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Binary Logistic Regression Analysis Of Foramen Magnum Dimensions For Sex Determination In Nigerian Skulls

Research Article

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Abstract

Introduction: Identification of skeletal is a vital tool in forensic investigations. The need to estimate sex from cranial fragments becomes apparent when only a part of the skull is brought for identification. The dimensions of the foramen magnum are clinically important because of the vital structures passing through it. This study investigated the sexual dimorphism of the sagittal diameter, transverse diameter and area of the foramen magnum inthe Nigerian population.

Materials and methods: The sagittal and transverse diameters and area of the foramen magnum of one hundred skulls (83 males and 17 females) from the Nigerian population were measured using Verniercalliperr. The SPSS was used to analyze linear correlation, histogram, Q-Q plot, and Binary Logistic Regression (BLR) to obtain a model for sex determination. The student'st-test was used to test male-female significance. The predicted probabilities of BLR were analyzed using Receiver Operating Characteristic (ROC) curve.

Result: The sagittal diameter, transverse diameter and area of the foramen magnum are found to be significantly larger in males than in females. The predictability of foramen magnum measurements in sexing of crania was 83.3% for transverse diameter and 92.3% for the sagittal diameter. For the area of foramen magnum that was calculated using the formula derived by Radinsky and Teixeira, the predicted probabilities were 89.5% and 90.2% respectively.

Conclusion: This study shows that there is statistically significant sexual dimorphism in the foramen magnum region, which will be useful in predicting sex in partial skull remains by binary function analysis when other methods tend to be inconclusive. This is an invaluable tool in forensic identification.

Keywords: Foramen Magnum; Sex Determination; Binary Logistic Regression; Anthropometry.

Introduction

The foramen magnum is the most conspicuous, large opening on the floor of the fossa. It transmits the medulla, the ascending portions of the spinal accessory nerve (XI), and the vertebral arteries. Configuration and size of the foramen magnum and posterior fossa (PF) play an important role in the pathophysiology of various disorders of the PF and craniovertebral junction. It is however of high clinical importance as reported by various researchers. Stenosis of the foramen magnum causes brainstem compression manifested by respiratory complications, lower cranial nerve dysfunctions, upper and lower extremity paresis, hypo-or hypertonia, hyperreflexia, or clonus % [1-3]. The configuration of the foramen magnum in patients with Chiari I and Chiari II malformations is larger than in the normal population [4].

In forensic investigations, one of the principal biological traits to be estimated from skeletal remains is the sex of the individual. Sex estimation relies on the sexually dimorphic expression of bony characteristics that are produced through different patterns, rates and periods of adolescent growth [5]. Sex can be determined by a gross examination of the skeleton using morphometric techniques. In man, sex estimation using the human cranium is largely based on size differences and skeletal robusticity [5, 6]. Several workers have determined sex with reasonable accuracy using various cranial landmarks and morphometries [7-10]. The observed

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differences in sex predictions using bones are thought to be population-specific and can be influenced by genetic, environmental and social factors [11].

This study has employed binary linearregression BLR analysisin predicting sexual dimorphism of the sagittal, transverse diameters and area of the foramen magnum in a Nigerian population to evaluate the reliabilityof the foramen magnum morphometry as a tool for sexing when only a fragment of base of the skull is available in forensic identification.

Materials and Methods

A total of 100 adult dry human skulls, free from damage and deformity fully ossified (83 males, 17 females) from Departments of Anatomy in Nigerian Universities constituted the materials for this study. The sagittal and transverse diametersof the foramen magnum were measured.

The index and area of foramen magnum were calculated using the following formulas:

(a) Radinsky's formula: $= 1/4 \times \pi \times s + t$
(b) Teixeira's formula: $= \pi \times \{(s+t)/4\}^2$.
(c) Foramen magnum index = (transverse length)/(Sagittal×100).

