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Original Article

Forensic Section

Determination of Sex using Foramen Magnum Measurements: A Cross-sectional Study from Karur, Tamil Nadu, India

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ABSTRACT

Introduction: Sex determination is a fundamental goal in both forensic analysis and archaeological studies. The foramen magnum, the largest opening in the base of the skull, carries vital structures from the brain to the spinal cord. Because of its resistant nature, this portion of the skull is not only anatomically noteworthy but also useful for forensic investigations.

Aim: To determine the sex of the individuals using measurements of the foramen magnum.

Materials and Methods: A cross-sectional study was conducted in the Department of Forensic Medicine at Government Medical College and Hospital, Karur, Tamil Nadu, India, from September 2022 to February 2023. A total of 100 skulls were taken from individuals aged above 20 years. The transverse and Anteroposterior Diameters (APD) of the foramen magnum were measured using a digital vernier calliper. The area of foramen magnum was calculated using the Radinsky formula (R) and Teixeira formula (T). All variables were analysed using Levene's test. The Binary Logistic Regression (BLR) model is run for all the foramen magnum variables. Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 20.0 statistical software.

Results: Males exhibited higher foramen magnum measurements than females, which were statistically significant ($p<0.05$). The mean APD for male skulls was found to be 38.10±2.90 mm, while that of the female skull was 36.08±3.46 mm. The mean Transverse Diameter (TD) for males was 29.89±3.17 mm, whereas for females it was 26.14±3.24 mm. The mean area (R) for male was 897.53±138.23 mm^2 and for females it was 745.16±146.64 mm^2. The mean area (T) for males was 911.43±136.10 mm^2, while for females it was 769.45±141.67 mm^2. The analysis of APD indicated a p-value of 0.013; the Foramen Magnum Index (FMI) showed a p-value of 0.005 and other parameters, including TD and areas (R and T), demonstrated p-value <0.001. The overall sex determination rate was 73% when the BLR model was applied to all the parameters, with the highest accuracy at 78% for TD.

Conclusion: Foramen magnum is regarded as an efficient tool for sex determination and it can be combined with other methods for higher accuracy.

Keywords: Craniometry, Forensic analysis, Sex determination, Sexual dimorphism

INTRODUCTION

Sex determination is used for the identification of individuals in forensic medicine and for archeological evidence. It is one of the four main identifiers (age, sex, stature and ethnicity) in forensic anthropology [1]. Determining sex using skeleton remains has been attempted by various researchers in the past and was found to be effective. The skull is the most useful bone for sex determination, second only to the pelvis. The accuracy of sex determination is 95% with pelvis, 90% with Cranium and 98% when both are found. If the entire skeleton is intact, sex can be determined with absolute precision [2].

However, in some forensic cases, complete human remains are not always available. Identification is also essential in case of death due to explosions, railway or aircraft accidents and mass disasters, which require a high level of medico-legal expertise.

The base of the skull is one of the significant bones in the human body due to its resistance to physical insults [3]. Additionally, studies have shown that sex determination remains achievable even when the skull base is heated to a level comparable to those experienced during house fires [4]. The foramen magnum, a large midline opening in the occipital bone, transmits important structures like medulla oblongata, vertebral arteries, spinal accessory nerve, apical ligament of dens and tectorial membrane [5]. Because of the soft tissue covering and skeletal arrangement, the foramen magnum is a well-protected part of the human body, allowing its use in forensic studies. Furthermore, within a specific race and historical period, there are considerable craniometric differences between the sexes regarding the foramen magnum [6].

Although it is of forensic importance, barely any morphometric studies of the foramen magnum have been done in the South Indian region. So the main objective of the present study is to analyse the sexual dimorphism in South Indian cranial bases by recording the anteroposterior and TDs as well as the area under these measurement.

