.22	0.27	1.62	2.9
WROC	1.17	0.2	0.66	1.9
LLOC	2.22	0.25	1.47	2.9
WLOC	1.2	0.2	0.70	1.7
MnICD	1.33	0.39	0.41	3.4
MxICD	3.22	0.34	2.36	4.5

Table 2. Foramen magnum index and area calculation using radinsky and teixeira formula.

Variable	Mean	SD	Minimum	Maximum
FMI	82.72	7.35	60.23	104.92
AREA(R)	8.15	1.04	5.36	11.77
AREA(T)	8.24	1.05	5.37	11.79

Table 3: Different shapes and its frequency.

Shape	Frequency	Percent
Round	7	2.34%
Egg	18	6.02%
Hexagonal	26	8.69%
Irregular	40	13.3%
Oval	136	45.48%
Pentagonal	4	1.33%
Tetragonal	68	22.7%
Total Observations	299	100%

Table 4. Two sample t-test with equal variance on sex of the individual.

Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	48.6	1.59	18.4	45.4-51.7
Male	165	44.5	1.60	20.6	41.3-47.7
Total (n=299)	299	46.3	1.14	19.7	44.1-48.6

Table 5. Two sample t-test with equal variance on foramen magnum length (FML) of both sexes.

Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	3.40	0.02	0.25	3.35-3.44
Male	165	3.66	0.01	0.23	3.62-3.70
Total (n=299)	299	3.54	0.01	0.27	3.51-3.57

Table 6. Two sample t-test with equal variance on foramen magnum width (FMW) of both sexes.

Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	2.83	0.01	0.22	2.79-2.87
Male	165	2.99	0.01	0.20	2.96-3.02
Total (n=299)	299	2.93	0.01	0.22	2.89-2.94

Table 7. Two sample t-test with equal variance on length of right occipital condyle (LROC) of both sexes.

Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	2.16	0.01	0.23	2.12-2.20
Male	165	2.27	0.02	0.30	2.23-2.32
Total (n=299)	299	2.22	0.01	0.27	2.19-2.25

Table 8. Two sample t-test with equal variance on width of right occipital condyle (WROC)of both sexes.

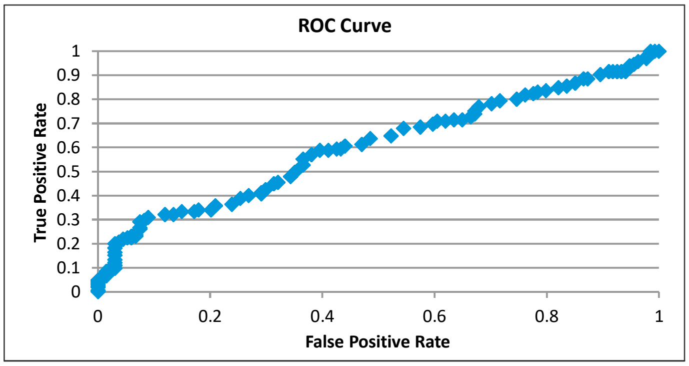
Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	1.13	0.01	0.19	1.10-1.17
Male	165	1.20	0.01	0.20	1.17-1.23
Total (n=299)	299	1.17	0.01	0.20	1.15-1.20

Table 9. Two sample t-test with equal variance length on left occipital condyle (LLOC)of both sexes.

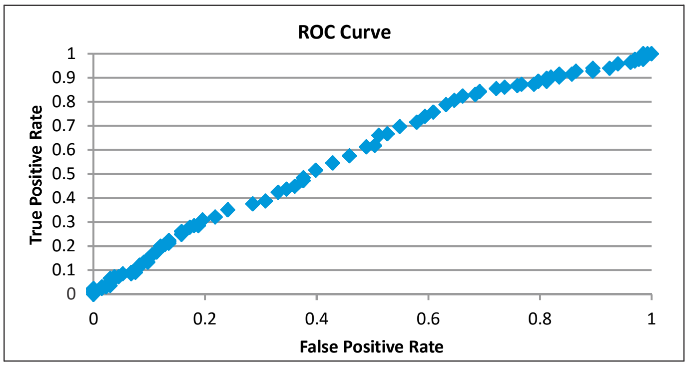
Group	Observation	Mean	Standard error	Standard deviation
Female	134	2.16	0.01	0.25
Male	165	2.27	0.01	0.25
Total (n=299)	299	2.22	0.01	0.25

Table 10. Two sample t-test with equal variance on width of left occipital condyle (WLOC)of both sexes.