Statistical analysis was performed using SPSS (Statistical Package for Social Sciences, version 20.0) two-tailed Student's -test (< 0.05), Receiver Operating Characteristic (ROC) curve, Quantile-Quantile plot, linear correlation, Binary Logistic Regression (BLR), Binary Logistic Regression is applied to obtain a predicting equation (BLR model) that estimates the sex of the individual. An equation is obtained for each variable and on applying the equation to the variable value apredicted value is obtained. In this model, the cut-off value is 0.5. If the predicted value is equal to or more than 0.5, it is considered male and if it is less than 0.5 it is considered to be female. The predicted probabilities of BLR were analyzed using Receiver Operating Characteristic (ROC) curve. The ROC curve is a strong indicator of the model's ability to distinguish two groups and the area under the curve is used to measure the strength of the equation. If the area is less than 0.5, it indicates that any observation is purely a matter of chance and a value close to 1 indicates that the equation strongly discriminates two groups.

Results

Table 1 shows the descriptive statistics of the sagittal diameter and transverse diameter of the foramen magnum (mm). The mean of the sagittal and transverse diameters were 35.98±3.41 and 29.43 ± 3.71mm respectively. The differences between these values were statistically significant (< 0.001) and were consistent with the shape of the foramen.

Table 2: The effect of sex on the foramen magnum is shown in Table 2. The mean sagittal diameter in males was 36.95 ± 2.29 mm and in females was 31.26 ± 4.08 mm. The mean transverse diameter in males was 30.33 ± 2.33 mm and in females was 25.04 ± 5.72 mm. The mean sagittal area by Radinsky's formula in males was 882.74 ± 106.44 mm and in females was 630.12 ± 196.4 mm. The mean transverse area by Teixeira's formula in males was 892.25 ± 106.10 mm and in females was 639.14 ± 191.73 mm. The differences were statistically significant ($p < 0.05$).

The BLR model for each variable is shown in Table 3 and on applying the model any predicted value <0.5 is considered to be female and equal to or more than 0.5 as male.

Figure 1. Foramen magnum sagittal diameter(S) – maximum internal length of the foramen magnum along the midsagittal plane, from opisthion to basion (White 2000(12)).

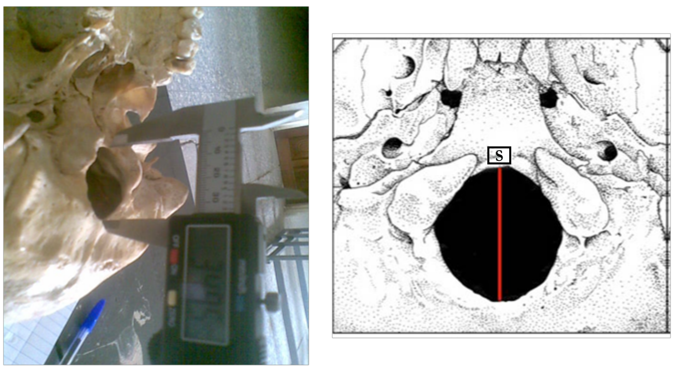


Figure 2. Foramen magnum transverse length– maximum internal width of the foramen magnum along the transverse plane(T).

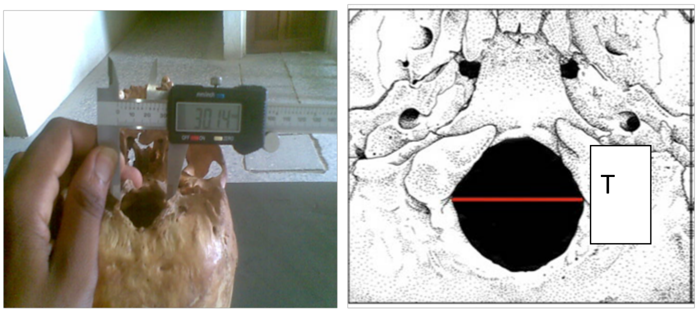


Table 1. Descriptive statistics of the sagittal diameter and transverse diameter of the foramen magnum (mm).

Foramen Magnum	N	Mean (mm)	Standard Deviation	Minimum - Maximum
Sagittal	100	35.98	3.41	21.00 - 41.93
Transverse	100	29.43	3.71	12.00 - 35.00

Table 2. Effect of sex on foramen magnum.

