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RESEARCH

Estimation of sex using craniofacial dimensions: a study of CT scan images in Kaduna State, Nigeria

Kraniyofasiyal boyutlar kullanarak cinsiyet tahmini: Kaduna Eyaleti, Nijerya'da BT tarama görüntüleri çalışması

Aliyu Jaafar[1], Tanko Murdakai[1], Moses Asongu Tersoo[1], Abdulrazak Muhammad[1], Zainab M. Bauchi[1] Usman Farrau[2], Ibrahim Sambo Aliyu[3], Lawan H. Adamu[4], Muhammad Zaria Ibrahim[5], Yusuf Nadabo Abdullahi[1], Zaharaddeen Muhammad Yusuf[1], Amiru Jaafar[6]

[1]Department of Human Anatomy, Faculty of Basic Medical Sciences, Ahmadu Bello University, Nigeria
[2]Department of Human Physiology, Faculty of Basic Medical Sciences, Ahmadu Bello University, Nigeria
[3]Department of Chemical Pathology, Ahmadu Bello University Teaching Hospital Zaria, Nigeria
[4]Department of Human Anatomy, Faculty of Basic Medical Sciences, College of Medicine and Allied Health Sciences, Federal University Duste, Nigeria,
[5]Department of Radiology Ahmadu Bello University Teaching Hospital Zaria.Nigeria
[5]Department of Human Anatomy, Faculty of Basic Medical and Health Sciences, College of Medicine and Allied Health Sciences, Federal University Duste, Nigeria,
[6]Department of Human Anatomy, Faculty of Basic Medical Sciences, Baze University Abuja, Nigeria

Abstract

Purpose: The aim of this study is to evaluate the potential of craniofacial dimensions in estimating sex in a sample population in Kaduna State, Nigeria.
Materials and Methods: This is a retrospective study of normal CT scan images of 399 Crania (comprising 236 males and 163 females) of age range 18–95 years that came for CT scans for the diagnostic purpose at the National Ear Care Centre, Kaduna between the years of 2017–2019. The images were randomly taken at the archives of the Radiology Department of the institute on an axial plane. The five craniofacial dimensions were measured directly from the computer screen using Vitrea CT Software.
Results: Maximum cranial width (13.49±0.57 cm), maximum cranial length (18.11±0.74 cm), and bizygomatic length (12.64±0.58 cm) of males were significantly greater than in females (13.35±0.49 cm), (17.82±0.66 cm) and (12.22±0.59 cm) respectively. The bizygomatic length on the receiver operating characteristic curve (Area under the curve = 0.711), logistic regression (odd ratio = 1.254), and discriminant function analysis (percentage accuracy after cross validation = 67.4 %.) was the best single variable for estimating sex. Bizygomatic and maximum cranial length were selected as the significant estimators of sex by

Öz

Amaç: Bu çalışmanın amacı, Kaduna eyaletinin Nijerya'daki örnek bir popülasyonda cinsiyeti tahmin etmede kraniyofasiyal boyutların potansiyelini değerlendirmektir.
Gereç ve Yöntem: Bu, 18-95 yaş aralığında 399 Crania'nın (236 erkek ve 163 kadın) normal BT tarama görüntülerinin retrospektif bir çalışmasıdır. 2017-2019 yılları. Görüntüler rastgele bir eksenel düzlemde Enstitünün Radyoloji Bölümü arşivlerinde çekildi. Beş kraniyofasiyal boyut, Vitrea CT yazılımı kullanılarak doğrudan bilgisayar ekranından ölçüldü.
Bulgular: Maksimum kraniyal genişlik (13.49 ± 0.57 cm), maksimum kraniyal uzunluk (18.11 ± 0.74 cm) ve tuhaf uzunluk (12.64 ± 0.58 cm) erkeklerden önemli ölçüde daha büyüktü (17.82 ± 0.49 cm) (17.82 ± 0.66 (CM) ve (12.22 ± 0.59 cm). Alıcı çalışma karakteristik eğrisi (eğrinin altındaki alan = 0.711), lojistik regresyon (tek oran = 1.254) ve ayırt edici fonksiyon analizi (çapraz validasyondan sonra yüzde doğruluğu = %67.4) üzerindeki tuhaf uzunluk. . Bizgomatik ve maksimum kraniyal uzunluk, sırasıyla 1.412 ve 3.984 ayarlanmış tek oranlara sahip çok değişkenli lojistik regresyon ile cinsiyetin önemli tahmin edicileri