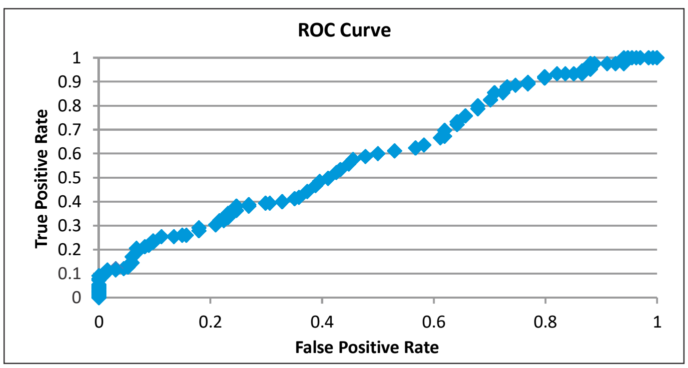
Group	Observation	Mean	Standard error	Standard deviation
Female	134	1.17	0.01	0.20
Male	165	1.23	0.01	0.20
Total (n=299)	299	1.20	0.01	0.20



Graph 3. LROC-- ROC Curve with AUC of 0.6103.



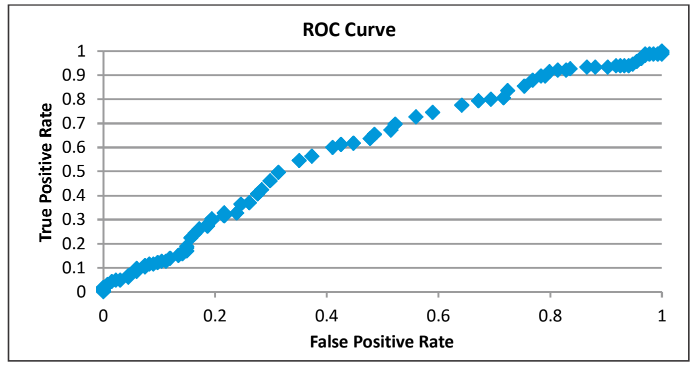
Graph 4. WROC-- ROC Curve with AUC of 0.5986.



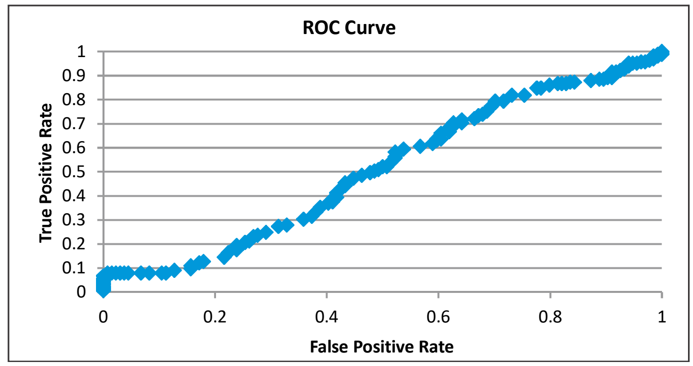
Graph 5. LLOC-- ROC Curve with AUC of 0.5989.

section view. Bone window was used to accentuate the bone details, with automatically set window level at 300 and window width at 1500. Both 2-D and 3-D images of the same case were analysed for optimal viewing. The following measurements were taken (metric and descriptive) according to Alijarrah K et al.,[3] Abtehag A Taib et al.,[4] Chovalopoulou and Bertsatos[5] : Foramen magnum length (FML): maximum antero- posterior distance, in median plane from basion to opisthion-