Foramen magnum dimensions	Male (n = 83)		Female (n = 17)		p-value
	Range	Mean (S.D)	Range	Mean (S.D)	
Length/Sagittal	30.42-41.93	36.95 (2.29)	21.00-36.33	31.26 (4.08)	<0.001*
Breadth/Transverse	22.88-35.00	30.33 (2.33)	12.00-30.72	25.04 (5.72)	0.002*
Area (R)	564.69-1121.97	882.74 (106.44)	197.95-876.66	630.12 (196.40)	<0.001*
Area (T)	579.01-1128.60	892.25 (106.10)	213.85-882.84	639.14 (191.73)	<0.001*

* = significant at p< 0.05

Table 3..Binary Logistic Regression model for sex estimation using foramen magnum dimensions.

Variables	BLR model	Wald	p-value
Length (L)/Sagittal	-23.116 + 0.713 (L)	18.43	<0.001*
Breadth (B)/Transverse	-10.954 + 0.440 (B)	13.471	<0.001*
Area (R)	-9.206 + 0.014 (R)	16.979	<0.001*
Area (T)	-9.646 + 0.014 (T)	17.301	<0.001*

BLR, binary logistic regression. P<0.001 is extremely significant in sexing
* = significant at p< 0.001

Table 4: Foramen magnum indices and sexual dimorphism ratios.

	M	F	Sexual dimorphism ratio	Sig. Level
Sagittal diameter	36.95 ± 2.29	31.26 ± 4.08*	1.18	p<0.05*
Transverse diameter	30.33 ± 2.23	25.05 ± 5.72*	1.21	p<0.05*
Foramen magnum index	82.08	80.13*		p<0.05*

Table 4 shows the foramen magnum indices and sexual dimorphism ratio. The foramen magnum indices in males and females were 82.08 and 80.13 respectively with higher values in males. The sexual dimorphism ratio using the Sagittal diameter was 1.18 whereas the sexual dimorphism ratio using the Transverse diameter was 1.21. The sexual dimorphism ratios were greater than the unity.

Figures 3 and 4 show the histograms of the descriptive characteristics of foramen magnum sagittal diameter and breadth/transverse respectively. High interindividual variability was seen in the sagittal and transverse diameter in Figures 3 and 4 respectively.

The Q-Q plot of the sagittal and transverse diameters of the foramen magnum are shown in Figures 5 and 6 respectively. The Q-Q plots confirm normal distribution.

The strength of each model was then tested by the area under the Receiver Operating Characteristic (ROC) curve drawn for the predicted probabilities of BLR. The ROC curve of each variable is shown in Figures 7-10. The area under the curve is a measure of the predictability of the variable in sexing the crania. The area under the curve was 0.923 and 0.833mm2 for sagittal and transverse diameters respectively. The area of foramen measured by Radinsky's method was 0.895 and 0.902 for the area of foramen measured by Teixeira's method.

The Correlation between the sagittal and transverse diameters of the foramen magnum is shown in Figure 11. There is a strong positive linear correlation between the sex-pooled sagittal and transverse diameters of the foramen (value = 0.802) and the correlation are significant (< 0.001) as shown in Figure 10.Figure 12 shows the incidence of male and female foramen magnum shapes. The majority of the skulls in males were circle-shaped (45.8%), while 64.7% of females were oval-shaped. The males had 36.1% and females 64.7% oval-shaped, males 2.4% and females 5.9% arrow-shaped, males 12 and 3.6% diamond and egg-shaped respectively without having any of these shapes.

Figure 3. Histogram showing the descriptive characteristics of foramen magnum sagittal diameter.

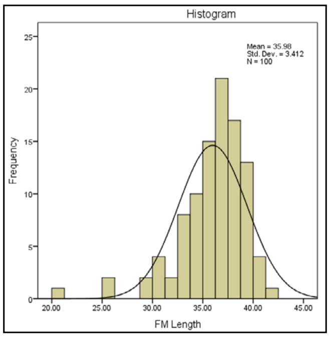


Figure 4. Histogram showing the descriptive characteristics of foramen magnum breadth.