Address for Correspondence: Aliyu Jaafar; Department of Human Anatomy, Faculty of Baic Medical Sciences, Ahmadu Bello University; Nigeria Email: ajaafar@abu.edu.ng
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multivariate logistic regression with Adjusted Odd Ratios of 1.412 and 3.984 respectively, as well as discriminant function analysis (percentage accuracy after cross validation = 66.9%).
Conclusion: Among the sample population in Kaduna State, Nigeria, there is sexual dimorphism in some of the craniofacial variable found in CT scan images. Multivariate logistic regression may be the best model to utilize for predicting sex among the Kaduna State sample group.
Keywords:. Forensic science, craniofacial, sex estimation, anthropology

olarak seçildi (ayrımcı fonksiyon analizi (çapraz validasyondan sonra yüzde doğruluk =%66.9).
Sonuç: Nijerya, Kaduna Eyaletindeki örneklem popülasyonunda, BT tarama görüntülerinde bulunan bazı kraniyofasiyal değişkenlerde cinsel dimorfizm vardır. Çok değişkenli lojistik regresyon, Kaduna Eyaleti örneklem grubu arasında cinsiyeti tahmin etmek için kullanılacak en iyi model olabilir.

Anahtar kelimeler: Adli bilim, kraniyofasiyal, cinsiyet tahmini, antropoloji

INTRODUCTION

The identification of an individual whether dead or alive is a major goal of forensic anthropologists which is achieved accurately when the individual body is in a complete state. However, in some situations, that becomes challenging either due to natural processes or disaster (e.g. postmortem body decomposition, earthquake, flood), deliberate action of a terror (e.g. deliberate mutilation, disfigurement, gouging) or accident (e.g. plane crash, road accident, train accident or fire outbreak) which consequently leads to body fragmentation. In such situations forensic experts will be charged with the responsibility of identifying the victims from the available body remains where they generate a biological profile of the victim in order to discover the sex, age, height and ethnicity.

Identification of sex is essential in establishing a victim's biological profile, and the human skeleton has become a central target for many researchers. The presence of complete bone makes things a lot easier [1] for sex identification[1,2] with a percentage accuracy of 98%[3]. However, If the complete skeleton is not available, accuracy depends largely on what bony components are available and if the skeleton can be linked to a specific population[4,5]. However, incomplete skeleton/dismembered or fragmented skeleton as well as juvenile skeleton makes it challenging for forensic anthropologists to identify victims. The human pelvis and the skull are the two most sexually dimorphic regions of the human skeleton that tends to withstand inhumation and individually give perfect accuracy of 95% and 90% respectively[3]. Consequently, the skull separately is considered one of the most reliable bones for sex differentiation[6].

The skull consists of the cranium and facial skeleton. The cranium is the bony container for the brain and the foundation for the facial skeleton. The cranium is made up of a number of originally separate bones joined by sutures.

The two methods used in the assessment of sex are the visual and metric methods. The former involves the use of differences in size between men and women or morphological differences related to childbirth in women[4] while the latter involves the measurement of a different part of the skeleton and subjecting it to statistical tools such as logistic regression or discriminant function analysis which likely will classify the individual into males or females by placing a sectioning point that equally classifies males and females correctly. Both cranial and facial measurements are used for estimating sex in situations when other evidence is unavailable[7].

The metric methods have been used in the estimation of sex using cephalo-facial measurements from different regions of the world with different levels of accuracy, for example, Shah et al[7] obtained an accuracy of 81.9% by logistic regression and 79.9% by discriminant function analysis from Indian population. Jain et al[8] also from the Indian population reported Bizygomatic breadth as a single parameter with the highest accuracy of 79.7% and Bizygomatic breadth in combination with Maximum cranial circumference giving the highest accuracy of 83.7% after cross-validation. Also, from South Africa, Dayal et al.[9] reported the highest accuracy of 75.8% by Bizygomatic breadth. Adefisan et al.[10] from Nigeria also reported an accuracy of 87.5% after cross-validation.

