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RESEARCH

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Ear morphology and morphometry as potential forensic tools for identification of the Hausa, Igbo and Yoruba populations of Nigeria

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Abstract

Background: The human external ear is unique in every individual in terms of shape, size and dimension making it suitable in forensic anthropology for sex estimation and personal identification purposes. The study aimed to evaluate sexual dimorphism and ethnic specificity of the external ear in major Nigerian ethnic populations.

Results: There was variation in the morphological features of the external ear of the sampled subjects. The external ear features vary in the right and left ears in both sexes of the ethnic groups. All variables were statistically significant ($p < 0.05$) except ear width. Univariate discriminant function gave sex prediction accuracies between 56.4 and 57.3% for left and right ears, respectively. Population-specific sex prediction accuracy using stepwise discriminant analysis of left ear variables ranged 58–69.7% and 57.5–74.2% for right ear.

Conclusion: The ear parameters showed potential for sex estimation, but cannot be solely relied upon for personal identification.

Keywords: Discriminant analysis, Morphology, Sexual dimorphism, Morphometry, Nigeria

Background

Human beings exhibit a wide range of variations that are unique and help to distinguish an individual or member of a geographical location from another. People differ in size, shape, skin colour and other heritable characters (Alexander et al. 2011; Osunwoke et al. 2018). When it comes to humans, the questions that come to mind are; are they identical? What are the distinctive features that can be used to distinguish one from another? Apart from DNA profiling, various morphological features and biometric parameters are usually employed in forensic investigation to distinguish one person from another. Some of the morphological features used for this purpose include fingerprints, facial traits, footprints and gait patterns. Others include the cranial, teeth, external ear and hand geometry (Gibelli et al. 2012; Kumar and Singla 2013; Krishan and Kanchan 2015). One of the major body parts that have caught the attention of the forensic community in recent times for human identification and discrimination is the human ear (Verma et al. 2016; Rubio et al. 2017). The human ear is unique to individuals and ear prints, like the fingerprints, are discrete enough to distinguish even identical twins (Chang et al. 2003; Rahman et al. 2007; Daramola and Oluwaninyo 2011). Studies have shown that the external ear can be used to identify both living and deceased individuals (Swift and Rutty 2003; Abbas and Rutty 2005; Krishan et al. 2019).

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According to Purkait (2016), studies on the application of the human ear for human identification date back to the nineteenth century by Bertillon (1893) and later by Iannarelli (1898).

The human ear is made up of three major parts which include the internal, middle, and external ear, of which the external ear (Fig. 1) is used in forensics (Krishan et al. 2019; Murgod et al. 2013; Ahmed and Omer 2015). The external part of the human ear also known as the pinna or auricle is one of the most definitive features of the human face (Alexander et al. 2011). Extensive studies by forensic anthropologists have revealed the role the auricle plays as an identification marker depending on the variation in morphology that is found based on gender, age and ethnicity (Murgod et al. 2013). Furthermore, the shape, position and dimension of the auricle are peculiar to every individual just as the fingerprint thereby aiding its applications in forensics (Alexander et al. 2011). Usually, ear marks are mostly obtained on doors and windows where a potential burglar has been listening for possible invasion. During forensic investigations, such marks are collected and evaluated with stored data to ascertain a match with suspects. Thus, ear prints serve as useful forensic evidences (Meijerman 2006). Ear morphology and biometrics are often used when there are no valid fingerprints which might result from wearing protective hand gloves.

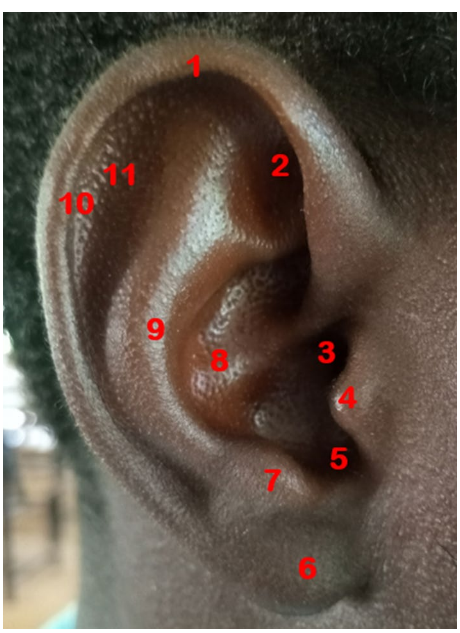

Fig. 1 shows anatomical structure of the human external ear: (1) helix, (2) fossa, (3) external auditory canal, (4) tragus, (5) incisura, (6) lobule, (7) antitragus, (8) concha, (9) antihelix, (10) Darwin's tubercle, (11) scapha

Conventional biometric traits such as the facial recognition has less advantage when compared to the ear in that the ear is less affected by ageing or use of facial disguise like spectacle and moustache. In addition, it is not influenced by facial expression changes (Victor et al. 2002; Hurley et al. 2005). Also, as opposed to other human traits like the retina and the iris, there is little or no anxiety emanating from capturing of the human ear, and it can be captured from a distance (Amirthalingam and Radhamani 2013). Likewise, certain features such as its stability and uniqueness in individuals from birth to adulthood have made the human ear a great forensic tool for personal identification purposes (Muntasa et al. 2011). Several findings have demonstrated that every part of the human ear is unique in shapes and sizes (Alexander et al. 2011; Muteweye and Muguti 2015). Krishan et al. (2019) established that morphological variations of the human ear can be used for personal identification. Murgod et al. (2013) assessed the sex-related dimensions of the ear shape and earlobe attachments as well as linear measurements of the ear in order to evaluate the extent of sexual dimorphism in 300 young adult Indians. They concluded that their finding was effective in the identification of sex with up to 69.3% accuracy in male individuals and 72% in females. Estimation of sex from the anthropometric ear measurements in a Sudanese population has also been documented (Ahmed and Omer 2015). There are several studies on ear morphometrics in Nigerian populations. Ekanem et al. (2010) carried out an anthropometric study of the external ear in Maiduguri, North-Eastern Nigeria. Eboh (2013) examined the morphological changes in the pinna in relation to age and gender among the Urhobo people in South-South Nigeria, while Taura et al. (2013) studied external ear anthropometrical variations among the Hausas in Northern Nigeria. To the best of our knowledge, this study is the first to document morphological and morphometrical variations among the three major ethnicities of Nigeria, that is, the Hausa, Igbo and Yoruba populations. Likewise, there are no existing ear morphometric data for the Igbo population. The aims of the study, therefore, were to evaluate sexual dimorphism and ethnic specificity of the external ear in a cross section of the major Nigerian ethnicities and provide sex estimation accuracy of ear landmarks for forensic identification of the ethnic populations.

Methods

Ethical consideration

The research design and methodology were approved by the Health Research Ethics Committee of College of Medicine, University of Lagos, Nigeria with approval number: CMUL/HREC/02/21/813.

Study subjects

A total of 307 individuals comprising 89 Hausa (38 males, 51 females), 112 Igbo (38 males, 74 females) and 106 Yoruba (55 males, 51 females) ethnicities of Nigeria were recruited for the study. The age of sampled individuals ranged between 10 and 55 years.