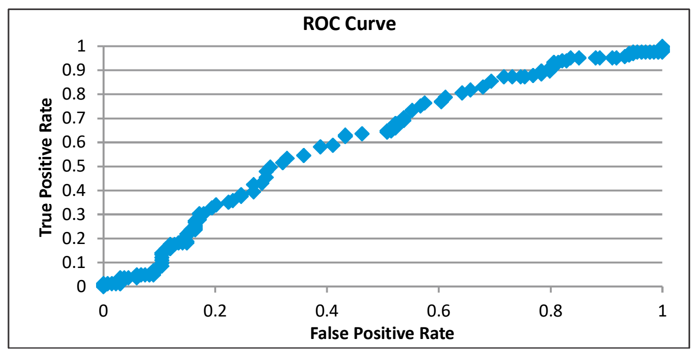
1. Foramen magnum width (FMW): Maximum width perpendicular to the FML, which is the greatest transverse distance between the lateral borders of the foramen magnum.
2. Length of the right occipital condyle (LROC): The maximum length of the articular surface, measured along its long axis.
3. Width of the right occipital condyle (WROC): The maximum width of the articular surface, measured perpendicular to the long axis.



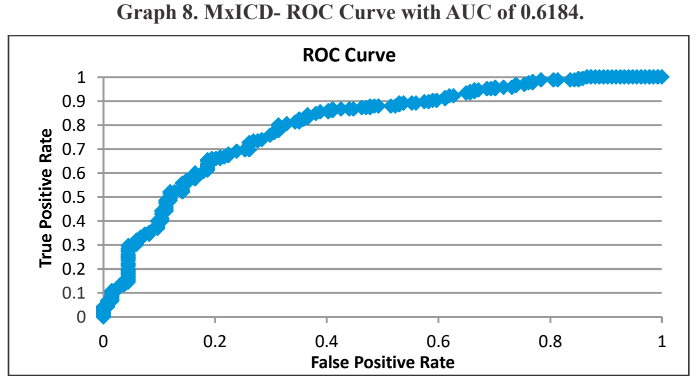
Graph 6. WLOC- ROC Curve with AUC of 0.6123.



Graph 7. MinICD- ROC Curve with AUC of 0.5133.

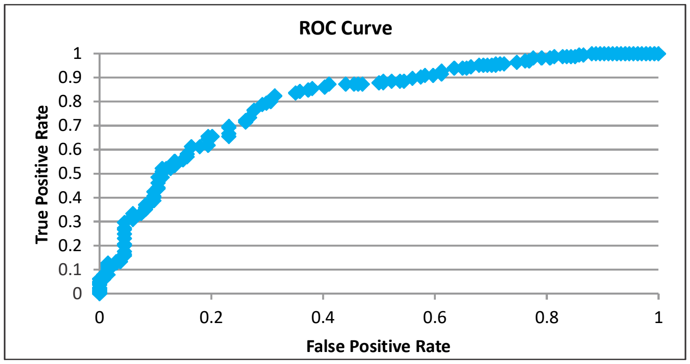


Graph 8. MxICD- ROC Curve with AUC of 0.6184.

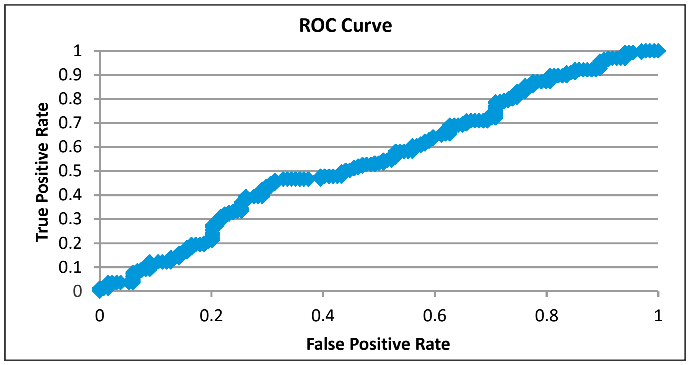


Graph 9. FMA by Radinsky formula- ROC Curve with AUC of 0.7981.

4. Length of the left occipital condyle (LLOC): The maximum length of the articular surface, measured along its long axis.
5. Width of the left occipital condyle (WLOC): The maximum width of the articular surface, measured perpendicular to the long axis.