Radiologically, metric measurements of the skull have shown promising results with almost similar results to the direct metric measurements of the dry skull[11]. The reports of Hilgers et al.[12] and Kamburoğlu et al.[13] using Come Beam Computed Tomography shows no difference with the direct metric measurement of the dry skull.

Few studies in Nigeria highlighted the use of metric measurements of Computed Tomography in the estimation of sex[14-16] even though CT imaging has shown good results in metric measurements of the skull[8]. This study aims to determine the accuracy of some craniofacial dimensions in sex estimation using logistic regression and discriminant function analysis. This will help in the determination of sex in situations whereby such fragments are the only available evidence brought for CT scans during the investigation of medico-legal cases among the Nigerian population. The hypothesis of this study is that, craniofacial dimension considered in this study do not accurately predict sex among Nigerian population using logistic regression and discriminant function analysis.

MATERIALS AND METHODS

Sample

This study was carried out retrospectively and the CT scan images were obtained from the database at the Radiology Department of the National Ear Care Centre, Kaduna, Nigeria from the year 2017 through 2019 by systematic random sampling. It is a specialized tertiary health institution that also serves as a referral Centre for ear, nose, and throat-related complications. Due to the scarcity of effective modern imaging facilities in many tertiary Centres in Nigeria, patients from different parts of the country are therefore referred to the Radiology Department of this Centre for CT services.

A total number of 399 normal scan images that are referred to the Radiology Department for cranial CT during this period were included in the study. Their imaging records, as well as their CT reports, were retrieved from the database and evaluated using Vitrea workstation software.

CT images that showed fractured skulls, skulls with tumors or congenital anomalies and blurred images were excluded for this study.

Ethical approval was obtained from the National Ear Care Centre, Kaduna Health Research Ethics Committee with the reference number NECC/ADM/197/1/95.

Image acquisition

Cranial CT studies were done using the Toshiba Alexion 32-slice multidetector CT scanners. A multislice protocol with 5 mm cuts from the base to the vertex was used. The current and voltage of the tube range 250–300 mAs and 120–150 kvp respectively were used for the cranial CT scans. Images were obtained in the axial plane with multiplanar reformatted sagittal and coronal images with the workstation software (vitrea version 6.9.2) at the respective point of measurement as previously reported by Paulinus et al.[17] and Jain et al.[18] as follows:

1. Maximum Cranial Width: Measured as the distance between both eurions
2. Maximum Cranial Length Maximum (MCL): Measured as distance from the Opisthocranion & glabella
3. Orbital Length (OBL): Measured as the lateral & medial border of the orbit
4. Bizygomatic Length (BZL): Measured as the distance between the two zygions
5. Cranial Index (CI): Obtained by measuring the ratio of MCW to MCL and then multiplied by 100 as reported by Williams and Roger[19].

Statistical analysis

Data were expressed as Mean ± standard deviation (SD). The differences in sexes were obtained using student t-tests. The Pearson's correlations were performed to establish the relationship between the craniofacial variables. Receiver Operating Characteristic Curve (ROC) was used for the significant parameters to determine the contribution of each parameter to the predictive model of the binary logistic regression equations. Univariate and multivariate logistic regressions were performed on CT images of normal 399 crania to establish best parameters for sex determinations. Univariate and multivariate discriminant function analyses using "leave one out classification" were performed to generate discriminant function equations for determination of sex so that the accuracy rate of the original sample and the one generated after cross-validation will be demonstrated. A significant level of 5% (p-value $\leq$ 0.05) was considered statistically significant. SPSS Version 20 was used for the analysis.

RESULTS

Table 1 indicates the mean, standard deviation and mean differences in males (n = 236) and females (n = 162) from the study population of Nigeria (n = 399). Table 2 indicates the student's t-tests for the study parameters. There is a significant sexual difference in maximum cranial width (MCW), maximum cranial length (MCL) and Bizygomatic length (BZL) with higher mean values in Males than their female counterparts

Table 1. Mean, standard deviation of the studied Nigerian population (n =399) with Mean differences in males (n = 236) and females (n =162).

