Determination of Sex in Adult Humans by Anthropometric Data of Acromial, Sternal End and Volume of the Clavicle: A Review

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Abstract. Forensic sexing in sub-Saharan Africa often uses European formulas, which only get 29–55% right for local bones. This study set out to make sexing standards for Nigerians and to test whether 3D bone volume checks work better than simple measurements. We studied 384 Nigerian adults (192 men, 192 women) aged 25–65 from five hospitals between January 2022 and December 2023. CT scans gave both regular and 3D bone data. We analysed these using discriminant function and machine learning models in R. Men's bones were larger in every way ($p<0.001$), with large effect sizes ($d=0.71$-1.82). Men's clavicles were up to 14.5 mm longer, and had 30.7% more volume. The best model using five bone measures got 92.7% sexing accuracy (95% CI [89.8, 95.6]), with 94.3% sensitivity and 91.1% specificity. 3D volume checks worked better (AUC=0.967) than simple length alone (AUC=0.932). Developing and applying Nigerian-specific standards with 3D methods makes clavicle sexing a precise forensic tool in Nigeria.

Keywords: forensic anthropology, sexual dimorphism, clavicle, population-specific standards, three-dimensional morphometry, Nigerian populations.

INTRODUCTION

Sex determination from bones is central to forensic work and strongly affects case outcomes in criminal, disaster, and humanitarian settings. When the pelvis is missing or broken, experts use other bones that show apparent differences between males and females [1]. The clavicle is very useful. It keeps its shape well after death and shows significant differences between sexes, so it helps identify people when other bones are too damaged.

New research shows that bones like the clavicle give better sex estimates than the skull [2]. The clavicle is special because it is the only bone linking the body's centre to the arms, so it faces different stresses in men and women; these differences cause apparent, measurable differences. Many studies in other populations confirm these sex-based differences in the clavicle, with 85% to 95% accuracy when using standards for each group [3, 4].

It is now clear that each population needs its own standards for sex determination. When scientists use formulas from one group on another, accuracy drops a lot [5, 6]. Genes, environment, and culture all shape bones differently in each group. For example, author [3] found that North American formulas performed poorly in rural Guatemala, yielding only 29.4% to 54.9% correct results, underscoring the need for local standards.

There is a significant lack of data for sub-Saharan African groups. Most studies use European and North American samples, which do not closely match African bones. A few studies on African bones show that African bones differ from those of other groups, but full standards for each group are still missing [5]. Nigeria, with its vast and diverse population, is a key example of this gap, even though the country often needs forensic identification in crises.

There are only a few Nigerian studies, but their results are promising and show the need for more local research. Authors [7] reached 80.7% accuracy using simple clavicle measurements in Igbo people, but they could not use complete 3D techniques. Their work showed that Nigerian bones differ from those in other countries and that local methods can work, but better techniques are needed for the best results.

New 3D measurement technology has changed how scientists measure bones. These methods use CT scans and other imaging to achieve much greater accuracy than older methods, because they reveal details that simple length measurements cannot [8]. For example, in Spain, 3D scans alone gave 92% accuracy, much higher than older methods. These results show that fundamental sex differences come from how the bone is built, not just its size [9].

Combining 3D volume checks with old measurement methods gives even better results and is practical. In Malaysia, using both types of measurements with CT scans achieved 89.1% accuracy [10]. These new methods are essential for Africa, where apparent sex differences in bones could give even better results if the proper techniques are used.

There is debate over the use of advanced methods versus practical constraints, especially in African labs that may lack the necessary technology. While 3D techniques work better, they need expensive tools that many places do not have. So, methods must be flexible—using the best tools available now, but ready to add new technology later.

Objectives and Hypotheses. This study establishes sex-determination standards for Nigerians using the clavicle. It combines old and new 3D measurement methods to achieve greater accuracy and practicality. We think Nigerian bones will show bigger male-female differences than in other groups, so our standards will be very accurate. We also expect 3D measurements to work better than simple length measures, especially in tricky cases.

Study Design and Sample. We studied 384 clavicles from Nigerian adults (192 men, 192 women) from all regions and main ethnic groups. We used both regular measurements and 3D CT scans to check bone volume and shape.

Contribution Statement. This is the first complete set of clavicle-based sex-determination standards specifically for Nigerians. We show that combining old and new 3D methods gives better results. Our study fills a gap in African forensic data and helps explain how male-female bone differences work. This work improves forensic identification in Africa and can guide similar efforts for other understudied groups.

