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Development of discriminant functions to estimate sex in upper limb bones for mixed ancestry South Africans

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ABSTRACT

South Africa has one of the highest murder rates in the world, which is associated with an increasing number of unidentified individuals. Forensic anthropologists can assist in these cases to reduce the number of potential victims the remains may belong to. Sex estimation potentially decreases the number of possible victims by half. The mixed ancestry population in South Africa is the second largest group of people; however, there remains a paucity of data and population-specific methods for sex estimation in this group. The aim of this study was to assess the potential for metrices obtained around the nutrient foramen and the maximum length of upper limb long bones to estimate sex in mixed ancestry South Africans using discriminant function analysis. A total of 328 humeri, radii and ulnae from individuals of mixed ancestry were analysed. Sex was correctly classified with an average classification accuracy of 84.3% in the humeri, 88.3% for radii and 83.5% for the ulnae. Total length was the single best predictor of sex; the combination of total length with dimensions related to the nutrient foramen produced high classification accuracies in the current study. Overall, sexual dimorphism was observed in mixed ancestry South Africans upper limb long bones. The findings of this study further emphasise the need for population-specific standards of sexing in an attempt to improve current methods of forensic identification of descendants.

1. Introduction

South Africa has one of the highest murder rates in the world, in the years 2016/2017, 19,016 cases of murder and 18,205 cases of attempted murder were recorded [1]. The Gauteng province had 4101 murders and 4872 attempted murders while the Western Cape Province had 3311 murders and 3387 attempted murders [1]. This high murder rate results in a high number of unidentified persons in South African mortuaries. In cases where typical modes of identification are not possible or difficult (for example, burnt, heavily decomposed, fragmented and or skeletonised human remains), the skills of a forensic anthropologist are often requested to assist in estimating the identity of the remains. When a missing person's docket is opened at the local police station, the biological details given to the police are sex, age-at-death, ancestry and living height. Using known morphological variations in the skeleton, a forensic anthropologist can estimate these biological characteristics [2–7]. Therefore, they can assist the police with identification, for example, estimating sex accurately rules out nearly half of the suspected candidates, and is thus, arguably the most important biological variable in human identification.

Sexing a skeleton is achieved using metric and non-metric methods. Non-metric methods are criticised for their subjectivity and reliance on whole and complete skeletonised remains [8,9]. Whereas, metric methods are suggested to be more objective, reliable, repeatable and can be applied to a single bone or part of a bone making them useful even in cases of fragmentation [8]. Sexual dimorphism varies within and between populations, posing a challenge in the application of existing discriminant function equations [10–15]. Therefore, in South Africa with its diverse population, a population-specific approach is required [9,15].

Sex estimation using upper limb long bone lengths and epiphyseal dimensions has been successfully demonstrated in several studies from

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Table 1
Skeletal sample distribution.

	Humeri		Radii		Ulnae	
	Females	Males	Females	Males	Females	Males
Dart Collection	27	39	30	38	29	36
UCT Collection	17	25	17	26	16	28
Total	44	64	47	64	45	64

Table 2
Intra-observer reliability using concordance correlation of reproducibility.

Measurement	Coefficient of reliability	
	Observer 1 (VG)	Observer 2 (PM)
maxlhum	0.9994	0.9757
penfhum	0.9996	0.9787
apdhum	0.9795	0.9633
mldhum	0.9321	0.9269
circhum	0.9973	0.8922
maxlrad	0.9993	0.9995
penfrad	0.9928	0.9930
apdrad	0.9419	0.9284
mldrad	0.9900	0.9428
circrad	0.9830	0.9317
maxluln	0.9997	0.9167
penfuln	0.9994	0.9698
apduln	0.9502	0.9213
mlduln	0.9775	0.9640
circuln	0.9920	0.9542

circhum = circumference at nutrient foramen of humeri; apdhum = anteroposterior diameter at nutrient foramen of humerus; mldhum = mediolateral diameter at nutrient foramen of humerus; maxlrad = maximum length of radius, penfrad = length of proximal end of radius to nutrient foramen; circrad = circumference at nutrient foramen of radius; apdrad = anteroposterior diameter at nutrient foramen of radius; mldrad = mediolateral diameter at nutrient foramen of radius; maxluln = maximum length of ulna; penfuln = length of proximal end of ulna to nutrient foramen; circuln = circumference at nutrient foramen of ulna; apduln = anteroposterior diameter at nutrient foramen of ulna; mlduln = mediolateral diameter at nutrient foramen of ulna.

around the world [3,5,10,11,15–17], including South Africa [4,15,18]. However, these methods require intact epiphyses, and in forensic cases these are often poorly preserved in comparison to the diaphysis [8,10,16,19]. To account for these challenges, midshaft measurements at a distinguishable landmark such as the nutrient foramen [20,21] on a fragmented bone may be more useful in sex estimation, and thus, identification. While several studies have been conducted on lower limb bones [12,14,15,19,22–24], relatively few have been done on upper limb bones [25].