	Total (n = 399)		Males (n = 236) 95% CI				Females (n = 162) 95% CI		
Parameters	Min- Max	Mean ± SD	Lower Bound	Upper Bound	Std. Error		Lower Bound	Upper Bound	Std. Error
MCW(cm)	11.75-14.77	13.43±0.54	13.41	13.56	0.04		13.27	13.43	0.04
MCL (cm)	14.66-19.77	17.99±0.72	18.01	18.21	0.05		17.72	17.93	0.05
OBL (cm)	3.15-4.75	4.02±0.32	4.00	4.08	0.02		3.95	4.05	0.03
BZL (cm)	11.06-14.39	12.47±0.62	12.57	12.71	0.04		12.13	12.31	0.05
CI	61.63-96.43	74.75±3.85	74.08	75.07	0.25		74.40	75.59	0.30

MCW = Maximum cranial width, MCL = Maximum Cranial Length, BZL = Bizygomatic length, cm = centimeter, CI = Cephalic Index

Table 2. The student's t-tests for the study parameters from the Nigerian population in males (n= 236) and females (n = 163)

Variables	Males (n = 236)		Females (n= 163)			
	Min-Max	Mean ± S.D	Min-Max	Mean ± SD	t-value	P
MCW(cm)	11.75-14.77	13.49 ±0.57	11.86-14.51	13.35±0.49	2.483	0.013
MCL (cm)	16.01-19.73	18.11 ±0.74	14.66-19.77	17.82±0.66	4.029	0.001
OBL (cm)	3.15- 4.75	4.04 ±0.32	3.20-4.60	4.00±0.32	1.288	0.199
BZL (cm)	11.17-14.39	12.64 ± 0.58	11.06-13.88	12.22±0.59	7.024	0.001
CI	61.63-86.08	74.57 ±3.86	65.68-96.43	75.00±3.83	-1.082	0.280

MCW = Maximum cranial width, MCL = Maximum Cranial Length, BZL = Bizygomatic length, cm = centimeter, CI = Cephalic Index

Tables 3 and 4 show the correlation metrics of the craniofacial dimensions in the study population among males and females respectively. There is a significant positive correlation between maximum cranial width (MCW) with the cephalic index (CI), Bizygomatic length (BZL) orbital length (OBL) and maximum cranial length (MCL) in order of precedence. A similar trend is also noted in females except for an insignificant correlation seen between maximum cranial width (MCW) and maximum cranial length (MCL).

Table 3. Correlation of craniofacial parameters in Males (n = 236)

Variable	MCW(cm)	MCL (cm)	OBL (cm)	BZL (cm)	CI
MCW(cm)	1	0.244**	0.323**	0.602**	0.629**
MCL (cm)		1	0.348**	0.295**	-0.599**
OBL (cm)			1	0.518**	-0.009
BZL (cm)				1	0.265**
CI					1

MCW = Maximum cranial width, MCL = Maximum Cranial Length, BZL = Bizygomatic length, cm = centimeter, CI = Cephalic Index

Table 4. Correlation of craniofacial parameters in females (n = 163)

Variables	MCW(cm)	MCL (cm)	OBL (cm)	BZL (cm)	CI
MCW(cm)	1	0.098	0.303**	0.527**	0.660**
MCL (cm)		1	0.268**	0.217**	-0.678**
OBL (cm)			1	0.567**	0.023
BZL (cm)				1	0.227**
CI					1

MCW = Maximum cranial width, MCL = Maximum Cranial Length, BZL = Bizygomatic length, cm = centimeter, CI = Cephalic Index

Figure 1 indicates the receiver operating characteristic curve for the significant univariate variables. The contribution of each variable to the predictive models of binary logistic regression is obtained by the area under the curve. The bizygomatic length (BZL) showed higher sex estimation potential [Area under the curve (AUC) of 0.711]. The maximum cranial length (MCL) is the second most contributing variable to our predictive models (AUC = 0.622) and maximum cranial width (MCW) is the last contributor to our predictive model of sex estimation in the present study. The overall percentage accuracies of the three variables are 67.4% (BZL), 58.5% (MCL) and 57.6% (MCW) respectively. However, the multivariate logistic model shows overall predictive accuracy of 70.4%.

