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Computed Tomography-Based Analysis of Foramen Magnum and Occipital Condyles in Adult Nigerians: An Anatomical Study

Análisis Basado en Tomografía Computarizada del Foramen Magnum y los Cóndilos Occipitales en Adultos Nigerianos: Un Estudio Anatómico

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SUMMARY: Precise identification of craniometric points is pivotal in forensic and anthropological research for reliable and accurate gender determination. The foramen magnum and occipital condyles' morphology offers valuable data for this purpose. The study aimed to determine variations in the morphology of the foramen magnum and occipital condyles among a population of 100 individuals, using advanced Computed Tomography (CT) scan technology. We assessed a prospective cohort of 100 individuals who underwent cranial CT scans. The study focused on the morphological variations of the foramen magnum and occipital condyles, recording shapes such as oval, round, egg, tetragon, pentagon, hexagon, and irregular for the foramen magnum, and kidney-type, oval, S-like, 8-like, ring-like, and triangular for the occipital condyles. Notably, males demonstrated higher measurement values for most parameters, with the exception of the width of the occipital condyle, where females presented larger dimensions. Furthermore, a strong positive correlation was observed between the measurements of the foramen magnum (length and width) and specific parameters of the occipital condyles. The study underscores the utility of foramen magnum dimensions, especially length, as a determinant in gender identification, with a success rate of 68 % in the studied population. This research enhances our understanding of cranial morphology and its applications in forensic and anthropological investigations.

KEY WORDS: Skull; Foramen magnum; Occipital condyles; Computed tomography; Morphological variations.

INTRODUCTION

Foramen magnum (FM) is the largest foramen of the skull located in an anteromedian position which consequently leads into the posterior cranial fossa. It has the largest diameter termed as anteroposterior diameter; it is usually oval in shape with a broad base. It comprises the distal end of the medulla oblongata, meninges, vertebral arteries, and the spinal accessory nerve (Standring *et al*., 2008; Kanodia *et al*., 2012; Muralidhar *et al*., 2014; Babu, 2016). The foramen magnum shapes differs. The shape variations is of great importance as it has effect on the vital structures that passes through it due to the role it plays in different surgical approaches. Dimensions of the foramen magnum also have clinical importance because the vital structures that pass through it may suffer compression; therefore, the cranial base is such a difficult structure that is only studied morphometrically (Murshed *et al*., 2003; Suazo *et al*., 2009; Babu, 2016; Kumar *et al*., 2019).

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In conditions of natural or man-made disasters where direct identification of victims is difficult, there is a need for an accurate, timely and simple method for sex determination (Vinutha *et al*., 2018; Tawfiq Zyoud *et al*., 2020). The anatomical characteristics of the foramen magnum and occipital condyle also differ in race, regions within the same race and may also varied in periods of evolution. Moreover, the anatomical characteristics of the FM and occipital condyle have been found to vary across races, regions, and even evolutionary periods, thus reflecting the complexity and diversity of these structures (Murshed *et al*., 2003; Singh *et al*., 2017).

Despite the potential importance of these variations, data is limited concerning the morphological characterization of the FM and occipital condyle among specific ethnic groups, such as those residing in the Bauchi metropolis. FM assessments bear significant implications not only for tailoring suitable surgical procedures but also for forensic medicine, where they contribute to identifying unknown sex and potentially ascertaining past trauma or causes of death (Erdil, *et al*., 2010; Edwards *et al*., 2013; Salih *et al*., 2015; El-Barrany *et al*., 2016) .

Thus, this study aims to analyse the FM and occipital condyles measurements as potential indicators for skull sex identification, with a focus on the Nigerian population of the Bauchi metropolis. This research not only addresses the paucity of data on this topic, but it also endeavours to provide valuable insights to clinicians, researchers, and forensic scientists, ultimately enhancing our understanding of these critical anatomical landmarks.

MATERIAL AND METHOD

Ethical clearance. Ethical clearance for this prospective study was granted by two authoritative bodies: the Bauchi State University Ethics Committee (BASUG/FBMS/REC/VOL. 2/005) and the Bauchi State Specialist Hospital’s Research and Ethical Committee (NREC/0/11/19B/2021/23). Data were accordingly collected from the Radiology Department of the Specialist Hospital in Bauchi, Nigeria, adhering to all ethical guidelines and practices mandated by these committees.

Selection criteria

Inclusion criteria

The study included individuals who met the following criteria:

1. Possession of cranial Computed Tomography (CT) scans.
2. No recorded history of cranial trauma.
3. Presentation of an intact foramen magnum and occipital condyles in the CT scans.
4. Clear visibility of the bony margins of the foramen magnum and occipital condyles in the CT scans.

Exclusion criteria

The study excluded individuals based on the following criteria:

1. Presence of a disrupted or damaged foramen magnum and occipital condyles in cranial Computed Tomography (CT) scans.
2. Evidence of diseases leading to cranial deformities.
3. History of accidents, surgery, or pathologies involving the foramen magnum region.
4. Any disorder potentially impacting the normal anatomy of the skull base.