MATERIALS AND METHODS

A cross-sectional study was conducted in the Department of Forensic Medicine at Government Medical College and Hospital, Karur, Tamil Nadu, India, from September 2022 to February 2023. The Institutional Ethical Committee approved the study (2284/ME1/2022-12/21). A convenience sampling method was used to select the study sample.

Sample size: A total of 100 samples were included, comprising 75 males and 25 females. Only skulls in good condition from individuals aged over 20 years were selected, as the sexual characteristics of the bone do not begin to manifest until puberty.

Inclusion criteria:

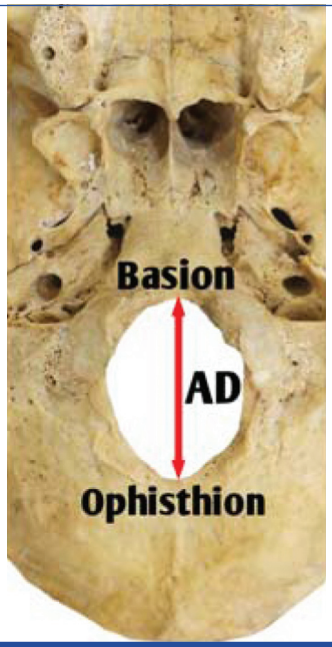
- Age more than 20 years
- Both sexes included

Exclusion criteria:

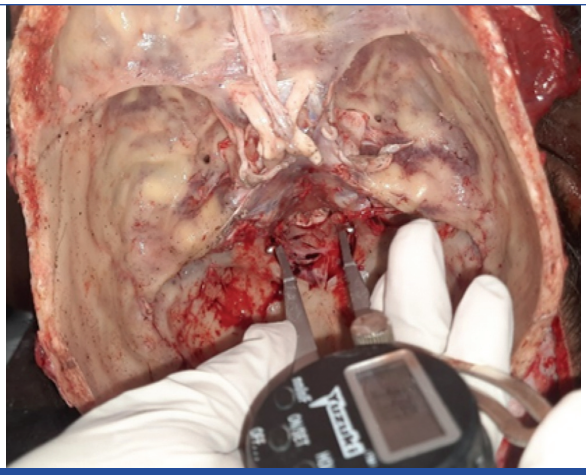
- Skulls with fractures
- Congenital anomalies like Chiari malformation and craniosynostosis

Study Procedure

The APD of the foramen magnum was measured from basion to opisthion, or the distance between the anterior and posterior margins of the foramen magnum as depicted in [Table/Fig-1]. The highest lateral curvature was used to calculate the TD of the foramen magnum, as shown in [Table/Fig-2].



[Table/Fig-1]: Measurement of Anteroposterior Diameter (APD) of foramen magnum.



[Table/Fig-2]: Measurement of Transverse Diameter (TD) of foramen magnum.

All measurements were made using a digital inside vernier calliper with an accuracy of 0.1 mm. To ensure accuracy and minimise errors, each measurement was taken twice or three times by a single observer. The TD divided by the APD yields the foramen magnum index. The area of the foramen magnum is calculated using the Radinsky formula and Teixeira formula as follows:

Radinsky L formula [7], Area (mm^2)=¼×π×w×h

Teixeira Formula [8], Area (mm^2)=π×(w×h/4)^2

STATISTICAL ANALYSIS

All values were entered into an Excel spreadsheet and the data were analysed using IBM SPSS (Statistical Product and Service Solutions, version 20.0) software. All quantitative data were represented mean, median and standard deviation. All the qualitative data were described in terms of frequency and proportion. Levene's test was used to assess associations, BLR analysis was performed to examine the variables in relation to sex determination.

RESULTS

Out of total of 100 cases, 75 were males and 25 were females. The APD analysis indicated a p-value of 0.013, while the foramen magnum index showed a p-value of 0.005. All other parameters, like TD and area calculated using the Radinsky formula, showed a p-value <0.001 [Table/Fig-3].