Participants recruitment

Participants for the study were recruited across the Northern, Eastern and South-Western geographical zones of the country representing the Hausa, Igbo and Yoruba ethnic groups, respectively. Only subjects with no congenital ear abnormalities or history of ear surgery were recruited for the study in accordance with the Helsinki Declaration on human research. All subjects gave verbal consent to participate in the study after they have been made to understand the scope and aim of the study.

Data collection and measurements

Each subject was provided with a data collection form that captures the age, gender and ethnic group of participants. For ear morphology, ear photographs were taken with a Nikon Z6 Body camera at a constant distance for all subjects. The photographs were then studied for the shape of the ear, the form of the helix, shape and attachment of earlobe, shape of ear tragus and Darwin's tubercle as described by Singh and Purkait (2009). For ear landmark measurement, participants were made to sit in a Frankfort horizontal position and measurements of the ear length (EL), ear width (EW), lobule height (LH), lobule width (LW), and concha length (CL) (Fig. 2) were taken with a standard digital Vernier caliper (Murgod et al. 2013; Ahmed and Omer 2015). Measurements were taken by only one individual to minimize sampling error, and for consistency. Both ear morphology and measurements were obtained for each individual. Ethnicity of each participant was determined based on self-report.

Data evaluation and analysis

Metric and non-metric evaluation of collected data were performed. Non-metric morphological features such as the shape of the ear (whether oval, round, triangular or rectangular), the shape of the earlobe (arch, square, tongue or triangular), attachment of the earlobe (partially attached, fully attached or free), forms of the helix (rolled, wide, flat or concave marginal), the shape of the tragus (knob, round or long), the form of Darwin's tubercle (enlarged, projected or nodosity) (Figs. 3, 4, 5, 6, 7, 8) were evaluated between sexes and among the three ethnic populations. Descriptive statistics of the measured variables was performed for both sexes of the three ethnic groups. Mean values were expressed as mean ± standard

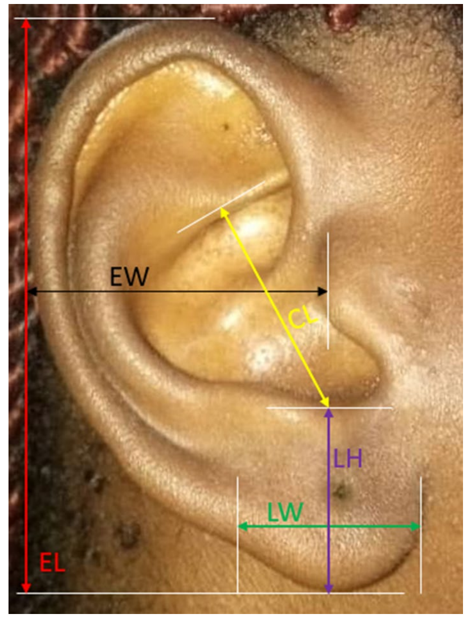

Fig. 2 Measured ear landmarks depicted with coloured arrows: ear length (red), ear width (black), lobule height (purple), lobule width (green) and concha length (yellow)

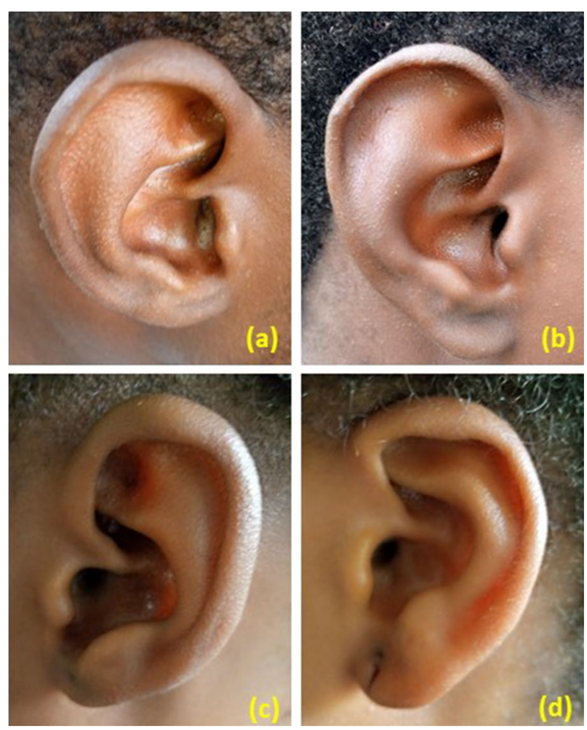

Fig. 3 Photographs of the shape of the ear: round (**a**), oval (**b**), rectangular (**c**), triangular (**d**)

Fig. 4 Photographs showing the different shapes of earlobe (arrowed): arched (**a**), triangular (**b**), tongue (**c**), square (**d**)

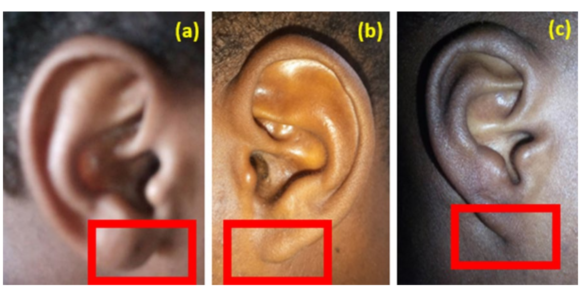

Fig. 5 Photographs of forms of earlobe attachment: free (**a**), partially attached (**b**), attached (**c**)

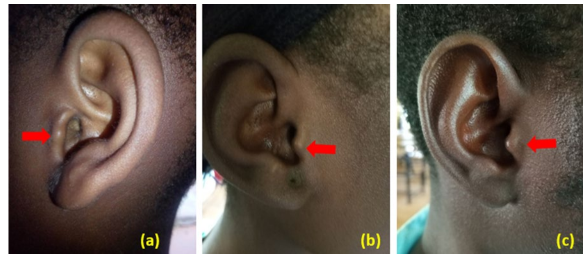

Fig. 6 Photographs of shapes of ear tragus: long (**a**), round (**b**), knob (**c**)

Fig. 7 Photographs of forms of ear helix: concave marginal (**a**), wide (**b**), rolled (**c**), flat (**d**)

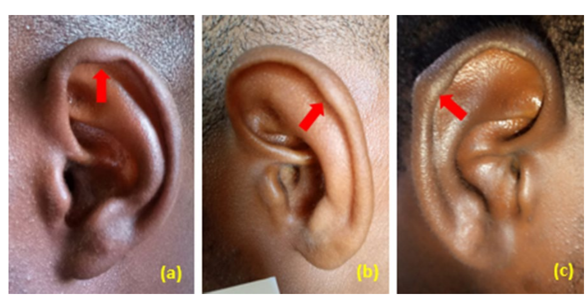

Fig. 8 Photographs of forms of Darwin's tubercle: enlarged (**a**), projected (**b**), nodosity (**c**)

deviation. The normality of the variables was determined by Shapiro–Wilk normality test at $p < 0.05$. One-way ANOVA was performed to examine the difference of means among the ethnic groups. Sexual dimorphism was estimated by computing demarking points for each of the measured variables in both ears. The demarking point is the average of the male and female means. Finally, population-specific gender classification was estimated using direct and stepwise discriminant function analyses. All

Table 1 Frequency of shape of ear among Nigerian ethnic groups across gender: Hausa = 89; Igbo = 112; Yoruba = 106