Only individuals in good health, having completed skeletal growth in adulthood, were considered for inclusion in the study.

Sampling frame. The study's sampling frame consisted of Computed Tomography (CT) scan samples procured from the Radiology Department of the Specialist Hospital in Bauchi, Nigeria. The acquisition of these samples was facilitated by obtaining written permission from the relevant authorities before the commencement of the data collection process.

Sample size and study subjects

This prospective study utilized cranial Computed Tomography (CT) scans from a random selection of individuals aged between 21 and 65 years, retrieved from the Radiology Department of Specialist Hospital Bauchi. Sample size was determined based on the formula by Lwanga and Lemeshaw (1991), yielding a requirement of 139 CT scans for this study. However, only 100 CT scans were available from the hospital database, consisting of 71 males and 29 females. Despite falling short of the calculated ideal, these 100 scans were deemed sufficient and were thus used for the assessment in this study. Sample size was calculated using the standard formula as follows:

$$n = \frac{z^2 .1-\frac{\alpha}{2}\, p(1-p)}{d^2} \quad \text{(Lwanga \& Lemeshaw 1991)}$$

Where;
n = minimum sample size
z = standard normal deviation, which is 1• 96 at 95 % confidence level

p = proportion in the target population, given as 10 %
d = sampling error, given as 0.05

By substituting these values into the formula, we get:

$$n = (1.96)^2 \times \frac{0.1(1-0.1)}{(0.05)^2}$$

$$n = 3.8416 \times 0.1 \times \frac{0.9}{0.0025}$$

n = 138.17856

Therefore, the minimum sample size needed for the study, when rounded up is 139.

Data collection and image processing

Socio-demographic data including age and sex were meticulously gathered for each subject. The measurements of the foramen magnum and occipital condyles were then recorded by a qualified radiographer, ensuring data accuracy. These measurements were obtained from high-resolution, multi-slice cranial CT scans. A total of 100 scans were analysed, providing ten distinct dimensions of the foramen magnum and occipital condyles for evaluation. For data analysis and visualization, the Digital Imaging and Communications in Medicine (DICOM) images were transferred to a CD plate and subsequently reviewed using a dedicated image viewer.

Cranial Computed Tomography (CT) imaging protocol

All subjects underwent assessment using a multi-slice NeuViz 16 scanner (Neusoft, N16E130043). During the scanning procedure, subjects were positioned supine to ensure optimal image quality. The images obtained were visually examined to note variations in the shapes of the foramen magnum and occipital condyles. Precise measurements were captured using the same NeuViz 16 multi-slice CT scanner, with a set scanning parameter of 120 kilovolt peak (kVp) and 40 milliamperes-seconds (mAs).

Foramen magnum and occipital condyles measurements

The foramen magnum length was defined as the greatest internal length along the mid-sagittal plane (Fig. 1A, A1-A2). Correspondingly, the foramen magnum width was determined as the widest internal measurement along the transverse plane (Fig. 1A, B1-B2). The area of the foramen magnum was calculated using Radinsky's formula: 1⁄4 ×π×Width×Length, while the circumference was estimated by tracing along the bony margin of the foramen magnum (Fig. 1D).

Moreover, the right occipital condyle's length was ascertained as the longest measurement along the articular surface, perpendicular to its width (Fig. 1B, D1-D2). Its width was measured along the articular surface, perpendicular to the length (Fig. 1B, D3-D4). For the left occipital condyle,