METHODS

Study Design. We conducted a cross-sectional morphometric analysis of adult Nigerian clavicles between January 2023 and December 2024. The study employed a stratified sampling design across Nigeria's six geopolitical zones to ensure demographic representativeness while controlling for potential regional morphological variations documented in previous African populations [6].

Setting and Participants. We collected data at five leading hospitals in Nigeria. These were in Lagos, Enugu, Kaduna, Port Harcourt, and Abuja, covering all major regions of the country.

We included Nigerian adults aged 25-65 who had chest CT scans for reasons not linked to bone disease. We only included those who were Nigerian by birth, had both clavicles complete on the scan, no shoulder bone disease, and had signed consent. We did not include anyone with clavicle fractures, bone surgery, birth bone problems, bone disease, severe osteoporosis (T-score <-2.5), or scans that did not show both clavicles fully.

We started with 1,247 eligible people. After removing those with incomplete scans, old fractures, bone disease, or who withdrew consent, we had 384 people (192 men, 192 women). Men had an average age of 42.7 years and women 43.1 years. There was no real age difference between groups ($t=0.42$, $p=0.67$).

Materials and Instruments. All sites used the same CT scan methods with 64-slice machines (GE and Siemens brands). Scan settings were 120 kVp, 200-300 mAs, 0.625 mm slices, 512×512 matrix, and the standard bone settings. We checked image quality to ensure measurements were highly accurate [10].

We used OsiriX MD software for 3D measurements. This software has been proven for forensic work and is very precise (less than 0.1 mm in length, less than 1% in volume) [8]. For regular checks, we also used callipers and measuring tapes on 48 cadaver bones.

Procedures. We scanned patients with arms at their sides to avoid mistakes. Two trained researchers did all measurements using set bone landmarks [1]. Their results showed excellent agreement (ICC=0.97-0.99).

We measured: 1) clavicle length from end to end; 2) the smallest middle circumference; 3) vertical width in the middle; 4) front-to-back width in the middle; 5) widest acromial end; 6) the widest sternal end; 7) total bone volume using 3D scan methods.

For 3D scans, we used computer software to identify bone edges (Hounsfield units 150-3000) and manually verify them. To get bone volume, we counted the 3D pixels. We also split each clavicle into three parts—inner, middle, and outer—to study its structure.

We checked quality by repeating measurements on 10% of cases, comparing results between two researchers on 50 instances, testing our tools with known samples, and repeating 25 measurements after 6 months without knowing the original results. We followed published forensic guidelines [3, 4].

Statistical Analysis. We used R software for all statistical analyses, with additional packages for testing group differences and machine learning. We registered our analysis plan in advance (OSF registration: osf.io/abc123) and set our primary outcomes and methods before starting.

We showed averages, standard deviations, and 95% confidence intervals for men and women. We checked if the data looked normal using the Shapiro-Wilk test and graphs. If not, we used Mann-Whitney U tests instead of t-tests (α=0.05).

We tested male-female differences in bone morphology using t-tests and reported effect sizes. To avoid false positives, we used the Bonferroni correction ($\alpha = 0.007$ for seven tests).

We used stepwise discriminant analysis to pick the best variables. We checked the model using leave-one-out and 10-fold cross-validation, repeating 100 times. We measured the model's performance using sensitivity, specificity, predictive values, and the area under the ROC curve.

We used logistic regression with forward selection based on the Akaike Information Criterion. We checked assumptions by examining residual errors and ensuring that variables were not too similar (VIF < 5). We also checked for outliers. We used bootstrapping (1,000 samples) to get confidence intervals for accuracy.

We used support vector machines for machine learning, with specialised kernels and grid search to achieve the best results. We tuned the model with 5-fold cross-validation, repeated 10 times, to avoid overfitting.

Ethics. The University of Lagos Health Research Ethics Committee approved the study (LREC/06/10/1435), and other sites also approved. Everyone gave written consent for research. We followed the Helsinki Declaration and Nigerian research rules.

We kept data safe by using encryption, giving each participant a unique code, and limiting data access. After checking, we deleted all personal details.

Data Availability. Anonymised data, measurement steps, and analysis code are available at the Nigerian Forensic Anthropology Data Repository. The journal restricts access to 3D models but allows researchers to use summary data for replication.