Studies aiming to establish the biological profile in South Africans focused more on the South African Africans and Europeans but less on the mixed ancestry South African population [26]. Recent studies have examined sex estimation in the mixed ancestry South Africans using osteometric data of the crania [27] and postcrania [15,28]. However, there is no information on skeletal dimensions related to the nutrient foramen on long bones for sex estimation in the second largest population group in South Africa [1], the mixed ancestry population. The mixed ancestry South African population group is a self-identified group socially known as Coloured, who possess a rich and diverse history within South Africa [15,29]. This diversity extends into their genetic make-up. Parental populations include admixture of Africans such as Khoesan individuals, African Bantu speaking population groups and non-Africans including Malaysians, Indonesians, Indians and Europeans [15,29–32]. This population group represent the largest number of people in the Northern and Western Cape Provinces of South Africa [1]. The Western Cape Province presents with the second highest

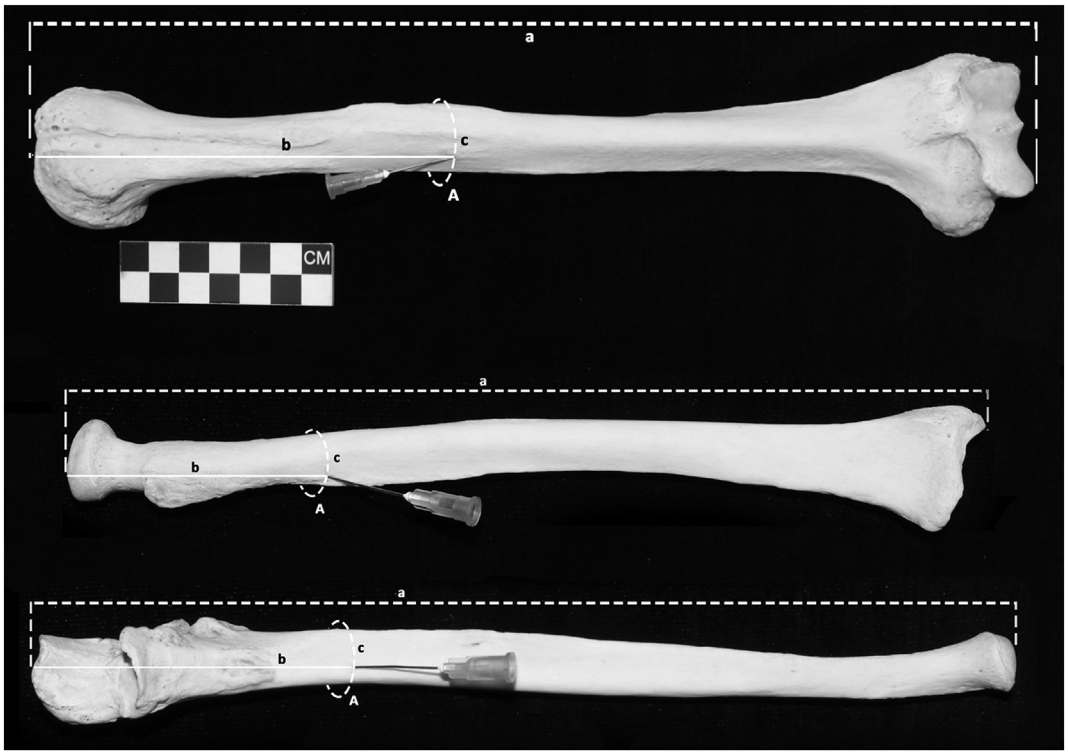

Fig. 1. Photograph showing the some of the measurements utilized in the study. a = maximum bone length; b = proximal end of the bone to the nutrient foramen (pierced by the hypodermic needle); c = circumference at the nutrient foramen; A = level of the nutrient foramen where the antero-posterior and medio-lateral diameters where obtained. Note: the direction of the hypodermic needle also indicates the direction of inclination of the nutrient foramen into the diaphysis of the bone. Scale bar = 1 cm applies to all parts of the image.

Table 3
Descriptive statistics of measurements of the humeri, radii and ulnae.

Variables	Females			Males			t-Statistic	*p*-Value
	No	Mean	SD	No	Mean	SD		
Humeri								
maxlhum	44	288.5	13.6	64	315.1	14.1	9.772	0.000*
penfhum	44	168.1	28.4	64	179.3	24.6	2.182	0.031*
apdhum	44	17.7	1.8	64	20.3	1.9	7.137	0.000*
mldhum	44	16.6	2.1	64	19.0	2.4	5.368	0.000*
circhum	44	55.0	4.3	64	63.4	5.0	9.071	0.000*
Radii								
maxlrad	47	215.9	12.3	64	240.3	12.8	9.889	0.000*
penfrad	47	74.7	10.9	64	84.9	10.9	4.778	0.000*
apdrad	47	9.7	1.1	64	11.6	1.1	8.820	0.000*
mldrad	47	13.0	1.6	64	14.8	1.5	5.963	0.000*
circrad	47	37.8	3.4	64	43.1	3.3	8.101	0.000*
Ulnae								
maxluln	45	233.6	13.5	64	256.9	14.1	8.584	0.000*
penfuln	45	89.1	15.4	64	97.0	14.3	2.734	0.007*
apduln	45	12.6	1.6	64	14.9	2.0	6.355	0.000*
mlduln	45	12.8	1.5	64	15.2	1.7	7.556	0.000*
circuln	45	42.0	3.9	64	48.8	4.5	8.138	0.000*