Table 5 shows the univariate and multivariate logistic regression for the study population. The bizygomatic length (BZL) is the best significant univariate model for sex prediction in our study, as indicated by the exponentiated B or odd ratio (OR = 3.503), this is followed by the maximum cranial length (OR = 1.765) and then lastly the maximum cranial width (OR = 1.606).

The multivariate logistic regression analysis selected BZL and MCL as the significant variables for sex estimation and the equation is given as Sex = 1.382* BZL + 0.345*MCL - 16.681. The betas Coefficients (B) are 1.382 and 0.345 respectively while - 16.681 is the regression constant.

Table 6 indicates univariate and multivariate Canonical discriminant functions and accuracy percentages of the craniofacial dimensions. The coefficient and constant are used in calculating the discriminant score. The discriminant score is gotten by multiplying each variable with the coefficient and then adding the constant. For instance: Univariate discriminant score of bizygomatic length – D = (BZL)* 1.708 - 21.290.

ROC CURVE

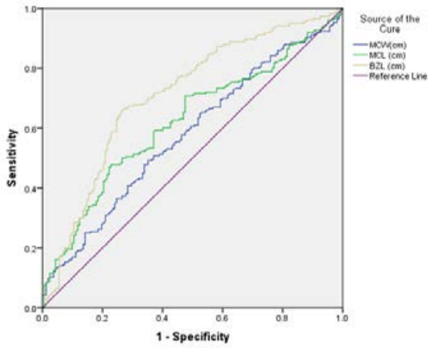

Fig 1. Receiver operating characteristic curve (ROC) for the significant univariate variables (MCW = 0.5770, MCL = 0.622, BZL = 0.711) among the studied parameters in the Nigerian population (n = 399). MCW (cm) Maximum cranial width, MCL (cm) = Maximum Cranial Length, BZL (cm) = Bizygomatic length

Table 5. Univariate and multivariate logistic regression for the study population

		Univariate Logistic Regression Analysis				Multivariate Logistic Regression Analysis		
Independent Predictors	**Constant**	**B**	**P-value**	**OR (95% CI)**	**Constant**	**B**	**P-value**	**AOR (95% CI)**
MCW(cm)	-5.984	0.474	**0.014**	1.606 (1.103-2.338)		-0.471	0.059	0.624 (0.383 – 1.018)
MCL (cm)	-9.835	0.568	**0.001**	1.765(1.315-2.369)		0.345	**0.033**	1.412 (1.029 -1.939)
BZL (cm)	-15.206	1.254	**0.001**	3.503 (2.383-5.150)	-16.681	1.382	**0.001**	3.984 (2.470-6.425)

MCW = Maximum cranial width, MCL = Maximum Cranial Length, BZL = Bizygomatic length, cm = centimeter, B = Beta coefficient, OR = Odd ratio (Exponentiated B), AOR = Adjusted odd ratio, CI = Confidence interval

Table 6. Univariate and multivariate Canonical discriminant functions and accuracy percentages of the craniofacial dimensions (n = 399)

S. NO.	Measurements	Coefficient	Centroid	Sectioning Point	Wilk's Lambda	Accuracy %	
						O	CV
Univariate Analysis							
1	MCW (cm) Constant	1.854 **-24.899**	M = 0.104 F = -0.151	-0.0235	.984	57.4%	56.9%
2	MCL Constant	1.408 -25.332	M = 0.164 F = -0.238	- 0.037	.962	58.4%	58.4%
3	BZL (cm) Constant	1.708 **-21.290**	M = .296 F = -.429	- 0.0665	.887	67.4%	67.4%
Multivariate Analysis							
	MCL (cm) BZL (cm) Constant	.428 1.499 **-26.399**	M = 0. .305 F = -0.445	- 0.14	.880	66.9%	66.9%

MCW = Maximum cranial width, MCL = Maximum Cranial Length, BZL = Bizygomatic length, cm = centimetre O = Original accuracy percentage; C = Cross-validated accuracy percentage; M = Male; F = Female.

0.0665 is the sectioning point. The sectioning point is the average of males and females group centroids (1/2 *Male centroid + Female Centroid).