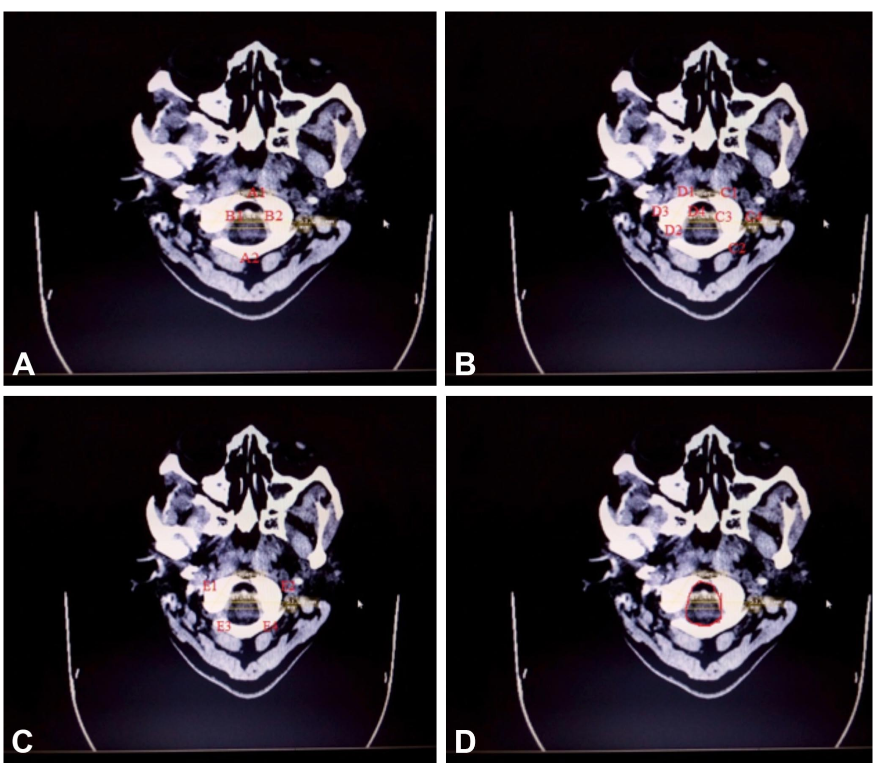

Fig. 1 1. Illustration of the measured parameters on computed tomographic images. (A) Foramen magnum length (A1-A2) and width (B1-B2). (B) Left occipital condyle length (C1-C2) and width (C3-C4), and right occipital condyle length (D1-D2) and width (D3-D4). (C) Maximum (E1-E2) and minimum (E3-E4) intercondylar distances. (D) Depicts the area and circumference of the foramen magnum.

the length was captured as the greatest measurement along the articular surface, perpendicular to the width (Fig. 1B, C1-C2). Meanwhile, the width was quantified along the articular surface, perpendicular to the length (Fig. 1B, C3-C4).

Additionally, the minimum intercondylar distance, or the shortest distance between the medial edges of the articular surfaces of the occipital condyles perpendicular to the mid-sagittal plane, was recorded (Fig. 1C, E3-E4). The maximum intercondylar distance, which was defined as the longest distance between the medial margins of the occipital condyles perpendicular to the mid-sagittal plane, was also measured (Fig. 1C, E1-E2).

Image analysis and statistical approach. Images generated were meticulously analysed employing DICOM image viewer software. All statistical computations were conducted utilizing the Statistical Package for Social Sciences (SPSS) version 21. An initial normality test was performed on the morphometric measurements for the Foramen Magnum (FM) and Occipital Condyle (OC) parameters. Differences between sexes were assessed using the Mann-Whitney U test. The Chi-square test was employed to evaluate the association between the shapes of the studied variables and distinct ethnic groups. Discriminant function analysis was utilized to predict sex and ascertain the accuracy of sex identification. A Spearman correlation was used to evaluate the relationship between parameters such as the Length of the Foramen Magnum (LFM), Width of the Foramen Magnum (WFM), Length of the Right Condyle (LRC), Length of the Left Condyle (LLC), Width of the Right Condyle (WRC), Width of the Left Condyle (WLC), Maximum Intercondylar distance (MIC), and Minimum Intercondylar distance (MnIC). Demographic data of the subjects were described using mean and standard deviation. A p-value of less than 0.05 was considered to indicate statistical significance.

RESULTS

Demographic and morphometric characteristics of study subjects. Table I summarizes the sociodemographic profiles and the morphometric dimensions of the foramen magnum (FM) and occipital condyle (OC) among patients at the Bauchi State Specialist Hospital, Bauchi, Nigeria. The study sample comprised of a significantly larger proportion of males (70 %) compared to females (30 %). The mean age for males was 40.00 ± 11.53 years, while for females it was 33.78 ± 9.79 years, within an age range of 21 to 65 years.

The average measurements for FM and OC dimensions differed between sexes across all variables. Specifically, for males, the mean length of the foramen magnum (LFM) was 26.33±6.51 mm, width of the foramen magnum (WFM) was 21.05±5.77 mm, area of the foramen magnum (AFM) was 427.34±208.85 mm, circumference of the foramen magnum (CFM) was 68.22±14.44 mm, length of the right condyle (LRC) was 16.77±8.83 mm, width of the right condyle (WRC) was 7.76±3.03 mm, length of the left condyle (LLC) was 18.28±5.42 mm, width of the left condyle (WLC) was 8.57±3.45 mm, maximum intercondylar distance (MIC) was 44.89±7.30 mm, and the minimum intercondylar distance (MnIC) was 22.70±4.89 mm.

For females, the mean LFM was 21.58±4.61 mm, WFM was 18.31±4.36 mm, AFM was 311.65±124.58 mm, CFM was 61.54±10.35 mm, LRC was 14.78±5.07 mm, WRC was 7.98±3.43 mm, LLC was 16.95±4.77 mm, WLC was 8.57±3.57 mm, MIC was 40.79±6.03 mm, and MnIC was 21.34±5.22 mm. These findings provide a comprehensive overview of the FM and OC dimensions among the male and female patients in this study group. The standard deviations, minimum and maximum values for each dimension are presented for both sexes in Table I.

Table I. Descriptive statistics of demographic data and morphometric dimensions of foramen magnum and occipital condyle stratified by sex (n= 100).