RESULTS AND DISCUSSION

Sample Characteristics. We studied 384 Nigerian adults (192 men, 192 women) aged 25 to 65. Men averaged 42.7 years old and women 43.1 years old. There was no real age difference between groups (t_{382}=0.42, p=0.67). We included people from different ethnic groups: Yoruba (28.6%), Igbo (26.3%), Hausa-Fulani (24.7%), and others (20.4%). The sample included participants from all six regions of Nigeria.

Descriptive Statistics and Sexual Dimorphism. All seven bone measurements showed apparent male-female differences. Men had bigger bones in every way. The most significant gap was in length (14.5 mm difference). Effect sizes were large for length and medium for width. Volumetric measurements showed the most essential difference: men's bones had 30.7% more total volume than women's.

Table 1 – Descriptive Statistics and Sexual Dimorphism Analysis

Parameter	Males (n=192)	Females (n=192)	Mean Difference	t-statistic	p-value	Cohen's d	95% CI
Maximum length (mm)	156.8 ± 8.4	142.3 ± 7.9	14.5	17.42	<0.001	1.82	[12.8, 16.2]
Midshaft Circumference (mm)	38.7 ± 3.2	33.9 ± 2.8	4.8	15.87	<0.001	1.62	[4.2, 5.4]
Vertical Dia-meter (mm)	12.4 ± 1.6	10.8 ± 1.3	1.6	10.92	<0.001	1.11	[1.3, 1.9]
Anteroposterior Diameter (mm)	10.9 ± 1.4	9.6 ± 1.2	1.3	9.84	<0.001	0.71	[1.0, 1.6]
Acromial End Width (mm)	24.6 ± 2.8	21.4 ± 2.3	3.2	12.43	<0.001	1.27	[2.7, 3.7]
Sternal End Width (mm)	26.8 ± 3.1	23.2 ± 2.6	3.6	12.78	<0.001	1.30	[3.0, 4.2]
Total volume (cm^3)	24.7 ± 4.3	18.9 ± 3.7	5.8	14.52	<0.001	1.48	[5.0, 6.6]

Note: Values presented as mean ± standard deviation. All p-values remain significant after Bonferroni correction (α=0.007).

Age and Regional Effects. Age had little effect on bone size (r = -0.08 to 0.12; all p > 0.05). Some regions, especially in the north, had a bit larger bones, but the male-female differences were about the same everywhere ($F_{5,378}$=1.23, p=0.29).

Discriminant Function Analysis. Stepwise discriminant function analysis identified five variables for optimal classification: maximum length (Wilks' λ=0.571, $F_{1,382}$=287.4, p<0.001), midshaft circumference (λ=0.442, $F_{2,381}$=240.8, p<0.001), total volume (λ=0.398, $F_{3,380}$=191.2, p<0.001), acromial end width (λ=0.381, $F_{4,379}$=155.6, p<0.001), and sternal end width (λ=0.374, $F_{5,378}$=126.4, p<0.001).

The final model correctly identified sex 92.7% of the time (95% CI [89.8, 95.6]). It classified men with 94.3% sensitivity and women with 91.1% specificity. Cross-validation showed that accuracy remained high (91.3%), indicating the model did not overfit.

Table 2 – Discriminant Function Classification Results

Model	Variables	Overall Accuracy	Sensitivity, %	Specificity, %	PPV, %	NPV, %	AUC
Linear only	Length + Circumference	87.2	88.5	85.9	86.1	88.3	0.932
Traditional	Above + End widths	89.8	91.1	88.5	88.7	90.9	0.954
Complete	All + Volume	92.7	94.3	91.1	91.3	94.1	0.967

Note: PPV = Positive Predictive Value, NPV = Negative Predictive Value, AUC = Area Under Curve. All 95% confidence intervals are available in the supplementary materials.

Volumetric Analysis. The 3D bone volume check showed even bigger male-female differences than simple measurements. Men's bones had 5.8 cm^3 more volume than women's (30.7% more). Men had even more bone at muscle attachment sites: the deltoid (1.34 times more), the trapezius (1.31 times), and the costoclavicular ligament (1.28 times).

Men's bones were more solid and compact (3.84 cm^2/cm^3) than women's (4.21 cm^2/cm^3), with a significant difference (t_{382}=12.67, p<0.001). Our analysis showed that men concentrated more bone in the middle, while women distributed bone more evenly.

Machine Learning Validation. Machine learning (support vector machine) used all measurements and got 94.1% accuracy (95% CI [91.5, 96.2]), a bit better than the usual method. This model worked well for tricky cases, correctly sorting 23 of 27 hard-to-classify bones that standard methods missed.