Graph 10. FMA by Tiexera formula- ROC Curve with AUC of 0.8044.



Graph 11. FMI- ROC Curve with AUC of 0.5531.

6. Maximum intercondylar distance (MxICD): The maximum distance between the medial margins of the condyles.
7. Minimum intercondylar distance (MnICD): The minimum distance between the medial margins of the condyles.
8. Foramen magnum index (FMI) = Foramen magnum width (FMW)/Foramen magnum length (FML) X 100.
9. The area of the FM was calculated by using 2 different formulas as described by Radinsky (1967) (1/4x π x FML x FMW) and Teixeira (1983) (considering the area of foramen magnum of that of a circle with radius as medium value of half measures of length and width) Area =πx [(length + width)/4]2 "π" = 3.14 in both formulas. The Foramen magnum area obtained from each of these 2 methods was compared to study whether there were any significant differences in between their results.
10. Classification of foramen magnum based on shape as noted grossly was categorised into 7 types, Abtehag A Taib et al.;[4] Oval, Egg, Round, Tetragonal, Pentagonal, Hexagonal type, Irregular type (Figure 1, 2A,2B).

Results:

At the start of the study, we initially had a total sample size of 468 individuals. However, after applying our exclusion criteria, we narrowed it down to 299 scans for analysis, consisting of 165 males and 134 females. These participants' ages spanned from 18 to 87 years. The various variables that were considered for this particular study are foramen magnum length, width, index and area using Radinsky and Teixeira formula that are the oldest and most reliable formulas to derive the same. In addition, the maximum length and width of both the occipital condyles have been measured along with the minimum intercondylar distance, and maximum intercondylar distance. The variations in shapes of foramen magnum were also appreciated and subjectively inferred. The differentiation between oval and round shapes were done using foramen magnum index where a FMI of less than 1.2

Table 11. Two sample t-test with equal variance on minimum intercondylar distance (MnICD) of both sexes.

Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	1.31	0.03	0.35	1.25-1.37
Male	165	1.35	0.03	0.41	1.29-1.42
Total (n=299)	299	1.33	0.02	0.40	1.29-1.38

Table 12. Two sample t-test with equal variance on maximum intercondylar distance (MxICD) of both sexes.

Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	3.16	0.03	0.36	3.10-3.23
Male	165	3.27	0.02	0.33	3.22-3.32
Total (n=299)	299	3.22	0.02	0.35	3.20-3.30

Table 13. Two sample t-test with equal variance of foramen magnum area using Radinsky formula -FMA (r) of both sexes.

Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	7.58	0.08	0.94	7.42-7.74
Male	165	8.62	0.06	0.88	8.49-8.76
Total (n=299)	299	8.16	0.06	1.04	8.04-8.28

Table 14. Two sample t-test with equal variance of foramen magnum area using teixeira formula -FMA (t) of both sexes.

Group	Observation	Mean	Standard error	Standard deviation	95% CI
Female	134	7.66	0.08	0.94	7.50-7.82
Male	165	8.72	0.07	0.88	8.59-8.86
Total (n=299)	299	8.25	0.06	1.05	8.13-8.37

Table 15. Two sample t-test with equal variance of foramen magnum index (FMI) of both sexes.

Group	Observation	Mean	Standard error	Standard deviation
Female	134	83.64	0.01	7.75
Male	165	81.97	0.01	6.93
Total (n=299)	299	82.72	0.01	7.34

Table 16. Chi square test of foramen magnum index (FMI) in the study sample.

FMI Category	Frequency	Percentage	Cumulative Percentage
Narrow	157	52.51	52.51
Medium	57	19.06	71.57
Large	85	28.43	100.00
Total (n=299)	299	100	

Table 17. Chi square test of foramen magnum index (FMI) in the both the sexes.

FMI Category	Sex		Total
	Female	Male	
Narrow	68 43.31	89 56.69	157 100.00
Medium	27 47.37	30 52.63	57 100.00
Large	39 45.88	46 54.13	85 100.00
Total (n=299)	134 44.82	165 55.18	299 100.00

was considered as round and more than 1.2 as oval (Mas N, Sibel et al.).[6] There was no significant statistical differences for the interexaminer reliability test for all the parameters studied indicating significant agreement and consistency between the two observers. The data were expressed in terms of mean and standard deviation. Inferential statistics was performed using t-test on the collected data for comparing different parameters between male and female groups. $p<0.05$ was considered significant. To study the correlation between data points, Pearson's two tailed Correlation was done. Statistical analysis of the collected data was done using SPSS 22.0 version.