Shape of the ear	HAUSA				IGBO				YORUBA			
	Male		Female		Male		Female		Male		Female	
	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)
Oval	10, 26.3%	9, 23.7%	8, 15.7%	8, 15.7%	15, 39.5%	12, 31.6%	30, 40.5%	28, 37.8%	20, 36.4%	22, 40.0%	23, 45.1%	23, 45.1%
Triangular	10, 26.3%	9, 23.7%	22, 43.1%	18, 35.3%	6, 15.8%	7, 18.4%	18, 24.3%	19, 25.7%	15, 27.3%	14, 25.4%	13, 25.5%	11, 21.6%
Rectangular	5, 13.2%	8, 21.1%	5, 9.8%	7, 13.7%	5, 13.2%	6, 15.8%	6, 8.1%	8, 10.8%	9, 16.4%	10,18.2%	4, 7.8%	6, 11.8%
Round	13, 34.2%	12, 31.5%	16, 31.4%	18, 35.3%	12, 31.5%	13, 34.2%	20, 27.0%	19, 25.7%	11, 20.0%	9, 16.4%	11, 21.6%	11, 21.5%
Total	38	38	51	51	38	38	74	74	55	55	51	51

Table 2 Distribution of shape of earlobe among Nigerian ethnic groups across gender: Hausa = 89; Igbo = 112; Yoruba = 106

Shape of earlobe	HAUSA				IGBO				YORUBA			
	Male		Female		Male		Female		Male		Female	
	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)
Tongue	6, 15.8%	8, 21.1%	6, 11.8%	6, 11.8%	5, 13.2%	7, 18.4%	13, 17.5%	11, 14.9%	8, 14.5%	7, 12.7%	8, 15.7%	8, 15.7%
Triangular	3, 7.9%	5, 13.2%	1, 2.0%	0, 0.0%	1, 2.6%	3, 7.9%	3, 4.1%	2, 2.7%	8, 14.5%	6, 10.9%	3, 5.9%	4, 7.8%
Arched	13, 34.2%	11, 28.9%	22, 43.1%	23, 45.1%	21, 55.3%	20, 52.6%	38, 51.4%	35, 47.3%	28, 50.9%	30, 54.5%	24, 47.1%	20, 39.2%
Square	16, 42.1%	14, 36.8%	22, 43.1%	22, 43.1%	11, 28.9%	8, 21.1%	20, 27.0%	26, 35.1%	11, 20.0%	12, 21.8%	16, 31.3%	19, 37.3%
Total	38	38	51	51	38	38	74	74	55	55	51	51

Table 3 Frequency of forms of earlobe attachment among Nigerian ethnic groups across gender: Hausa = 89; Igbo = 112; Yoruba = 106

Earlobe attachment	HAUSA				IGBO				YORUBA			
	Male		Female		Male		Female		Male		Female	
	Right ear	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear	Left ear
	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)	(*N*, %)
Free	21, 55.3%	20, 52.6%	27, 52.9%	27, 52.9%	22, 57.9%	24, 63.2%	50, 67.6%	50, 67.6%	37, 67.3%	35, 63.6%	28, 54.9%	32, 62.7%
Partially attached	12, 31.6%	13, 34.2%	16, 31.4%	17, 33.3%	12, 31.6%	11, 28.9%	22, 29.7%	22, 29.7%	11, 20.0%	10, 18.2%	18, 35.2%	16, 31.4%
Attached	5, 13.2%	5, 13.2%	8, 15.7%	7, 13.7%	4, 10.5%	3, 7.9%	2, 2.7%	2, 2.7%	7, 12.7%	10, 18.2%	5, 9.8%	3, 5.9%
Total	38	38	51	51	38	38	74	74	55	55	51	51

data analyses were performed using IBM SPSS Statistics 25.0 (IBM Inc., NY, USA). The level of statistical significance was $p < 0.05$.

Results

Prevalence of ear morphological variations in Nigerian populations

The prevalence of the various ear morphological features examined in the study is presented in Tables 1, 2, 3, 4, 5 and 6. Results obtained showed a level of morphological variation in the external ear of the sampled subjects. The uniqueness of every individual's ear was evident in the bilateral distribution of the morphological features in the three ethnic groups considered in the study. The ear morphological features vary in the right and left ears in both sexes and among the ethnic groups.

Table 1 illustrates the frequency of the shape of ear in the Hausa, Igbo and Yoruba populations of Nigeria. The human ear can either be oval, triangular, rectangular or round in shape. Round ear shape was found to be more common in the Hausa males accounting for 34.2 and 31.5% of their right and left ears, respectively. Triangular shape (43.1% right ear and 35.3% left ear) is more frequent in Hausa females. In the Igbo population, oval shape was found to be common in both sexes. In males, the distribution was 39.5% right ear and round shape was common in the left ear (34.2%) among the males, whereas in females it is 40.5% right ear and 37.8% left ear. Also, oval shape which accounts for 36.4% right ear and 40% left ear in males, and 45.1% both in the right and left ears of the females appears more frequently. Rectangular ear shape was found to be rare in all sampled subjects with varying degrees of expression.

Table 2 shows the distribution of the shape of the earlobe. This feature was expressed differently in the sampled individuals as tongue, triangular, arched, or square. In the Hausa population, the square shape (42.1% right ear and 36.8% left ear) was common in the males. The arch and square shapes with a joint distribution of 43.1% in the right ear were common in the females, while the arch shape has 45.1% in the left ear. In the Igbo population, the arch shape with 55.3% right ear and 52.6% left ear among the males; and 51.4% right ear and 47.3% left ear among the females are the most frequent in both sexes of the population. In the Yoruba ethnic group, the arch shape was also found to be prevalent with 50.9 and 54.5% in right and left ears, respectively, for males and 47.1% right ear and 39.2% left ear in females. The triangular shape was found to be the least common in all sampled subjects.

Table 3 shows the frequency of forms of the earlobe attachment in Nigerian populations. Earlobe attachment can be either of the three forms: free, partially attached or fully attached to the skin of the scalp or the upper cheek. The free earlobe attachment was the most frequent among the Nigerian populations (60.3% right ear, 61.2% left ear), followed by the partially attached (29.6% right ear, 29.0% left ear), while the attached earlobe (10.1% right ear, 9.8% left ear) is the least expressed. In the Hausa population, the frequency of the free earlobe attachment was 55.3% right ear and 52.6% left ear in males, while it is 52.9% for both right and left ears for the females. In the Igbo population, the free earlobe attachment is 57.9% right ear and 63.2% right ear for the males; and 67.6% for both right and left ears for the females. In the Yoruba ethnic group, the frequency of free earlobe attachment was 67.3% right ear and 63.6% left ear for the males; and 54.9% right ear and 62.7% left ear for the females.

The distribution of the shape of the ear tragus is presented in Table 4. There are three forms of shapes of ear tragus observed in the study which are knob, round and long. On the overall, the knob shape is the most common of the three shapes. In the Hausa population, the knob-shaped ear tragus is 63.1% right ear and 57.9% left ear in the males; and 47.1% right ear and 54.9% left ear in the females, whereas in the females, the distribution is 47.1% right ear and 54.9% left ear. In the Igbo male population, the distribution is 57.8 and 52.6% for right and left ears, respectively, and 48.6% right and 51.4% left ear in the females. Among the Yorubas, the knob ear shape is found in 81.8% right ear and 76.4% left ear of males; and 58.8% right ear and 72.5% left ear of females. The long ear tragus was also found in all three populations considered in the study.