The BLR model was run to predict the probability of a two-category outcome and to determine the sex of the individual using the value of the variable. The BLR model for each variable was determined and any predicted value less than 0.5 is interpreted as female and equal to or greater than 0.5 as male. Next, each model's strength was evaluated by looking at the area under the Receiver Operating Characteristic (ROC) curve for the predicted probabilities of BLR. The strength of each model was then tested by the area under the ROC curve drawn for the predicted probabilities of BLR. The TD and the foramen magnum index significantly contributed to the model.

The BLR model for all the foramen magnum measurements is shown in [Table/Fig-4]. The ROC curve for each variable is shown in [Table/Fig-5-7]. The area under the curve represents the predictive possibility of the variable in determining the sex. Furthermore, all the values for the area under the curve were greater than 0.5, indicating that the variables considerably discriminate between the two groups (males and females).

The larger the area under the ROC curve, the higher the predictive possibility of the parameters regarding sex determination. The

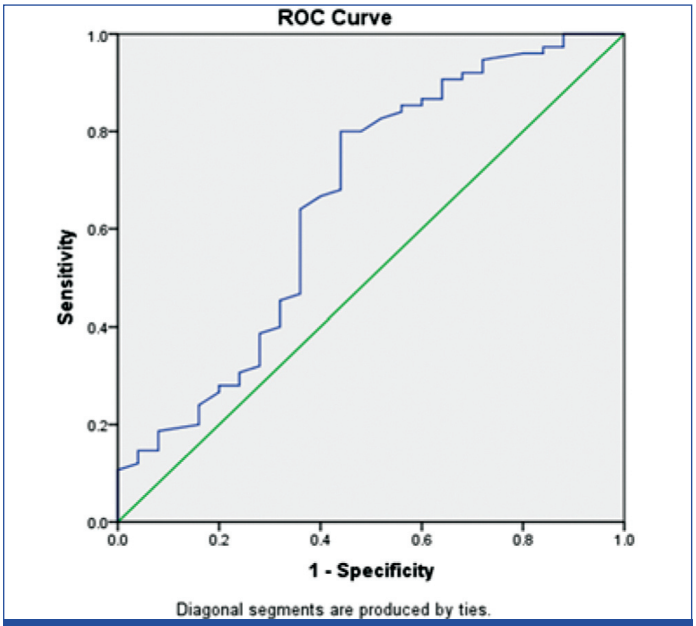
Parameters	Gender	Mean±Std. deviation	Mode	Median	p-value	Minimum	Maximum
Anteroposterior diameter (mm)	Male	38.10±2.90	33.20	38.05	0.013	29.7	45
	Female	36.08±3.46					
	Overall	37.60±3.15					
Transverse Diameter (TD) (mm)	Male	29.89±3.17	28.30	28.30	<0.001	21	35.9
	Female	26.14±3.24					
	Overall	28.95±3.56					
Area (mm^2) using Radinsky formula	Male	897.53±138.23	688.60	858.70	<0.001	537.4	1208
	Female	745.16±146.64					
	Overall	859.43±154.57					
Area (mm^2)-Teixeira formula	Male	911.43±136.10	867.80	867.80	<0.001	563.8	1231
	Female	769.45±141.67					
	Overall	875.94±150.10					
Foramen magnum index	Male	78.34±8.08	70.30	76.65	0.005	56	95.6
	Female	72.91±8.17					
	Overall	76.98±8.40					

[Table/Fig-3]: Mean, median, mode and standard deviation of variables.
Levene's test for equality of variances and the t-test for equality of means were used for independent samples testing.