The foramen magnum length ranged from 2.68mm to 4.3mm, the foramen magnum width 2.35mm to 3.73mm. The right occipital condyle length varied between 1.62mm to 2.96mm and the right occipital condyle width between 0.66mm to 1.91mm. The left occipital condyle length measured between 1.47mm to 2.9mm and the left occipital condyle width measured between 0.70mm to 1.76mm. Minimum intercondylar distance was 0.41mm to 3.4mm whilst maximum intercondylar distance was 2.36mm to 4.52 mm (Table 1).

The foramen magnum index had a mean of 82.72 ±7.35 with a minimum of 60.23 and maximum value of 104.92. Area of the foramen magnum calculated using Radinsky formula yielded a mean of 8.15mm.[2]

Discussion:

In a a study conducted by Aljarrah et al.[3] on 472 CT scans (236 males and 236 females; age range, 18-72 years), the results were similar to our study. In their study, shapes were classified into 8 types: oval, egg, round, hexagonal, pentagonal, tetragonal, irregular (A) and irregular (B).They revealed a sexing accuracy of FML (62.5%), FMW (62.5%) and FM area (66.1%), and concluded that they could be reliable individual variables in sex determination. This is similar to our study which showed an accuracy of 68.2% for FML, 65.8% for FMW and 75.2% and 74.9% accuracy for FM area calculated by Tiexera and Radinsky formula respectively. These results indicate that these variables are dependable when it comes to distinguishing gender when analyzing the foramen magnum.

Tambawala et al.[8] conducted a study using 266 CBCT scans and employed four parameters (FML, FMW, FMA) by two methods for sex determination, resulting in an overall accuracy rate of 66.4%. In contrast, our study utilized eleven parameters and achieved an overall accuracy of 73.6%.

Aghakhani et al.[9] examined foramen magnum parameters like sagittal diameter, transverse diameter, and area, concluding that these parameters had high sensitivity and specificity in determining sex, with a maximum accuracy of 96%. This finding aligns with a study conducted by Gargi et al.[10] in Uttar Pradesh, where measurements of the FM sagittal diameter, FM transverse diameter, FM circumference, and FM index (FMI) led to an overall accuracy of 90.9%. However, the small sample size in both of these studies raises questions about the validity of the results. After a comprehensive literature review, the highest accuracy on a considerably larger sample size of 720 was reported in a study conducted by Kartal et al.[11] in Turkey. They

Table 18. Cumulative table of female.

Values	FML	FMW	LR OC	WR OC	LL OC	WL OC	MnI CD	MxI CD	FMI
Mean	3.40	2.83	2.16	1.13	2.16	1.17	1.31	3.16	83.64
SD	0.25	0.22	0.23	0.19	0.25	0.19	0.35	0.35	7.75
Range	1.2	1.13	1.15	0.96	1.18	0.93	1.38	1.68	36.67
Minimum	2.68	2.35	1.62	0.66	1.47	0.74	0.49	2.57	68.25
Maximum	3.88	3.48	2.77	1.62	2.65	1.68	1.87	4.25	104.92
p50	3.41	2.80	2.15	1.14	2.16	1.15	1.37	3.16	81.93

achieved an overall accuracy of 86.7% using four parameters: foramen magnum length, width, foramen magnum index, and foramen magnum area.

In studies using CT images of the foramen magnum, Aljarrah et al.[3] predicted an overall accuracy of 66.1%. Singh PK et al.[12] conducted a study on the Nepalese population and found that measurements of the foramen magnum and its calculated areas demonstrated high predictability for both sexes, with a maximum predictability of 75%. Meral et al.[13] examined the relevance of the foramen magnum in sex determination among the Turkish population using CT images and found that the discriminant parameters were reliable with an accuracy of 75%.