The discriminant score D should be compared with the sectioning point; the value of D higher than the sectioning point is considered male while a value less than the sectioning point is considered as female.

The percentage of the original group membership is 66.9% which is the same even after cross-validation and classify males correctly in 80.5% of the cases and females in 47.2% of the cases respectively, in situations where BZL and MCL are brought for determination of sex using CT scan in our study population.

DISCUSSION

The determination of the sex of an unknown victim is paramount in developing the biological profile for personal identification in medico-legal cases[5,20]. Forensic experts find it difficult to achieve that especially when some few skeletal elements are the only available evidence found in the scenes[21]. Therefore several researchers have used the direct metric measurements of the different parts of skull bones[22-24] and the radiologic metric measurements[13-16,25-30] to test the accuracy and reliability of individual parts of the skull in identifying the sex when only such parts are available for investigations.

The results of the studies from different populations are comparable to our study population.

The significant difference in sex found in maximum cranial breadth, maximum cranial length and bizygomatic length with males having higher mean values than females corresponds to the findings of Ekizoglu et al (2016) from Turkey[31], González-colmenares et al. 2019 from Colombian population[32], Paulinus et al. (2019), Musa and Danfulani (2015) from Nigerian population[16,17], Jain et al. (2016), Nidugala et al. 2013, and Khanduri et al. (2021) all from Indian population[8,33,34]. Also similar findings from Ghanian population[35] have also been reported.

Statistically significant correlation between craniofacial measurements in this study shows that there is homogenous growth of both sexes in our population which corroborate with the findings of Abo- El-Atta et al. (2020), Uthman et al. (2012) and El-Barrany et al. (2016), Khanduri et al. (2021), Nagwani et al. (2020) from Egypt, Iraq, Sudan and Indian population respectively[2,34,36-38] who reported significant correlation between the craniometric variables using CT scan images.

The ROC curve applied for the significant variables to determine the best contributory variable to the prediction model in this study have indicated bizygomatic length as the best predictor of sex and this is in line with the previous report of Ekizoglu et al. 2016 and Adel et al. 2019[31,39] from Turkey and Egyptian population respectively.

The use of logistic regression to determine the sex from Nigerian population in this study is in line with the report of Shah et al. 2015 from Indian population[7] who reported bizygomatic breadth as the best univariate regression model for sex determination with an accuracy of 82.69%. However, this study reported lower accuracy of 67.4% likely due to different metric measurements used. Moreover, contrary to the same report that shows reduced in accuracy after multiple logistic regressions (81.9%), our findings show higher accuracy of 70.4% following multiple logistic regression which identifies males in 83.1% of the cases and females in 51.9% of the cases respectively. Another report from the Indian population showed an accuracy of only 64.6% in estimating sex[40] using logistic regression analysis. In line with the present study, Adamu et al. 2016 from Nigeria reported upper facial height as the best single variable for sex estimation using logistic regression [41] and higher accuracy was achieved after multiple regression analysis (91.1%).

The present study considered five craniofacial measurements and of the three significant measurements, the bizygomatic length has the highest significant contribution and accuracy (67.4%) in discriminant function analysis. This report corroborates the report of Dayal et al. (2008) from South Africa thought with higher accuracy (i.e 75.8%)[9]. Saini et al. 2011 from the Northern Indian population also reported bizygomatic breadth as the best parameter for sex determination using discriminant function analysis[42]. Contrary to our present findings on multivariate discriminant function analysis that shows reduced accuracy, better accuracy was observed than those in the reports of Shanthi et al. (2013) and Geetanjali et al. (2013)[43,44].

However, this study considered only 399 normal CT scan images with differences in the number of males and females, which will reduce correct prediction rate among the two sexes.

The results of the study indicated that three variables out of five that are considered were sexually dimorphic with males scoring higher mean values than females. However, Bizygomatic length is the best univariate variable for estimating sex while Bizygomatic length and maximum cranial length are the two significant parameters for discriminating sex in this study population.

The logistic regression equations show higher accuracy than the discriminant function equations. However, both the models could be used to determine sex of a part of skull when brought for CT scans, even though caution must be applied using discriminant function due to lower accuracy rate. The models should be applied in further studies with larger sample size to confirm the accuracy and reliability of the generated equations in this study.

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