Variable	Sex	Mean ± SD	Min	Max
Age	Male	40.00±11.53	21	65
(Years)	Female	33.78±9.79		
LFM	Male	26.33±6.51	13.87	46.76
(mm)	Female	21.58±4.61	11.68	35.60
WFM	Male	21.05±5.77	7.80	35.05
(mm)	Female	18.31±4.36	11.19	27.29
AFM	Male	427.34±208.85	84.93	1286.57
(mm)	Female	311.65±124.58	168.04	762.65
CFM	Male	68.22±14.44	34.00	99.79
(mm)	Female	61.54±10.35	39.91	85.87
LRC	Male	16.77±8.83	7.09	74.59
(mm)	Female	14.78±5.07	7.55	31.04
WRC	Male	7.76±3.03	3.31	16.01
(mm)	Female	7.98±3.43	3.38	14.86
LLC	Male	18.28±5.42	7.65	30.16
(mm)	Female	16.95±4.77	8.50	28.81
WLC	Male	8.57±3.45	3.57	16.65
(mm)	Female	8.57±3.57	3.72	15.02
MIC	Male	44.89±7.30	28.17	59.74
(mm)	Female	40.79±6.03	32.79	59.90
MnIC	Male	22.70±4.89	11.28	32.90
(mm)	Female	21.34±5.22	13.42	33.35

SD; standard deviation, Min; Minimum, Max; Maximum

Frequency distribution of foramen magnum (FM) and occipital condyle (OC).

The morphological variations of the foramen magnum (FM) and occipital condyle (OC) shapes are depicted in Tables II and III respectively. In our cohort, the most prevalent shape of the foramen magnum was found to be oval, constituting 33.3 % of the sample. This was followed by round (18.2 %), egg (12.1 %), tetragonal (10.1 %), irregular and pentagonal (each 9.1 %), and hexagonal (7.1 %) shapes.

Table II. Frequency distribution of foramen magnum morphological variations.

Types	Number	Percentage
Oval	33	33.3
Round	18	18.2
Egg	12	12.1
Tetragonal	10	10.1
Pentagonal	9	9.1
Hexagonal	7	7.1
Irregular	10	10.1
Total	99	100

Table III. Frequency distribution of occipital condyles morphological variations.

Types	Number	Percentage
Kidney	39	39
Oval	14	14
8-like	10	10
S-like	17	17
Ring-like	10	10
Triangular	10	10
Total	100	100

For the occipital condyles, the dominant morphological variation was a kidney-like structure, accounting for 39 % of the sample. The other shapes observed were the S-like (17 %), oval (14 %), and 8-like, ring-like, and triangular types (each 10 %).

Variations of foramen magnum and occipital condyles dimensions among sex

Table IV present the sex-based variations in foramen magnum and occipital condyle dimensions. The Mann-Whitney U test was employed to assess these differences. A statistically significant disparity was observed in the length of the foramen magnum (LFM), width of the foramen magnum (WFM), area of the foramen magnum (AFM), circumference of the foramen magnum (CFM), and maximum intercondylar distance (MIC), with males demonstrating larger dimensions than females ($p<0.05$).

In contrast, no significant difference between sexes was observed in the length of right/left occipital condyle (LRC, LLC), width of right/left occipital condyle (WRC, WLC), and minimum intercondylar distance (MnIC) ($p>0.05$).

Table IV. Sex-based variations of foramen magnum and occipital condyles dimensions.

Variable	Sex	Median	IQR	Z-statistic	*P* value
LFM	Male	25.0	8.1	-3.912	< 0.001
	Female	21.2	4.8		
WFM	Male	22.1	7.5	-2.799	< 0.020
	Female	18.4	6.9		
AFM	Male	425.9	209.4	-3.566	< 0.001
	Female	296.5	127.4		
CFM	Male	68.2	22.3	-2.461	< 0.020
	Female	61.8	14.1		
LRC	Male	15.0	6.3	-1.166	< 0.260
	Female	14.1	6.4		
WRC	Male	6.8	5.1	-110	> 0.930
	Female	7.1	5.7		
LLC	Male	17.4	6.9	-1.033	> 0.340
	Female	17.1	6.7		
WLC	Male	7.3	4.9	-0.668	> 0.510
	Female	7.2	5.0	-3.080	
MIC	Male	45.2	11.4	-3.080	< 0.010
	Female	39.4			
MnIC	Male	22.9	6.01	-1.664	> 0.140
	Female	20.8	7.4		

Ethnic variation in the shapes of the foramen magnum

Table V presents the association of different shapes of the foramen magnum with various ethnic groups. The distribution of foramen magnum shapes across the ethnic groups was evaluated using the chi-square (X2) test. The test produced a chi-square statistic of 44.135 with 54 degrees of freedom (df). The p-value was determined to be 0.829, which is above the commonly used significance level of 0.05, suggesting that the shapes of the foramen magnum do not significantly differ across the ethnic groups investigated in this study.