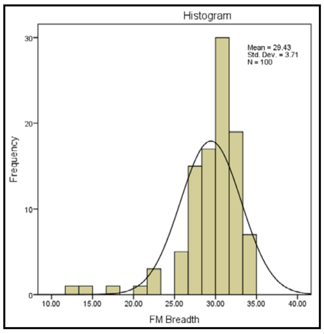


Figure 5. The Q-Q plot of the sagittal diameter of the foramen magnum.

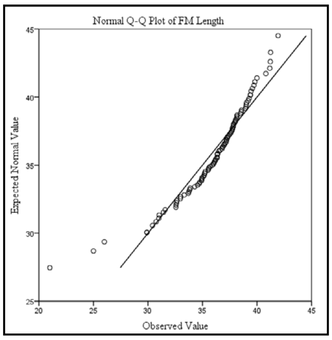


Figure 6. The Q-Q plot of the transverse diameter of the foramen magnum.

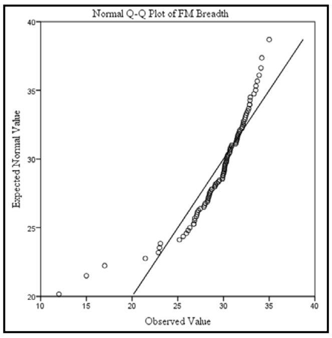


Figure 7. ROC curve for the predicted probabilities of sagittal length.

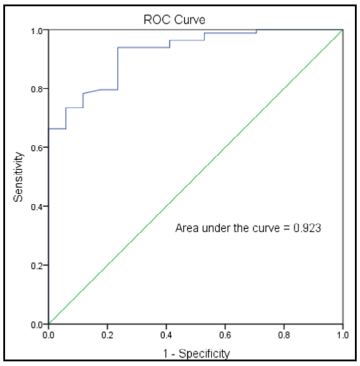


Figure 8. ROC curve for the predicted probabilities of the transverse diameter.

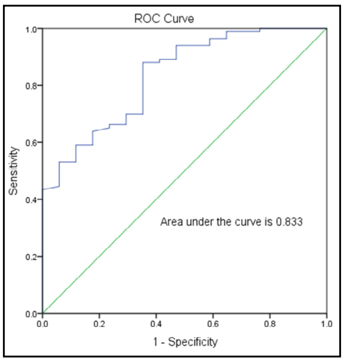


Figure 9. ROC curve for the predicted probabilities of the area using Radinsky's formula.

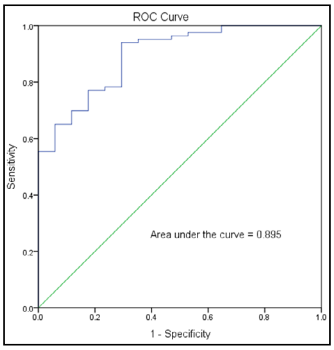


Figure 10. ROC curve for the predicted probabilities of the area using Teixeira's formula.

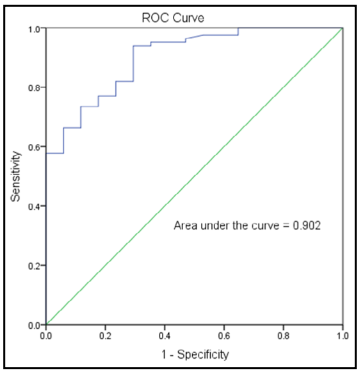
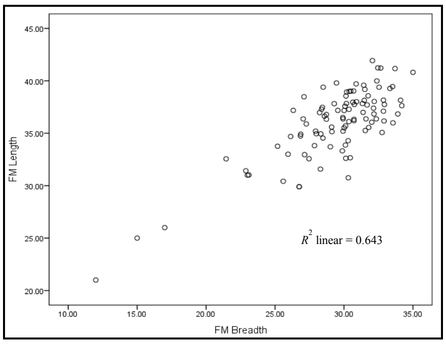


Figure 11. Correlation between the sagittal diameter (mm) and transverse diameter of the foramen magnum (r = 0.802, p< 0.001).