Table 5 represents the frequency of the forms of ear helix. Ear helix is broadly categorized into four forms, namely; rolled, wide, flat and concave marginal. The distribution of the four forms was found to be different in the Hausa, Igbo, and Yoruba populations. While the Hausa and Igbo ethnicities have wide helix as the most frequent in their populations, the rolled helix is prevalent among the Yorubas. The other forms were also found in different percentages among the subjects. The frequency of the wide helix as observed in the Hausa population was 44.7% right and 47.4% left ear in the males; and 54.9 and 52.9% for right and left ears, respectively, in the females. The Igbo population has 34.2% right ear and 29.5% left ear distribution in the male individuals; and 50.0% right ear and 47.3% left ear among the females. The rolled ear helix which is commonest in the Yoruba population was found in 38.2% right ear and 40.0% left ear in the males; and 39.2% right ear and 41.2% left ear in the females.

Table 6 shows the prevalence of the forms of Darwin's tubercle among Nigerian ethnic groups. Darwin's tubercle, a congenital malformation found in the posterior end

Table 4 Distribution of shape of ear tragus among Nigerian ethnic groups across gender: Hausa = 89; Igbo = 112; Yoruba = 106

Shape of ear tragus	HAUSA				IGBO				YORUBA			
	Male		Female		Male		Female		Male		Female	
	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)
Knob	24, 63.1%	22, 57.9%	24, 47.1%	28, 54.9%	22, 57.8%	20, 52.6%	36, 48.6%	38, 51.4%	45, 81.8%	42, 76.4%	30, 58.8%	37, 72.5%
Round	8, 21.1%	10, 26.3%	14, 27.4%	13, 25.5%	8, 21.1%	9, 23.7%	24, 32.4%	25, 33.8%	6, 10.9%	8, 14.5%	15, 29.4%	10, 19.6%
Long	6, 15.8%	6, 15.8%	13, 25.5%	10, 19.6%	8, 21.1%	9, 23.7%	14, 18.9%	11, 14.9%	4, 7.3%	5, 9.1%	6, 11.8%	4, 7.8%
Total	38	38	51	51	38	38	74	74	55	55	51	51

of the ear helix can appear to be protruding (nodosity), enlarged, or projected. The nodosity shape appeared to be the most prevalent in the Hausa and Igbo populations, while the enlarged Darwin's tubercle was more common among the Yoruba population. The frequency of the nodosity Darwin's tubercle in the Hausa population was 52.6% right ear and 47.4% left ear in the males; and 39.2% right ear and 43.1% left ear in the females. In the Igbo population, the distribution was 42.1 and 52.6% for right and left ears, respectively, in the males, while in the females, the nodosity and projected shape both have 41.9% occurrence for the right ear and the nodosity was 39.2% for the left ear. In Yoruba males, the prevalence of Darwin's tubercle was 43.6% enlarged shape for the right ear and 40.0% projected shape for the left ear. The enlarged shape was common among the Yoruba females having 60.8 and 39.2% for right and left ears, respectively.

Results of morphometry analyses

Descriptive analysis

The results of means (± standard deviation) of ear measurements for right and left sides between male and female individuals of the Hausa, Igbo and Yoruba populations are presented in Figs. 9, 10 and 11, respectively. Bilateral differences were observed in the measured landmarks. For the Hausa population, the means ear length, ear width, lobule height and concha length were higher in males than females for the right ear except lobule width. For the left ear, the means of ear length and lobule height were higher in males than females. The reverse is the case for ear width, lobule width and concha length. Figure 10 represents results for the Igbo population. The figure revealed that the means of ear length, ear width, lobule width and concha length were higher in females than males on both right and left sides. Only lobule height was higher in males on both sides. Means of the ear width, lobule height and concha length of the right ear was higher among males of the Yoruba males than the females, while ear width, lobule height and lobule width measurements were males' left ear than the females. Statistical parameters such as mean, standard deviation, minimum and maximum values of ear measurements for each of the measured parameters are presented in Table 7. Test of equality of means of both right and left ears performed using one-way ANOVA was statistically significant in all parameters, except ear width ($p < 0.05$).

Discriminant analyses

Table 8 shows series of direct univariate discriminant performed to determine which of the variables can singly discriminate between sexes (Functions 1–10), while Table 9 depicts the stepwise analysis to determine which of the variables offers the best description when the variables are combined. The population-specific stepwise discriminant analysis showed that lobule width, lobule height and concha length are best for differentiating among individuals of the ethnic groups. Sex prediction accuracies among the three ethnic groups for the right ear are 74.2% (Hausa), 58.9% (Igbo) and 57.5% (Yoruba), while for the left ear, they are 69.7, 58 and 65.1% for Hausa, Igbo and Yoruba, respectively. The highest accuracy was seen in the Hausa population with combined ear width and lobule width (Table 10).

The original and cross-validated classification accuracies for these variables were presented in Table 11. The most sexually dimorphic landmark was the right lobule height (57.3%) and the least is the left concha length (49.5%). Stepwise discriminant analysis showed that the ear length, lobule height, lobule width and concha length mostly contribute to sex classification, majorly contribute in both right and left ears with cross-validated classification accuracies of 57.3 and 57.0%, respectively.

Discussion

Ear morphological variations

The goal of forensic inquiry is to ascertain who can be included or excluded in a web of criminal investigation and this is usually based on biological evidence collected

Table 5 Frequency of forms of ear helix among Nigerian ethnic groups across gender: Hausa = 89; Igbo = 112; Yoruba = 106

Form of Helix	HAUSA				IGBO				YORUBA			
	Male		Female		Male		Female		Male		Female	
	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)
Rolled	10, 26.3%	11, 28.9%	5, 9.8%	9, 17.6%	12, 31.6%	10, 26.3%	23, 31.1%	27, 36.5%	21, 38.2%	22, 40.0%	20, 39.2%	21, 41.2%
Wide	17, 44.7%	18, 47.4%	28,54.9%	27, 52.9%	13, 34.2%	15, 29.5%	37, 50.0%	35, 47.3%	18, 32.7%	16, 29.1%	18, 35.3%	19, 37.3%
Flat	4, 10.5%	2, 5.3%	10, 19.6%	5, 9.8%	1, 2.6%	3, 7.9%	6, 8.1%	2, 2.7%	4, 7.3%	7, 12.7%	6, 11.8%	2, 3.9%
Concave marginal	7, 18.4%	7, 18.4%	8, 15.7%	10, 19.6%	12, 31.6%	10, 26.3%	8, 10.8%	10, 13.5%	12, 21.8%	10, 18.2%	7, 13.7%	9, 17.6%
Total	38	38	51	51	38	38	74	74	55	55	51	51

Table 6 Frequency of forms of Darwin's tubercle among Nigerian ethnic groups across gender: Hausa = 89; Igbo = 112; Yoruba = 106