It can be observed that the oval shape of the foramen magnum is most common among the Fulani ethnic group, while the Hexagonal shape is most common in the Hausa group. The Igbo ethnic group showed a higher frequency of the round shape, while the Sayawa group showed a higher frequency of the Tetragonal shape. However, it's important to note that due to the p-value being above

0.05, these apparent trends do not represent a statistically significant association between ethnicity and the shape of the foramen magnum. Therefore, these observations could have resulted from random variation within the sample population. Further investigation with a larger sample size may be needed to determine whether there are meaningful differences in foramen magnum shape across different ethnic groups.

Table V. Association of foramen magnum shapes and ethnicity.

	Shapes of foramen magnum, n (%)								
Variable	Oval	Round	Egg	Tetra	Penta	Hexa	Irregular	X^2 (df)	*P* value*
Ethnicity								44.135 (54)	0.829
Hausa	6(18.8)	2(11.1)	3(25.0)	1(10.0)	2(22.2)	3(42.9)	1(10.0)		
Fulani	7(21.9)	4(22.2)	3(25.0)	1(10.0)	1(11.1)	1(14.3)	0(0.0)		
Yoruba	5(15.6)	1(5.6)	1(8.3)	1(10.0)	1(11.1)	1(14.3)	2(20.0)		
Igbo	2(6.3)	4(22.2)	0(0.0)	1(10.0)	1(11.1)	1(14.3)	1(10.0)		
Sayawa	1(3.1)	0 (0.0)	2(16.7)	3(30.0)	2(22.2)	1(14.3)	0(0.0)		
Jarawa	3(9.4)	1(5.6)	1 (8.3)	2(20.0)	0(0.0)	1(14.3)	0(0.0		
Kanuri	2(3.1)	2(11.1)	1(8.3)	0(0.0)	0(0.0)	0 (0.0)	2(20.0)		
Kare-kare	2(6.3)	1(5.6)	0(0.0)	0(0.0)	1(11.1)	0(0.0)	0(0.0)		
Warjawa	2(6.3)	2(11.1)	1(8.3)	0(0.0)	1(11.1)	0(0.0)	0(0.0)		

Ethnic variation in the shapes of the occipital condyles

Table VI investigates the association between different shapes of occipital condyles and various ethnic groups. The distribution of occipital condyle shapes across the ethnic groups was evaluated using the chi-square (X2) test, which yielded a statistic of 42.112 with 45 degrees of freedom (df). The resulting p-value was 0.595, exceeding the conventional significance level of 0.05, indicating that the occipital condyle shapes do not significantly differ among the ethnic groups examined in this study.

In the observed data, the kidney shape of the occipital condyles was most frequently seen in the Fulani ethnic group, while the 8-like shape was most common among the Hausa group. The Igbo and Sayawa ethnic groups showed a higher frequency of the S-like shape, whereas the ring-like shape was more frequent in the Yoruba group. The triangular shape was equally distributed among Hausa, Fulani, Yoruba, Igbo, Sayawa, Jarawa, and Warjawa.

However, the above p-value signifies these trends do not denote a statistically significant association between ethnicity and the shape of occipital condyles. As such, these observations could potentially be the product of random variation within the sample population. A more comprehensive investigation with a larger sample size might be required to determine if there are significant differences in occipital condyle shapes across various ethnic groups.

Table VI. Association of occipital condyles shapes and ethnicity.

	Shapes of occipital condyles, n (%)							
Variables	Kidney	Oval	8-like	S-like	Ring-like	Triangular	X^2 (df)	*P* value*
Ethnicity							42.112(45)	0.595
Hausa	7(17.9)	2(14.3)	3(30.0)	4(23.5)	1(10.0)	1(11.1)		
Fulani	8(20.5)	4(28.6)	2(20.0)	1(5.9)	0(0.0)	2(22.2)		
Yoruba	6(15.4)	0(0.0)	1(10.0)	1(5.9)	3(30.0)	1(11.1)		
Igbo	3(7.7)	2(14.3)	0(0.0)	3(17.6)	2(20.0)	1(11.1)		
Sayawa	2(5.1)	3(21.4)	1(10.0)	4(23.5)	1(10.0)	1(11.1)		
Jarawa	4(10.3)	0(0.0)	2(20.0)	0(0.0)	1(10.0)	1(11.1)		
Kanuri	2(5.1)	1(7.1)	1(10.0)	0(0.0)	0(0.0)	2(22.2)		
Gerawa	2(5.1)	1(7.1)	0(0.0)	3(17.6)	0(0.0)	0(0.0)		
Kare-kare	3(7.7)	0(0.0)	0(0.0)	0(0.0)	1(10.0)	0(0.0)		
Warjawa	2(5.1)	1(7.1)	0(0.0)	1(5.9)	1(10.0)	1(11.1)		

Sex discrimination through discriminant function analysis. The results in Tables VII and VIII provide insight into the sex differentiation capabilities of the foramen magnum and occipital condyle dimensions based on computed tomography (CT) scans.