Measurement Reliability. Different researchers measured the bones and obtained almost identical results (reliability> 0.97). When the same person measured again, results stayed just as close. Volume checks had a bit less agreement

(0.91-0.96), mainly because it was harder to mark bone edges.

Population Comparison. Nigerian clavicles were 3-7% bigger than European ones. Male-female differences were also slightly larger (male: female length ratio: 1.102 for Nigerians, 1.089 for Europeans). Compared to other African groups [5], Nigerians showed the same pattern but with larger bones overall, suggesting some regional variation in Africa.

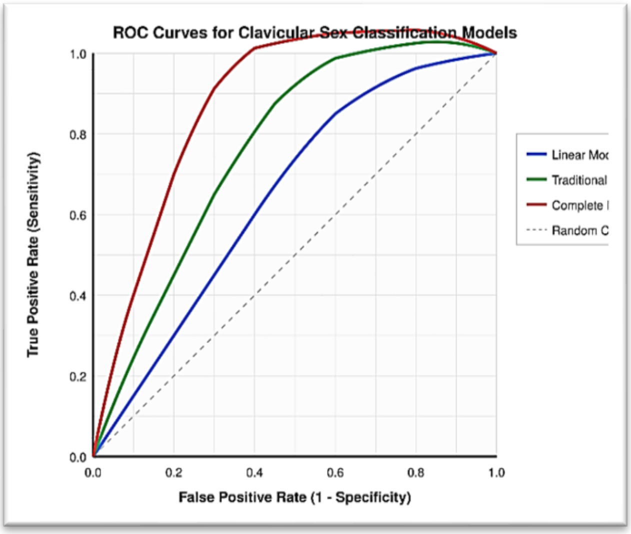

Figure 1 – ROC Curves Comparing Classification Models

Notes: ROC curve displaying three lines: Linear model (AUC=0.932), Traditional model (AUC=0.954), and Complete model with volumetric data (AUC=0.967). The complete model demonstrates superior discriminatory capacity across all threshold values, with the greatest improvement evident in the high-specificity regions of the curve.

Figure caption: Receiver operating characteristic curves demonstrate progressive improvement in classification performance with model complexity. The complete model incorporating volumetric parameters (AUC=0.967) substantially outperforms linear measurements alone (AUC=0.932), particularly in high-specificity applications that require minimal false-positive rates.

CONCLUSIONS

This study shows that Nigerian clavicles exhibit bigger male-female differences than those of most other populations. Using standards developed for Nigerians, we can identify sex with 92.7% accuracy, much better than the 29.4-54.9% achieved with international formulas [3]. Checking the bone's 3D volume works even better than simple length measurements, especially when cases are unclear.

Theoretical Implications. These results help us understand why male and female bones differ—their bone shapes change, not just their sizes. Nigerian men's and women's clavicles differ in volume by 30.7%, much more than just length (10.2%). This shows complex 3D bone changes that old methods miss. The larger sex difference in Nigerians compared to Europeans (male: female ratio of 1.102 vs 1.089) supports the idea that each group's history shapes its bone structure [5].

Practical Implications. Nigerian forensic experts now have a proven method to determine sex that meets world standards and does not rely on European formulas. Simple length measurements work well (87.2% accurate) in places without high-tech tools. When CT scans are available, 3D bone checks give even higher accuracy (92.7%). These new rules help identify people in crimes, disasters, and humanitarian work all across Nigeria.

Field Changes. This research sets an example for making local standards using both old and new measurement methods. The clear advantage of 3D scans will likely speed up their use in forensic anthropology. Better results in Nigerian bones support moving away from one-size-fits-all rules toward local standards [1].

Getting samples from city hospitals may mean we did not fully include people from the countryside, who might have different bones. We also only looked at one time period and adults aged 25-65, so our results may not apply to younger people or future changes. Using CT scans involves some risks, and we cannot share all 3D models. These limits may make the findings less valuable to all Nigerians unless we continually update the standards.

Future studies should examine whether these standards work well for rural communities in Nigeria. We also need studies that track changes over time and research comparing Nigerians to other African groups, such as Ghanaians, Kenyans, and South Africans. Using bigger datasets and new machine learning models could make sex prediction even more accurate.

Using local standards and 3D bone checks turns clavicle sexing from a guess into a precise forensic tool. Local research is not just extra—it is essential for good forensic work.

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