Darwin's tubercle	HAUSA				IGBO				YORUBA			
	Male		Female		Male		Female		Male		Female	
	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)	Right ear (*N*, %)	Left ear (*N*, %)
Nodosity	20, 52.6%	18, 47.4%	20, 39.2%	22, 43.1%	16, 42.1%	20, 52.6%	31, 41.9%	29, 39.2%	12, 21.8%	14, 25.5%	8, 15.7%	12, 23.5%
Enlarged	3, 7.9%	4, 10.5%	12, 23.5%	10, 19.6%	13, 34.2%	8, 21.1%	12, 16.2%	19, 25.7%	24, 43.6%	19, 34.5%	31, 60.8%	20, 39.2%
Projected	15, 39.5%	16, 42.1%	19, 37.3%	19, 37.3%	9, 23.7%	10, 26.3%	31, 41.9%	26, 35.1%	19, 34.5%	22, 40.0%	12, 23.5%	19, 37.3%
Total	38	38	51	51	38	38	74	74	55	55	51	51

Table 7 Descriptive statistics and demarking points (in mm) for both ears among Nigerian ethnic groups

Variables	Hausa					Igbo					Yoruba					One-way ANOVA	
	Mean	SD	Min	Max	Demarking point	Mean	SD	Min	Max	Demarking point	Mean	SD	Min	Max	Demarking point	$F_{2, 304}$	*P* value
Right ear																	
Ear Length	59.38	4.19	50.6	68.1	F < 59.46 < M	62.68	5.04	47.6	73.4	F < 62.52 < M	60.17	4.81	45.7	69.3	F < 60.19 < M	13.800	0.000
Ear Width	31.74	4.25	24.8	41.4	F < 31.90 < M	31.93	3.83	26.4	38.9	F < 31.80 < M	31.99	4.40	24.5	40.8	F < 31.97 < M	0.091	0.913**
Lobule Height	18.00	3.13	11.0	24.6	F < 18.02 < M	18.03	3.58	10.1	24.3	F < 18.27 < M	20.72	3.01	12.4	27.0	F < 20.72 < M	23.816	0.000
Lobule Width	16.28	1.93	12.0	21.5	F < 16.16 < M	15.60	2.61	10.1	23.5	F < 15.51 < M	19.02	3.28	11.5	25.8	F < 19.02 < M	47.891	0.000
Concha Length	27.41	1.02	25.1	30.1	F < 27.43 < M	28.69	1.64	24.6	39.0	F < 28.67 < M	31.07	1.65	26.1	33.3	F < 31.09 < M	154.269	0.000
Left ear																	
Ear Length	60.04	4.36	51.1	68.5	F < 60.07 < M	62.37	5.07	47.0	72.3	F < 62.27 < M	59.64	4.71	45.7	68.0	F < 59.66 < M	10.405	0.000
Ear Width	32.14	3.69	25.0	39.8	F < 32.21 < M	31.89	4.07	25.4	40.5	F < 31.80 < M	31.86	4.56	23.1	41.5	F < 31.85 < M	0.129	0.879**
Lobule Height	17.86	3.10	10.2	23.6	F < 17.88 < M	17.94	3.54	9.2	24.1	F < 18.16 < M	20.92	3.02	12.4	27.1	F < 20.90 < M	29.926	0.000
Lobule Width	16.18	1.94	11.7	21.6	F < 16.05 < M	15.71	2.62	10.4	23.2	F < 15.57 < M	18.87	3.28	11.2	25.6	F < 18.87 < M	41.983	0.000
Concha Length	27.35	1.24	23.5	30.3	F < 27.34 < M	28.58	1.32	25.9	32.1	F < 28.56 < M	31.14	1.68	26.1	33.6	F < 31.17 < M	180.837	0.000