Table VII compares the mean and standard deviation (SD) values of these dimensions between male and female participants. The sex discrimination significance for each variable is assessed using the Wilk's lambda test, F-value, and the corresponding p-value. The lower the Wilk's lambda, the more significant the variable is in distinguishing the two groups. The F-value assesses the degree of variation between groups compared to the variation within groups. The length of the foramen magnum (LFM) had the greatest contribution to sex discrimination, as evidenced by the smallest Wilk's lambda value (0.876), highest F-value (13.875), and a p-value less than 0.001. This shows that there is a statistically significant difference between males and females concerning the LFM, and it effectively discriminates between the two sexes.

In contrast, variables such as WRC, WLC, and MnIC exhibit high Wilk's lambda values and non-significant p-values, indicating they do not significantly contribute to sex differentiation in this context.

Table VII. Discriminant function analysis using foramen magnum and occipital condyle dimensions in CT scan.

Variable	Male Mean	SD	Female Mean	SD	Wilk's λ	F	*P* value*
LFM	26.35	6.47	21.45	4.50	0.876	13.875	0.001
WFM	21.19	5.87	17.74	4.72	0.925	7.970	0.006
AFM	430.99	209.63	300.66	126.89	0.910	9.720	0.002
CFM	68.37	14.49	61.36	10.32	0.946	5.611	0.020
LRC	16.72	8.78	14.51	5.01	0.984	1.610	0.208
WRC	7.72	3.03	7.77	3.42	1.000	0.003	0.953
LLC	18.24	5.39	16.74	4.66	0.983	1.710	0.184
WLC	8.54	3.44	8.29	3.60	0.999	0.103	0.749
MIC	44.90	7.25	40.26	6.15	0.914	9.190	0.003
MnIC	22.72	4.86	20.90	5.30	0.973	2.751	0.100

Table VIII. Canonical discriminant function coefficient.

Sex	Predicted group membership Male	Female
Male (n=71)	45	26
Female (n=29)	6	23
Male (100 %)	63.4	36.6
Female (100 %)	20.7	79.3

Efficacy of foramen magnum length in predicting sex

Table IX presents the results of the predictive accuracy of using the foramen magnum length to determine sex within the Bauchi population. The results are divided into predicted group membership *versus* actual sex, with values indicating the number of correctly sexed cases Out of 71 male cranial CT scans, 45 were correctly identified as male, resulting in an accuracy rate of 63.4 %. However, 26 male cases were incorrectly classified as female, indicating a misclassification rate of 36.6 %.

Table IX. Accuracy of foramen magnum length for sex prediction in Bauchi population.

Sex	Predicted group membership Male	Female
Male (n=71)	45	26
Female (n=29)	6	23
Male (100 %)	63.4	36.6
Female (100 %)	20.7	79.3

On the other hand, the predictive accuracy was higher for females. Out of 29 female cranial CT scans, 23 were accurately identified as female, giving an accuracy rate of 79.3 %. However, 6 female cases were incorrectly classified as male, denoting a misclassification rate of 20.7 %. While the foramen magnum length was a significant predictor of sex, as demonstrated in previous tables, the accuracy of sex identification varied between males and females. The accuracy was higher for females compared to males in the studied population. This suggests that the discriminant function using the foramen magnum length is more reliable for sexing female crania than male in this population. However, overall, it correctly classified 68.0 % of all cases, demonstrating its utility in sex identification in the Bauchi population.

Correlation analysis of foramen magnum and occipital Condyle Dimensions.

Table X explores the correlations between different dimensions of the foramen magnum and occipital condyles. There is a statistically significant strong correlation between Length of Foramen Magnum (LFM) and Length of Right Condyle (LRC) (r=0.279, p<0.005), suggesting that as the length of the foramen magnum increases, the length of the right condyle also increases in a meaningful way.

Moreover, a similar trend can be observed with LFM and MIC (r=0.316, p<0.001), suggesting a significant

Table X. Relationship of foramen magnum and occipital condyle dimensions.

Variable	correlations	LRC	WRC	LLC	WLC	MIC	MniC
LFM	r	0.279	0.194	0.252	0.231	0.316	0.220
	p value	0.001	0.053	0.012	0.021	0.001	0.028
WFM	r	0.337	0.203	0.296	0.264	0.404	0.259
	p value	0.001	0.042	0.003	0.008	0.001	0.009

correlation between these two measurements. The Width of Foramen Magnum (WFM) also shows strong correlations with several other dimensions. Notably, there is a strong relationship between WFM and LRC (r=0.337, p<0.001), Width of Left Condyle (WLC) (r=0.264, p<0.008), and MIC (r=0.404, p<0.001).

Thus the results revealed significant relationships between various foramen magnum and occipital condyle dimensions, providing key insights into the intricate anatomical relationships between these structures in among Bauchi population.

DISCUSSION

This comprehensive study provides a detailed examination of the foramen magnum and occipital condyle dimensions within the Bauchi population, encompassing an array of morphological variations and their potential significance in sex determination.

As our study demonstrates, the foramen magnum's most prevalent shapes were oval and round, mirroring the results of previous research (Espinoza *et al*., 2011). Similarly, the occipital condyle shapes noted in our sample - kidney, oval, 8-like, S-like, ring-like, and triangular - align with the shapes identified in other studies (Ozer *et al*., 2011; Kumar *et al*., 2019), though there was a discrepancy in the most common shape, with our study identifying the kidney shape as the most common, in contrast to the oval-like shape identified by Ozer *et al*. (2011).