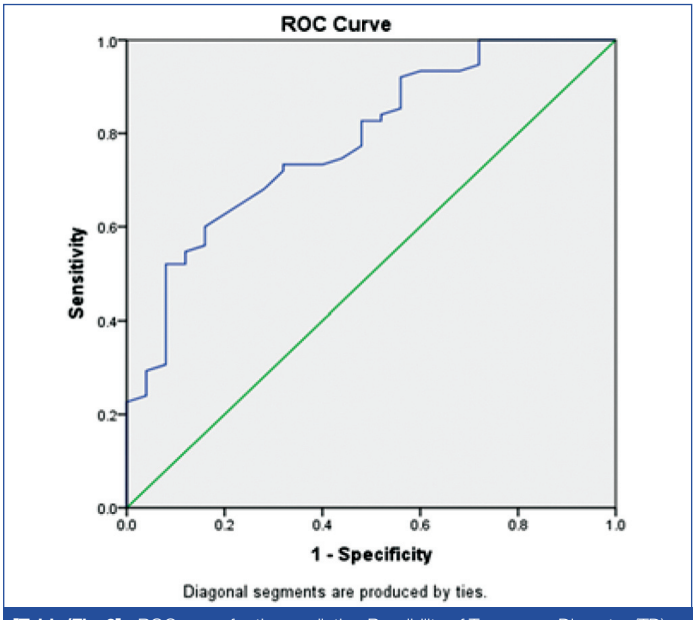
Variables	B	SE	Wald	Sig.	Exp (B)	95% CI for Exp (B)	
						Lower	Upper
APD	-0.369	0.947	0.152	0.697	0.691	0.108	4.426
TD	-3.272	1.647	3.946	0.027	0.003	0.002	0.957
Area (R)	0.031	0.44	0.476	0.490	1.031	0.945	1.125
Area (T)	0.027	0.44	0.371	0.542	1.027	0.942	1.120
FMI	0.494	0.379	1.703	0.042	1.639	0.780	3.442

[Table/Fig-4]: BLR model for the variables.
Exp (B): Exponentiation of the regression coefficient (B), SE: Standard error

predictive capability is highest with TD (78%), followed by Area (77%), foramen magnum index (67%) and then APD (66%) [Table/Fig-8].



[Table/Fig-5]: ROC curve for the predicting possibility of Anteroposterior Diameter (APD).

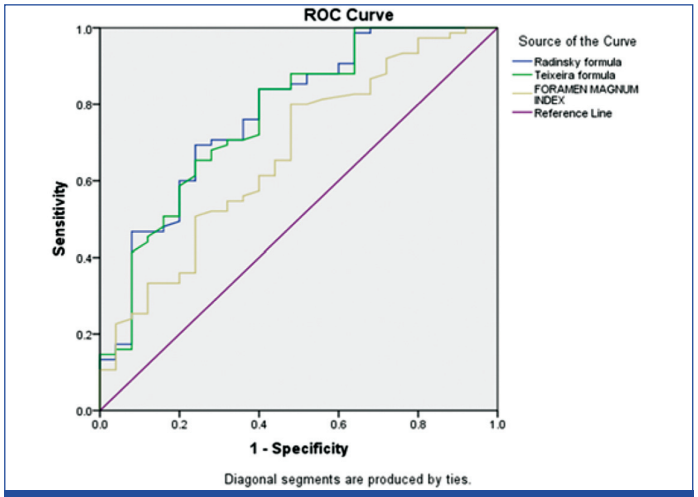


[Table/Fig-6]: ROC curve for the predicting Possibility of Transverse Diameter (TD).

DISCUSSION

The fundamental focus of anthropologists and forensic science investigators is identifying the sex of individuals from bony remains. However, the morphometric studies of the foramen magnum show variations within ethnicity and geographic region [3,9]. Previous studies determining sex using measurements of the foramen magnum region measurements have found varying but high accuracy levels.

In a survey of Indian crania, Routal RV et al., reported 100% accuracy in sex determination by measuring the foramen magnum [10].



[Table/Fig-7]: ROC curves for the predicting possibility of Area (R), Area (T) and FMI.