Jaitley et al.[14] analyzed 280 CBCT scans and observed a sexing accuracy of 72.1% by measuring the sagittal diameter, transverse diameter, area, and circumference of the foramen magnum. This result closely mirrored our study, which achieved an overall sexing accuracy of 73.6%.

Similar results in terms of overall accuracy were reported by other researchers, such as Tambawala et al. (66.4%),[8] H.M.A El Atta et al. (64.7%),[15] Hosseni et al. (70.9%),[16] Lashin et al. (69%),[17] Madadin et al. (65%),[18] Mehta et al. (69.1%),[19] Patricia et al. (66%),[20] and Vinutha et al. (65%).[21] Consequently, the overall range for accuracy across diverse populations predominantly falls between 65% and 75%.

The best parameter as per Tambawala et al.[8] for sex determination was the Area of the FM. Jaitley et al.[14] also. found area of the FM as most dimorphic with 72% sexing accuracy. Our study is in agreement with both these studies and found FMA to be the most accurate parameter.

Mehta M et al.[19] studied applicability of foramen magnum for sex determination in Western Indian population on a sample size of 553 adults and found foramen magnum length to be the best variable for gender differentiation (69.1%). In concurrence Tellioglu et al.[22] studied 100 CT scans in Turkey and concluded foramen magnum length to be the best predictor.

Madadin et al.[18] performed radiological measurements of the foramen magnum region on 200 adults of Saudi Arabia comprising of 100 males and 100 females. They observed five parameters - length of the right occipital condyle (LROC), length of the left occipital condyle (LLOC), width of the foramen magnum (WFM), area of the foramen magnum (AFM) and length of the foramen magnum (LFM). They found length of right occipital condyle to be the best individual parameter with an accuracy of 65.5% for discriminating sex. This was followed by length of the left occipital condyle which showed an accuracy of 65% in determining sex. This was in agreement with a study by

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Chovalopoulou et al.[5] on Greek population who found occipital condyles to be superior determinants of sex than foramen magnum.

Our research revealed that the oval shape of the foramen magnum is the most frequently observed shape. This finding aligns with similar studies conducted on the Indian population by Vinutha et al.,[21] Rajkumar et al.,[23] Sampada PK et al.,[24] Mishra AK et al.,[25] and Singh D et al.,[26] all of which also identified oval as the predominant shape. Additionally, Alvia Batoo et al.[27] in Lahore and Aghakhani et al.[9] in Iran reported oval as the most common shape. However, in studies conducted on the Saudi Arabian population, Aljarrah et al.[3] found hexagonal to be the most prevalent shape, while Taibi et al.[4] observed hexagonal as the most common shape in the Libyan population. On the other hand, round shape was reported as the most frequent shape in studies by Rohinidevi M et al.[28] and Sharma S et al.[29] in the Indian population and by Mursheed KA et al.[30] in the Turkish population. In South African population, Moodley[31] identified egg shape as the most widespread shape. Though shape of the foramen magnum has been extensively studied in different parts of the world, however they show no utility in sex determination.

Variations in research outcomes exist across various populations, highlighting the need for more comprehensive studies that are specific to each population group. This underscores the importance of conducting in-depth investigations into the morphometry of the basicranium within distinct populations. The low degree of variation in sexual differences of foramen magnum was explained by Gapert et al.[32] They suggested that since foramen magnum attained the adult size in dimensions early on in life hence is immune to secondary sexual changes. From a biomechanical perspective, the foramen magnum is not influenced by muscles. Its primary function is to allow the passage of structures , particularly the medulla oblongata, which matures at a young age and doesn't require size increase. As the head's weight is supported through the atlanto-occipital joint, there is little influence on weight transfer in the foramen magnum region.

Conclusion:

One could make the case that because sexually distinctive characteristics are not very pronounced in the foramen magnum region, it might not be advisable to rely on methods involving this anatomical feature when dealing with intact skulls. However, if confronted with an incomplete human skull or a fragment of the cranial base, the statistically significant accuracy demonstrated in this study provides an accessory tool for determining whether the skull belonged to a male or female. This is especially true when employing the formulas tailored to the relevant population data.

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