Sex-related differences in foramen magnum dimensions were evident in our research. We discovered that the mean Length and Width of the Foramen Magnum (LFM, WFM) were larger in males than in females, echoing the results of with (El-Barrany *et al*., 2016). However, when compared to previous studies (Uthman *et al*., 2012; Gopalrao *et al*., 2013; El-Barrany *et al*., 2016), the dimensions found in our study were lower. This disparity could be attributed to differences in population, methodology, or measurement techniques and further emphasizes the need for population-specific studies.

Our findings also reveal that the mean Area of Foramen Magnum (AFM) of male skulls (427.34± 208.85 mm^2) is significantly larger than female skulls (311.65±124.58 mm^2) (Table I and IV). Even though the AFM values in our study were lower than those reported in previous studies (Günay & Altinkök, 2000) in both male and female (909.9 and 819.0 mm^2), (Catalina and Herrera 1987) (888.4 and 801.0 mm^2), (Routal *et al*., 2014) (819.0 and 771.0 mm^2) and (Salih *et al*., 2015) (819.84 and 692.13 mm^2), the trend of males having larger AFM than females remains consistent.

Interestingly, we found that the width of the occipital condyles (CFM) was broader in females than in males (68.22±14.44 and 61.54 ±10.35) (Table I), a finding that contradicts earlier studies but aligns with (Sneha *et al*., 2014). The variability in these results underlines the complexity of the biological factors shaping these structures and calls for further research to elucidate these sex-based discrepancies.

In terms of sex determination, our study indicates that LFM could predict sex in the Bauchi population with an overall accuracy rate of 68.0 %. This finding corroborates other research that identified single variables as significant sex discriminators (Macaluso Jr., 2010; Singh & Talwar, 2013). Moreover, our study establishes significant correlations between various foramen magnum and occipital condyle dimensions, lending further credence to the hypothesis that these structures could be used for sex determination. However, some relationships such as the correlation between the LFM and LLC or the width of the right and left occipital condyle were not found to be significant, emphasizing the need for continued research in this field.

In conclusion, our findings contribute to the growing body of literature emphasizing the value of foramen magnum and occipital condyle morphology and dimensions in anthropological and forensic contexts. Additionally, variations in dimensions should be taken into consideration when performing clinical and radiological diagnoses and during a surgical procedure. This study also reveals that the shape of the foramen magnum and the occipital condyle is not a mark of a specific ethnic group. Future studies should consider these findings when examining morphological sex differences and explore the potential of these structures as markers of sexual dimorphism.

Ethical approval. Prior approval was obtained from both the Faculty of Basic Medical Sciences, Bauchi State University, Gadau, Nigeria (approval no: BASUG/FBMS/REC/VOL. 2/005) and Bauchi State Health Research Ethical Committee (HREC) of the Ministry of Health (approval no: NREC/0/11/19B/2021/23) to conduct this research. Patient's consent and data confidentiality were maintained and protected against any unlawful/unauthorized access.

MUHAMMAD, F.; AHMAD, U.; TAWFIQ ZYOUD, T.Y.; JIBRIL, M. M.; KWAIRANGA, S. H. & SUPPIAH, S. Análisis basado en tomografía computarizada del foramen magnum y cóndilos occipitales en adultos nigerianos: Un estudio anatómico. *Int. J. Morphol., 43(3)*:1021-1029, 2025.

RESUMEN: La identificación precisa de los puntos craneométricos es fundamental en la investigación forense y antropológica para la determinación confiable y precisa del sexo. La morfología del foramen magnum y los cóndilos occipitales ofrece datos valiosos para este propósito. El estudio tuvo como objetivo determinar las variaciones en la morfología del foramen magnum y los cóndilos occipitales entre una población de 100 individuos, utilizando tecnología avanzada de tomografía computarizada (TC). Evaluamos una cohorte prospectiva de 100 individuos que se sometieron a tomografías computarizadas craneales. El estudio se centró en las variaciones morfológicas del foramen magnum y los cóndilos occipitales, registrando formas como ovalada, redonda, en forma de huevo, tetrágono, pentágono, hexágono e irregular para el foramen magnum, y tipo riñón, ovalada, en forma de S, en forma de 8, en forma de anillo y triangular para los cóndilos occipitales. Cabe destacar que en los hombres se demostraron valores de medición más altos para la mayoría de los parámetros, con la excepción del ancho del cóndilo occipital, donde las mujeres presentaron dimensiones mayores. Además, se observó una fuerte correlación positiva entre las mediciones del foramen magnum (largo y ancho) y parámetros específicos de los cóndilos occipitales. El estudio subraya la utilidad de las dimensiones del foramen magnum, especialmente la longitud, como determinante en la identificación del sexo, con una tasa de éxito del 68 % en la población estudiada. Esta investigación mejora nuestra comprensión de la morfología craneal y sus aplicaciones en investigaciones forenses y antropológicas.