Variables	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% confidence interval	
				Lower bound	Upper bound
Anteroposterior Diameter (APD)	0.660	0.69	0.17	0.525	0.795
Transverse Diameter (TD)	0.784	0.051	0.000	0.684	0.884
Area using the Radinsky formula	0.775	0.056	0.000	0.665	0.885
Area using the Teixeira formula	0.771	0.57	0.000	0.660	0.882
Foramen magnum index	0671	0.063	0.011	0548	0.794

[Table/Fig-8]: Test result variables.

Holland TD used regression analysis in skulls to determine sex from the foramen magnum with an accuracy of 71-90% [11]. Uysal SE et al., observed 81% accuracy in sex determination by employing 3D CT to study the foramen magnum in Turkish individuals [12]. In their research on British specimens, Gapert R et al., found an accuracy of 70.3% using discriminant function analysis [3].

Despite it being less dimorphic compared to the pelvis or skull as a whole, the foramen magnum remains useful when other bones are missing. It achieves a moderate accuracy of approximately 65-80%, contributes to the identification of unknown remains and is best used in combination with other cranial features.

The conclusions were made after comparing the findings with those from earlier research, as shown in [Table/Fig-9] [3,6-8,10,13-16].

In the current study, the area (R) of the male skull is measured at 897.53 mm^2, which is similar to that reported by Günay Y and Altinkök M [17] at 909.91 mm^2. BLR model is evaluated using the area under the ROC curve, indicating a maximum predictive possibility of the sex at 78% (based on TD), with an average predictability of all the foramen magnum variables at 73%. Gapert R et al., conducted a similar study within a British population with binary regression analysis, projected a sex identification accuracy of 70.3% [3]. Similarly, Edwards K et al., studied the foramen magnum of the Swiss population and showed a sex accuracy of an overall classification rate for sex accuracy of 66.4% using BLR [18].

Author/Year of study	Population	TD male (mm)	TD female (mm)	APD male (mm)	APD female (mm)	Area (R) male (mm²)	Area (R) female (mm²)	Area (T) male (mm²)	Area (T) female (mm²)
Teixeria WR (1982) [8]	M-20 F-20	-	-	-	-	-	-	963	805
Radinsky L (1967) [7]	NA	-	-	-	-	819	771	-	-
Routal RV et al., (1984) [10]	M-104 F-37	29.6	27.1	35.5	32	819.0	771	-	-
Sayee R et al., (1987) [13]	M-83 F-36	28.5	28	34.6	33.7	769.0	746	-	-
Raghavendra Babu YP et al., (2012) [6]	M-50 F-40	28.91	28.19	36.59	32.57	811	722	821	727
Catalina Herrera CJ (1987) [14]	M-74 F-26	31.1	29.6	36.2	34.30	888.53	801	-	-
Gapert R et al., (2008) [3]	M-82 F-76	30.5	29.36	35.91	34.71	862	801	868	808
Çiçekcibaşi AE et al., (2003) [15]	M-57 F-53	31.6	29.3	37.2	34.6	-	-	-	-
Singh G and Talwar I (2013) [16]	M-26 F-24	27.77	27.21	33.54	32.31	733	692	741	699
Present study (2023)	M-75 F-25	29.89	26.14	38.8	36.08	897.53	745	911.43	769.45

[Table/Fig-9]: Comparison of the findings of the present study with those of earlier research [3,6-8,10,13-16].

Limitation(s)

Considering the overlap in the male and female values for the foramen magnum measurements, it is suggested that the application of these measurements in sex estimation should be restricted to cases where only a fragment of the base of the skull is brought for examination. While sexual dimorphism is frequently seen in FM measurements, these variations might differ significantly differ among populations. Such population-specific differences may limit the generalisability of sex determination methods based on these measurements.

CONCLUSION(S)

The present research found that the foramen magnum measurements show a statistically significant difference between female and male skulls and can be used to determine sex. Using the BLR model, the predictability of sex based on the TD of the foramen magnum is as high as 78%.

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