SD, standard deviation

**Not statistically significant ($p > 0.05$)

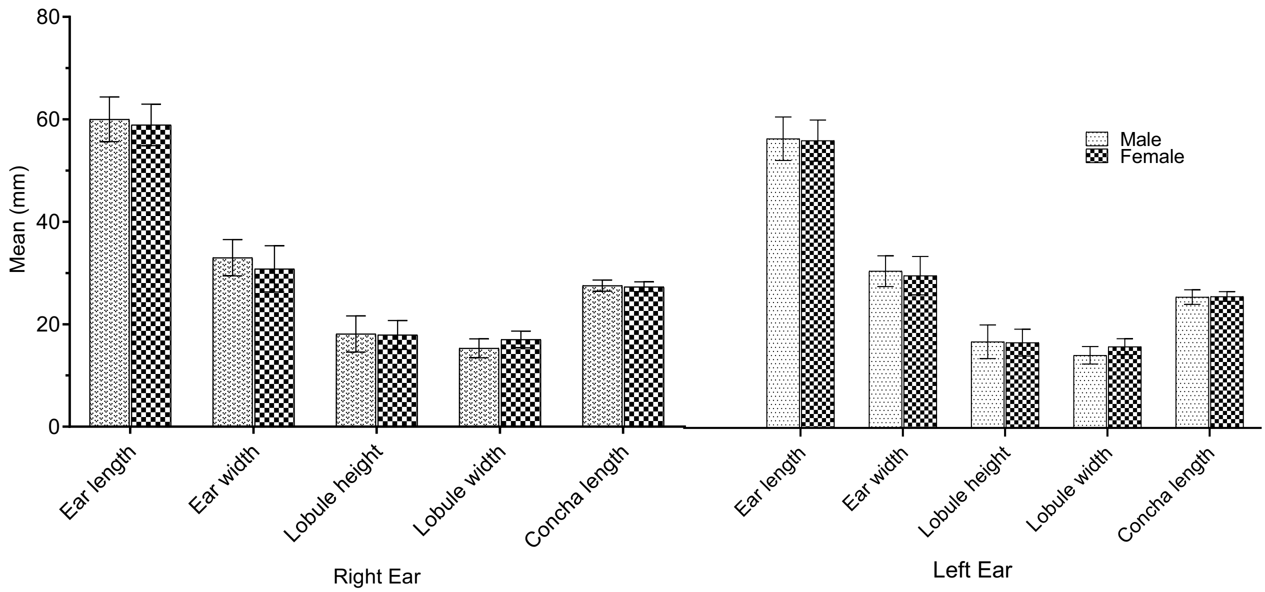

Fig. 9 Mean ± SD of measured variables in Hausa ethnicity

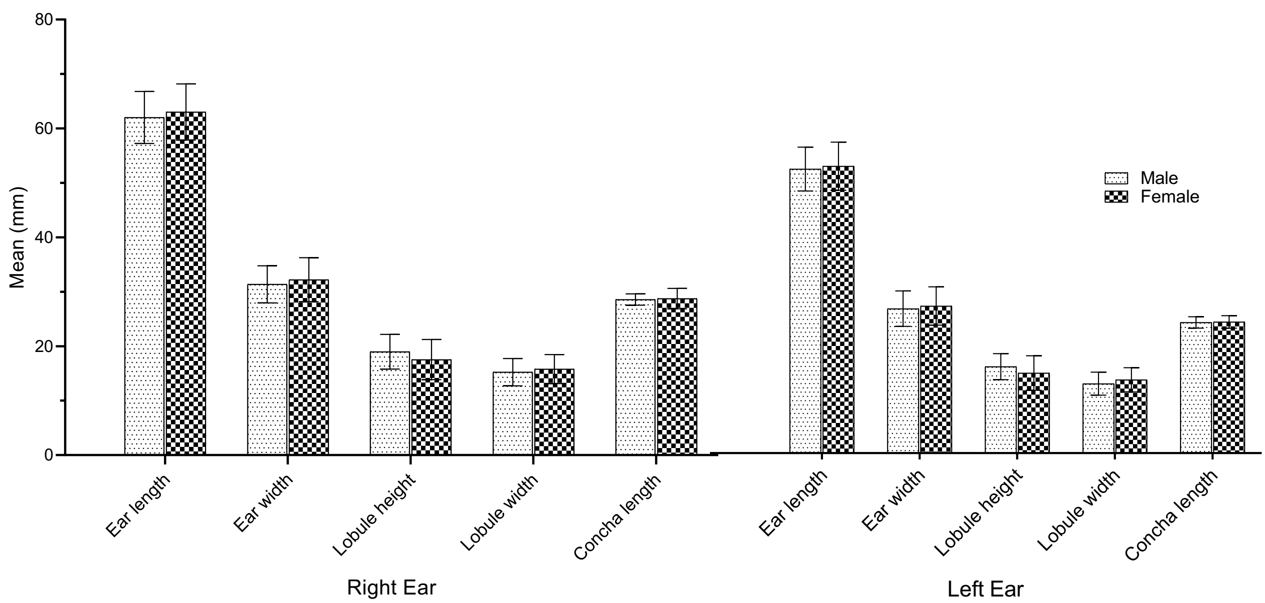

Fig. 10 Mean ± SD of measured variables in Igbo ethnicity

at a crime scene. In some instances, however, forensic scientists are left with the sole option of gathering non-visible forensic evidences such as finger or ear prints order to unravel who was present at a crime scene or might have perpetrated a crime. Anthropometric dimensions of morphological features such the cranial, teeth, humerus, ear and other body parts have been helpful in personal identification in forensic investigations. Morphological variations of the human ear may be employed together with forensic DNA analysis to resolve knotty cases, especially where fingerprints or facial recognition devices are not available. Deep knowledge of the shapes and relative positions of the ear as well as its biometric variations between different ethnic populations, age and gender have not only aided forensic and anthropological studies, literatures abound on its applications in plastic surgeries,

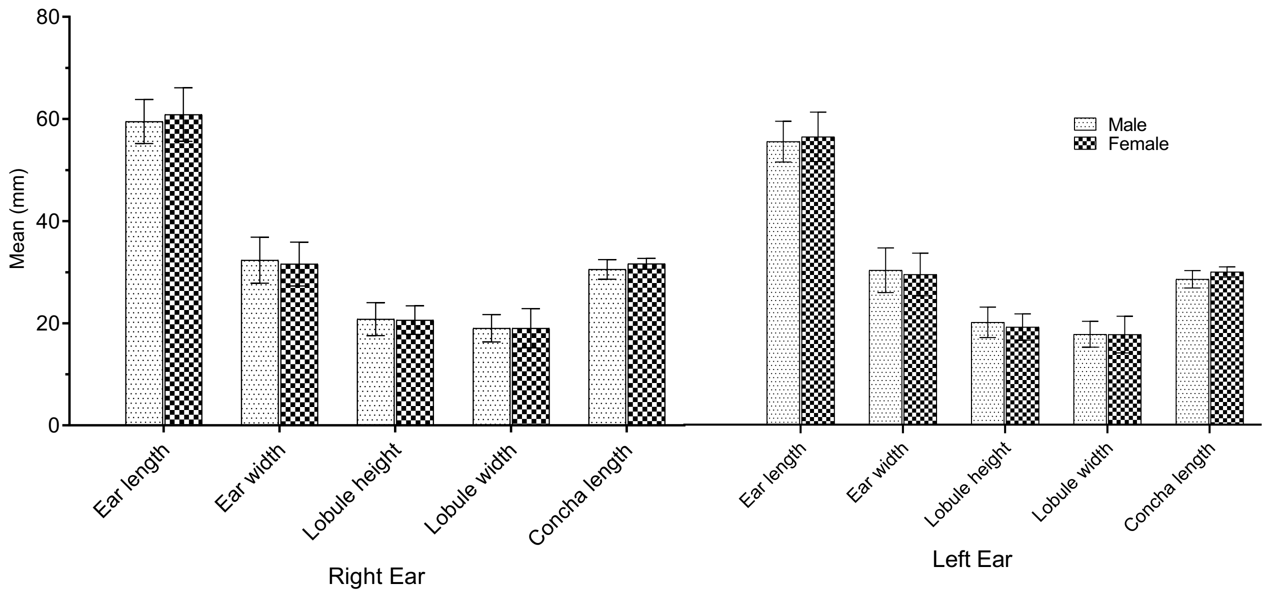

Fig. 11 Mean ± SD of measured variables in Yoruba ethnicity

Table 8 Direct discriminant function analysis of ear measurements in all subjects

Function	Variables	Standardized coefficient	Unstandardized coefficient	Wilks' lambda	Structure matrix	Groups centroids
1	REL	− 0.444	− 0.090	0.961	− 0.040	Male = 0.234
2	REW	0.358	0.086		0.330	Female = − 0.174
3	RLH	0.850	0.245		0.441	
4	RLW	− 0.488	− 0.158		0.845	
5	RCL	− 0.135	− 0.064			
6	REL	0.368	0.075	0.938	− 0.699	Male = − 0.297
7	REW	− 0.182	− 0.044		0.319	Female = 0.22
8	RLH	− 0.917	− 0.263		0.255	
9	RLW	0.450	0.148		0.242	
10	RCL	0.388	0.184		− 0.181	

R, right; L, left; EL, ear length; EW, ear width; LH, lobule height; LW, lobule width, CL, concha length

paediatrics, as well as diagnosis of acquired and congenital abnormalities (Alexander et al. 2011; Verma et al. 2016; Murgod et al. 2013; Azaria et al. 2003). Lately, scientists have developed a wide range of techniques for the extraction and analysis of CCTV images for the purpose of ear recognition and human identification (Tariq and Akram 2012; Kumar and Chan 2013; Emeršič et al. 2017).

In this study, the results of the distribution of the shapes of the ear showed that the oval shape was the predominant in the Nigerian populations, while the least is the rectangular ear shape. This is in agreement with the finding of Osunwoke et al. (2018) who reported prevalence of oval ear shape among University of Port Harcourt (Nigeria) students. The prevalence of round and triangular ear shapes in the Hausa males and females is further supported by other studies. Whereas Chattopadhyay and Bhatia (2009) reported a higher percentage of triangular-shaped ear in the Indian Brahmin males, our study revealed more females with the triangular shape in the Hausa population. In contrast to our findings, Dinkar and Sambyal (2012) reported the prevalence of triangular ear shape in Indians of Goa origins. The shape of earlobe which can be triangular, tongue, arched or squared showed bias towards the arched shape in the sampled subjects. The prevalence of the four shapes of earlobe attachment can be expressed as

Table 9 Stepwise discriminant analysis of ear measurements in all subjects

Function	Variables	Standardized coefficient	Unstandardized coefficient	Wilks' lambda	Structure matrix	Groups centroids
11	REL	−0.068	−0.014	0.917	−0.040	Hausa = −1.163
	RLH	0.302	0.093	0.865	0.330	Igbo = −0.573
	RLW	0.398	0.147	0.760	0.441	Yoruba = 1.581
	RCL	0.854	0.574	0.496	0.845	
	Constant = −20.098					
12	LEL	−0.104	−0.022	0.936	−0.098	Hausa = −1.279
	LLH	0.365	0.113	0.836	0.335	Igbo = −0.638
	LLW	0.375	0.139	0.784	0.381	Hausa = 1.748
	LCL	0.871	0.607	0.457	0.831	
	Constant = −20.824					