PALABRAS CLAVE: Cráneo; Foramen magnum; Cóndilos occipitales; Tomografía computarizada; Variaciones morfológicas.

REFERENCES

Babu, F. F. K. Y. Evaluating the shape of foramen magnum and overlapping of occipital condyle on the foramen. *Int. J. Sci. Res., 5(9)*:1078-82, 2016.

Edwards, K.; Viner, M. D.; Schweitzer, W. & Thali, M. J. Sex determination from the foramen magnum. *J. Forensic Radiol. Imaging, 1(4)*:186-92, 2013.

El-Barrany, U. M.; Ghaleb, S. S.; Ibrahim, S. F.; Nouri, M. & Mohammed, A. H. Sex prediction using foramen magnum and occipital condyles computed tomography measurements in Sudanese population. *Arab. J. Forensic Sci. Forensic Med., 1(4)*:414-23, 2016.

Erdil, F. H.; Sabanciogullari, V.; Cimen, M. & Isik, O. Morphometric analysis of the foramen magnum by computed tomography. *Erciyes Med. J., 32(3)*:167-70, 2010.

Espinoza, G. E.; Ayala, P. C.; Ortega, B. L.; Collipal, L. E. & Silva, M. H. Tomographic morphometry of the foramen magnum and its relation to sex and Mapuche ethnicity. *Rev. ANACEM, 5(1)*:28-31, 2011.

Gopalrao, S. R.; Solanke, P.; Ugale, M. & Balsurkar, S. Computed tomographic scan study of morphometry of foramen magnum. *IJCRR Int. J. Curr. Res. Rev., 5(19)*:41-8, 2013.

Günay, Y. & Altinkök, M. The value of the size of foramen magnum in sex determination. *J. Clin. Forensic Med., 7(3)*:147-9, 2000.

Kanodia, G.; Parihar, V.; Yadav, Y. R.; Bhatele, P. R. & Sharma, D. Morphometric analysis of posterior fossa and foramen magnum. *J. Neurosci. Rural Pract., 3(3)*:261-6, 2012.

Kumar, A.; Potdar, P.; Singh, K. & Dhakar, J. S. A study of foramen magnum and its clinical relevance. *Santosh Univ. J. Health Sci., 5(2)*:72-7, 2019.

Macaluso Jr., P. J. Metric sex determination from the basal region of the occipital bone in a documented french sample. *Bull. Mem. Soc. Anthropol. Paris, 23*:19-26, 2011.

Muralidhar, P. S.; Magi, M.; Nanjundappa, B.; Pavan, P. H.; Premalatha, G. & Shaik, H. S. Morphometric analysis of foramen magnum. *Int. J. Anat. Res., 2(1)*:249-55, 2014.

Murshed, K. A.; Cicekcibasi, A. E. & 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., 33*:301-6, 2003.

Ozer, M. A.; Celik, S.; Govsa, F. & Ulusoy, M. O. Anatomical determination of a safe entry point for occipital condyle screw using three-dimensional landmarks. *Eur. Spine J., 20(9)*:1510-7, 2011.

Salih, A. M.; Ayad, C. E.; Ahmed, E.; Kajoak, S. A.; Arabia, S. & Ayad, C. E. (2015). Morphometric analysis of the Sudanese foramen magnum: a computerized tomography study. *Diagn. Radiol., 22(6)*:46-54, 2015.

Singh, G. & Talwar, I. Morphometric analysis of foramen magnum in human skull for sex determination. *Hum. Biol. Rev., 2(1)*:29-41, 2013.

Singh, K. C.; Rai, G. & Rai, R. Morphological variations of the foramen magnum in adult human dry skull in Eastern UP (India) population. *Int. J. Med. Res. Prof., 3(2)*:205-8, 2017.

Standring, S. *Gray's Anatomy. Anatomical Basis of Clinical Practice*. 40th ed. London, Churchill Livingstone, 2008.

Suazo, G. I. C.; Russo, P. P.; Zavando, M. D. A. & Smith, R. L. Sexual dimorphism in the foramen magnum dimensions. *Int. J. Morphol., 27(1)*:21-3, 2009.

Tawfiq Zyoud, T. Y.; Abdul Rashid, S. N.; Suppiah, S.; Abdul Rahim, E. & Mahmud, R. Decoding death by unknown causes using post mortem image-guided virtopsy: A review of recent literature and the Malaysian experience. *Med. J. Malaysia, 75(4)*:411-8, 2020.

Uthman, A. T.; Al-Rawi, N. H. & Al-Timini, J. F. Evaluation of foramen magnum gender determination using helical CT scanning. *Dentomaxillofac. Radiol., 41(3)*:197-202, 2012.

Vinutha, S. P.; Suresh, V. & Shubha, R. Discriminant function analysis of foramen magnum variables in South Indian population: a study of computerised tomographic images. *Anat. Res. Int., 2018*:2056291, 2018.

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