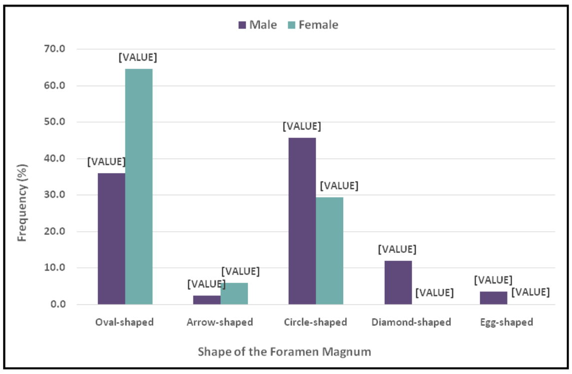


Discussion

It is generally accepted that in cases where a human skull shows better preservation than the pelvis, the basicranial and specifically the area around the foramen magnum can be used for sexing an unknown individual. It is especially relevant for highly fragmented remains when the cranial base preserves well due to the large mass of soft tissue and ligaments surrounding it [10, 13].

In this present study, the mean dimensions of the foramen were higher in males than in females. This agrees with previous studies [13-21]. The present study has employed descriptive statistics, and predictive models and applied Binary Logistic Regression. The differences in the data may be attributed to ethnicity and sample size. The present study confirms the sex predictability employing any of these parameters. It is observed that the sex predictability is highest for sagittal diameter (92.3%), followed by the area of Teixeira (90.2% and Radinsky (89.9%) and least for transverse diameter (83.3%) which agree with the work done by Babu and coworkers [17].

Figure 12. Percentage incidence of shapes of the foramen magnum.



Kamath et al 2015 [21]. however, reported the sex predictability is highest for bothareas 70.3%, followed by sagittal diameter (69.6%), and least for transverse diameter (66.4%). In another study using 118 dry skulls in a south Indian ethnic group, it was observed that the areas of the foramen calculated by Radinsky's and Teixeira's formulae are better predictors of sex than the sagittal and transverse dimensions [22].

Gapert and coworkers in a British ethnic group study using discriminant function and regression analysis predicted a sexing accuracy of 70.3% [20]. In the analysis of CT scans of 250 adults from the Swiss ethnic group to determine the value of foramen magnum dimensions in sexing crania, revealed 66% accuracy in cranial sexing by discriminant function analysis and Binary Logistic Regression% [23]. In another study, involving fifty adult skulls, the accuracy of sex prediction based on discriminant function analysis ranged from 66% to 70% [24].

Several workers have concluded that the foramen exhibits sexual dimorphism [25-30] used Fisher's linear discriminant function test on three-dimensional computed tomography measurements and concluded 81% accuracy in sexing with foramen width and right condyle dimension [29]. used helical CT scanning in the measurements of the foramen diameters, area, and circumference was statistically analyzed using discriminant analysis and multiple regression analysis to suggest that circumference and area were the best discriminant parameters for sex determination with an overall accuracy of 67% and 69.3%. The present study however has turned out higher predictable values of 90.2 and 89.5% using Teixeira and Radinsky models respectively.

Foramen magnum indices in the present study are 82.03 and 80.13 in males and femalesrespectively which is inconsistent with the work done by Madadin et al 2017 [30]. However, another study has reported higher values in females than males [31]. The significant positive correlation between length and breadth of foramen observed in the present study agrees with previous studies [21, 32] Our study also shows that the sagittal diameter was significantly larger than the transverse diameter. This observation is in agreement with reports using skulls from other ethnic regions [21, 33-35].

Usually, the morphology of the foramen magnum is classified by visual assessment into seven shape types. A Kenyan based study involving two hundred and two adult skulls recorded that the shape of the foramen magnum was oval, circular, and polygonal in 13%, 24%, and 63% of the cases, respectively [36]. This present study reported the majority of the skull in females tobe oval-shaped (64.7% while a majorityof the males were circle-shaped (45.8%) which conforms with reports by other researchers [32].

Taken together, the present study lends further credence to the use of foramen sexing of skulls in forensic science since morphometric considerations of the foramen are important for neurosurgeons, radiologists and anthropologists. Although foramen magnum dimensions appear to demonstrate statistically significant differences between the sexes, singular or isolated use of this method is not encouraged unless as a suggestive finding when other features of assessment are absent or limited.

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