R, right; L, left; EL, ear length; EW, ear width; LH, lobule height; LW, lobule width, CL, concha length

Table 10 Sex prediction accuracy for population-specific stepwise discriminant analysis

Function	Ethnic group	Variables[a]	Correctly predicted (%)
Right ear			
13	Hausa	LW, EW	Male: 28/38 Female: 38/51 (74.2%)
	Igbo	LH	Male: 24/38 Female: 42/74 (58.9%)
	Yoruba	CL	Male: 26/55 Female: 35/51 (57.5%)
Left ear			
14	Hausa	LW	Male: 30/38 Female: 32/51 (69.7%)
	Igbo	LH	Male: 32/38 Female: 43/74 (58.0%)
	Yoruba	CL	Male: 29/55 Female: 40/51 (65.1%)

LW, lobule width; EW, ear width; LH, lobule height; CL, concha length

[a] Variables used in analysis in order of contribution to sex determination;

Table 11 Prediction accuracies for direct and stepwise discriminant functions

Variable	Predicted group	Expected accuracy		
		Total (%)	Male (%)	Female (%)
F1 REL	Original	53.4	50	56
	Cross-validated	53.4	50	56
F2 REW	Original	54.1	53	55
	Cross-validated	54.1	53	55
F3 RLH	Original	57.3	65	52
	Cross-validated	57.3	65	52
F4 RLW	Original	55.0	50	59
	Cross-validated	55.0	50	59
F5 RCL	Original	51.1	63	43
	Cross-validated	51.1	63	43
F6 LEL	Original	52.8	52	53
	Cross-validated	52.8	53	53
F7 LEW	Original	54.1	55	53
	Cross-validated	54.1	55	54
F8 LLH	Original	56.4	63	52
	Cross-validated	56.4	63	52
F9 LLW	Original	55.7	53	58
	Cross-validated	55.7	53	58
F10 LCL	Original	49.5	58	43
	Cross-validated	49.5	58	43
F11	Original	57.3	65	52
	Cross-validated	57.3	65	52
F12	Original	58.0	62	51
	Cross-validated	57.0	61	54

arched > square > tongue > triangular. The arch-shaped earlobe accounts for 48.9% of the left ear and 47.8% of the right ear of all participants, while the least prevalent earlobe shape which is the triangular is 6.5 and 7.8% of the left and right ears of the total sampled individuals. The high prevalence of the arched shape in this study is in tandem with the study of Krishan et al. (2019) in Himachal Pradesh state, India. They reported 67.8% arched shape in both males and females left ears and 74.4% males and 72.4% females for the right ear in the Northern India population.

This study further revealed that the free earlobe was the most common of the three types pf earlobe attachment examined in the study. This was found in a high proportion (53–68%) in both ears of the male and female individuals of our study. Our results agree with the findings of Kapil et al. (2014) among auto-rickshaw drivers in Uttar Pradesh, India. They reported 65.1% free and 34.9% attached earlobe attachment in their study. On the contrary, Gaya and Yahaya (2019) reported 76% attached earlobe in Nigerian students of Bayero University Kano. Krishan et al. (2019) observed that 50–56% of their study population of Indian origins have the attached earlobe. Furthermore, the incidence of the shape of ear tragus reported in our study agreed with that of Krishan et al. (2019) in that the knob tragus was found to be the most common. The occurrence of this shape ranged from 47.1% in the Hausa females' right ears to 81.8% in the Yoruba males' right ears. The pattern of distribution of this trait indicated that the knob ear tragus showed bias towards the right ear. The frequency of the long ear tragus was very low in this study. Our results on ear tragus aligned with that of Krishan et al. (2019) who reported frequency of single knob tragus as 66.3% males and 95.3% females for the left ear, whereas the trait was found in 72.2% males and 94.3% females for the right ear of their studied population. They concluded that there was a significant gender difference in the expression of this trait and that single knob tragus was predominant in females.

The distribution of the forms of Darwin's tubercle revealed that the ear feature exhibited a form of population-specific expression among the studied Nigerian populations. This feature is classified on the degree of protuberance with a variety of clinical presentations. However, the influence of genetics on the expression of Darwin's tubercle is still obscure and there are conflicting observations about its correlations with age and gender (Sforza et al. 2009). The three forms of Darwin's tubercle evaluated in the study, that is, the projected, enlarged and nodosity had different percentages in the three ethnic populations under study without any form of gender bias. This agrees with studies of Gurbuz et al. (2005) and Rubio et al. (2015) who reported that there were no significant differences between gender and Darwin's tubercle in Spanish and Turkish, respectively. The nodosity tubercle was the most prevalent in the Hausa and Igbo population (39.2–52.6%), while the enlarged form was more prominent among the Yorubas (34.5–60.8%). Our finding is in agreement with other studies. Singh and Purkait (2009) reported a higher percentage of nodosity (54–62%) among central Indian populations. Also, Krishan et al. (2019) reported a 46–67.8% nodosity tubercle in a Northern Indian population. Darwin's tubercles which are unique and benign helical features, usually exhibit bilateral symmetry in individuals who express the trait. Still, a portion of the same population could display asymmetric expressions. Studies of patterns of the external ear have suggested that Darwin's tubercles may be distinctive to each individual (Purkait and Singh 2008; Loh and Cohen 2016). Results obtained on the frequency of the forms of the ear helix showed an asymmetric distribution in our subjects. While the wide ear helix was found to be predominant in the Hausa and Igbo ethnicities, the rolled helix dominates the Yoruba ethnic group. The other forms i.e. concave marginal and flat helices are also reported in our study with different degree of representations. In support of findings, Singh and Purkait (2009) reported 56–60% rolled helix in Indian populations. Also, Krishan et al. (2019) found 44–51% normally rolled helix in their subjects. In addition, the result obtained from this study also agreed with the result of the study of Dharap and Than (1995) who carried out their study in a Malaysian population. They reported the incidence of rolled helix in males to be 97.1 and 86.8% for the left and right ears, respectively; and corresponding values of 89.1 and 88.9% in females.

The high levels of interpersonal and inter-ethnic variations of the human ear reported in our study may be attributed to genetic, environmental and ethnic backgrounds of the sampled populations. Several authors have reported on the uniqueness of the human ear and its applications in personal identification to determine whether a person could be validly suspected to have committed a certain crime (Purkait 2015, 2016; Purkait and Singh 2008; Hoogstrate et al. 2001). For instance, a person with an attached earlobe may be exempted from the suspects' list if direct observation or closed-circuit television (CCTV) footage of the crime scene showed a different feature. It should be mentioned however that these features alone are not sufficient for individualization or adjudication, and may need to be substantiated with other evidences at the crime scene.

Ear morphometry

In the study, there was sexual dimorphism in the measured variables in that they were statistically significant between gender for both right and left ears except for ear width (Table 7). Sexual dimorphisms have been reported for different age groups, gender and ethnic populations such as the Sudanese (Ahmed and Omer 2015), Indians (Verma et al. 2016; Murgod et al. 2013; Deopa et al. 2013), Zimbabweans (Muteweye and Muguti 2015), Italians (Gaya and Yahaya 2019) as well as Turkish school children (Barut and Aktunc 2006). The mean ear length for the right and left ears of Nigerian males was found to be 60.38 ± 4.56 and 60.29 ± 4.60, respectively, indicating that the ear length was higher in females than males for both ears. Conversely, ear width was found to be larger in males (32.25 ± 3.96 in right ear, 32.17 ± 4.06 in left ear) than females (31.79 ± 4.19 in right ear, 31.63 ± 4.27 in left ear). In the study of Ahmed and Omer (2015), both ear length and width were found to be significantly different in males and females. The means of both measurements were higher in males than females for left and right ears. An earlier study by Deopa et al. (2013) among medical students in the Uttarakhand region, Indian showed that the mean height of the ear was higher in males than females of their studied population. They reported a

6.03 cm total ear height in males and 5.77 cm in females. Our report of sexual differences in ear measurements was further corroborated by Sforza et al. (2009) who reported that both ear length and width were significantly different in Italian males and females. Furthermore, Murgod et al. (2013) reported differences in the right and left ears of Indians. They reported that left ears were longer than the right, whereas right ears were found to be larger than left ear in width. Knowledge of the human ear length and width is important in the diagnosis of congenital abnormalities such as Down's syndrome and microtia—characterized by disproportionately smaller ears (Muteweye and Muguti 2015; Taura et al. 2013), Crouzon and Apert syndromes—disproportionately smaller ears (Deopa et al. 2013), cleft lip and palate—hearing loss (Sharma and Nanda 2009).

Differences were also observed in lobule height and width in our sampled subjects. Our results indicated that lobule height was higher in the left and right ears of the males than females. In contrast, lobule width was larger in females than males for both ears. These results were in agreement with several authors (Verma et al. 2016; Ahmed and Omer 2015; Muteweye and Muguti 2015; Deopa et al. 2013; Meijerman et al. 2007). Bozkir et al. (2006) reported a 1.8 cm lobule height in adult males and 1.7 cm in females. Azaria et al. (2003) observed earlobe lengths of 2.13 and 2.11 cm for right and left ears for men, respectively, while women had 1.96 cm for the right ear and 1.91 cm for the left ear. Our report of larger lobule width in females than males was corroborated by Brucker et al. (2003) who reported the earlobe width to be 1.97 cm in women and 1.95 cm in men of their studied populations, whereas no significant difference was found by Kalcioglu et al. (2003) in the ear width of males and females. Mean concha length was found to be significantly different in male and female individuals of our studied populations and it is higher in females. This finding is in disagreement with existing reports of Ahmed and Omer (2015) and Verma et al. (2016) on concha length in other populations. In this study, concha length measurement was 29.10 ± 1.96 and 29.17 ± 2.22 mm in males and females, respectively, for the right ear, while for the left ear, it was 28.95 ± 2.06 mm in males and 29.23 ± 2.16 mm in females. The concha length was higher in Sudanese and Indian males than females. Nevertheless, while Ahmed and Omer (2015) found significant difference in mean concha length of the Sudanese, no statistically significant difference was reported among the North Eastern and North Western subpopulations of Rajasthan, India (Verma et al. 2016).

Results from our study and other findings showed that the presence of sexual dimorphism in ear dimensions is not limited to ethnic background only, it can also be seen in the right and left ears of an individual. Therefore, in sex estimation using ear morphometrics, factors such as population and gender should be considered as anthropometric data differ even among family members. Several factors such as lifestyle, elastic fibre and gravitational forces can affect the human external ear. It has been reported that earrings exert pressure that pulls the earlobe thereby affecting the earlobe height. Physiological processes such as ageing also affect both earlobe length and width (Singh and Purkait 2009; Deopa et al. 2013). Studies have shown that earlobe height increases with age (Alexander et al. 2011; Brucker et al. 2003). Differences in the pattern of auricular expansion between male and female is also important factor as human females tend to attain ear maturity earlier than males (Gaya and Yahaya 2019; Meijerman et al. 2007).

It is worthy of mention that sex estimation is a fundamental and integral part of forensic investigation. Although sex has been estimated using various body/skeletal parts such as the mandibles in South African (Franklin et al. 2008) and Brazilian populations (Lopez-Capp et al. 2018), skulls in Japanese (Ogawa et al. 2013) as well as pelvic, femur and humerus in different populations (Frutos 2005; Gonzalez et al. 2009; Curate et al. 2016), our study explores the efficacy of sex prediction using external ear parameters which have largely been unexplored until now. This becomes necessary due to the heterogeneous nature of the Nigerian population. Several options such as the demarking points, direct univariate and stepwise discriminant analyses were considered for the purpose of sex estimation in the study. The demarking point which is the average of male and female means is very useful sex determination. Measurement above the demarking point is usually classified as male, while measurement below the point is classified as female (Table 7). Sex classification accuracy for the univariate discriminant analysis was 56.4% for the left ear, and peaked at 57.3% for the right ear with males better assigned than females. The stepwise analysis utilized four variables i.e. left and right ear length, lobule height, lobule width and concha length to give prediction accuracies of 57.3% for right ear and 57% for left ear. Murgod et al. (2013) reported 71% sex classification accuracy for the Indian population using ear length, ear breadth, lobule length, lobule breadth, base of auricle and physiognomic ear index. The sex classification accuracy obtained in this study was low compared to other populations, a result that might be attributed to relatively smaller sample size compared to other studies. In their study of the Sudanese population, Ahmed and Omer (2015) obtained 70% sex estimation accuracy for right ear and 68% for left ear using direct analysis of ear length, ear width, lobule width, concha length and concha width, while stepwise discriminant analysis gave 71% accuracy for right ear and 71.5% for left ear. On population-specific sex prediction for the studied population, it was observed that lobule height, lobule width and concha length, including ear width for the Hausas, were best variables for estimating sex in each of the ethnic populations. This implies that sexual dimorphism is relatively high in these three variables. Classification accuracy however differs in the ethnic groups, an indication of differences in anthropological features in the studied Nigerian populations.

Conclusion

The study presented morphological features and dimensions of the normal human external ear in the three major Nigerian ethnic populations. Findings showed that variation exists in shape and forms of the examined features in both ears of the sampled individuals. Sexual dimorphism estimation and sex classification accuracy of the measured variables were found to be low. Hence, although the ear parameters showed potential for sex estimation, it should not be solely relied upon for personal identification.

Abbreviations

REL: Right ear length; RER: Right ear width; RLH: Right lobule height; RLW: Right lobule width; RCL: Right concha length; LEL: Left ear length; LER: Left ear width; LLH: Left lobule height; LLW: Left lobule width; LCL: Left concha length.

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Authors' contributions

All authors certify that they have participated sufficiently in contributing to the intellectual content, concept, design of this work, and writing the manuscript. STF and KOA: conceptualization, methodology; TPF and JOO: DATA curation; STF: data analysis, and writing- original draft preparation; KOA and BO: supervision, and writing- reviewing and editing. All authors read and approved the final manuscript.

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Availability of data and materials

All datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The research design and methodology were approved by the Health Research Ethics Committee of College of Medicine, University of Lagos, Nigeria with approval number: CMUL/HREC/02/21/813. All participants signed an informed consent document prior to enrolment in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interest.

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