No = number of specimens; SD = standard deviation; maxlhum = maximum length of humerus; penfhum = length of proximal end of humeri to nutrient foramen; circhum = circumference at nutrient foramen of humerus; apdhum = anteroposterior diameter at nutrient foramen of humerus; mldhum = mediolateral diameter at nutrient foramen of humerus, maxlrad = maximum length of radius; penfrad = length of proximal end of radius to nutrient foramen; circrad = circumference at nutrient foramen of radius, apdrad = anteroposterior diameter at nutrient foramen of radius; mldrad = mediolateral diameter at nutrient foramen of radius, maxluln = maximum length of ulna; penfuln = length of proximal end of ulna to nutrient foramen; circuln = circumference at nutrient foramen of ulna; apduln = anteroposterior diameter at nutrient foramen of ulna; mlduln = mediolateral diameter at nutrient foramen of ulna.

* Statistically significant values (P ≤ .05).

rate of murder in the country, the mixed ancestry population group presents as the largest demographic within this region, consequently leading to their representation as a larger number of victims in associated forensic cases. Hence, there is a need for population specific standards for sexing individuals of mixed ancestry to improve victim identification, case resolution, and thus, social criminal justice and closure for the victims and their families. In this study, we aim to assess if measurements of upper limb long bones taken at the level of the nutrient foramen and in combination with the maximum bone length can be used to accurately estimate sex of mixed ancestry South Africans.

2. Materials and methods

An ethical clearance waiver was obtained from the School of Anatomical Sciences, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg (clearance certificate number: W-CJ-140604-1) prior to the commencement of this study. A total sample of 328 bones (humeri: 108, radii: 111 and ulnae: 109) from mixed ancestry South Africans of known sex and age-at-death were analysed. Only intact humeri, radii and ulnae of individuals whose ages-at-death ranged between 21 and 65 years were included. Skeletal material with any visible pathology, trauma or curatorial damage that hindered the accuracy of measurements were excluded. The sample was obtained from two separate cadaver-based research repositories: (i) Raymond A. Dart Collection of Human Skeletons [33] housed in the School of Anatomical Sciences, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, measurements here obtained by PM and (ii) UCT Human Skeletal Collection housed in the Department of Human Biology, University of Cape Town, Cape Town, measurements obtained by VG. The distribution of the sample with respect to sex is shown in Table 1.

On each bone five parameters were measured, which are defined below as described by İşcan and Miller-Shaivitz [23] and Brauer [34] (Fig. 1)

A. Maximum length measurements were obtained using a laboratory osteometric board:

1. The maximum length of the humerus (maxlhum) was taken from the most proximal aspect of the humeral head to the most distal point of the trochlea.
2. The maximum length of the radius (maxlrad): This is the linear distance from the most proximal point of the radial head to the distal end of the styloid process radius.
3. The maximum length of the ulna (maxluln): The linear distance between the most proximal aspect of the olecranon process to the distal end of the styloid process of ulna

B. The linear distance from the most proximal end of the humerus (penfhum), radius (penfrad) or ulna (penfuln) to the nutrient foramen. These were taken using a digital sliding calliper.

C. Circumference at nutrient of foramen: These measurements were taken at the level of the nutrient foramen of the humerus (circhum), radius (circrad) and ulna (circuln) with masking tape and then quantified on a measuring ruler by following the contours of the bone.

D. The anteroposterior diameters were obtained with a digital sliding calliper.

1. Humerus (apdhum): This is the linear distance from the anterior border to the posterior surface of the humerus taken at the level of the nutrient foramen.
2. Radius (apdrad): The linear distance between the anterior border/anterior oblique line to the posterior surface of the radius at the level of the nutrient foramen.
3. Ulna (apduln): This is the distance between the anterior surface and the posterior border at the level of the nutrient foramen.

E. The mediolateral diameters were obtained using a digital sliding calliper.

1. Humerus (mldhum): This is the distance between the medial and lateral borders of the humerus at the level of the nutrient foramen.
2. Radius (mldrad): This measurement was taken from the interosseous border to the lateral surface of the radius at the level on the nutrient foramen.
3. Ulna (mlduln): The distance between the medial and interosseous borders at the level on the nutrient foramen.

Two observers (PM and VG) collected data from two different centres and each observer performed intra-observer reliability test for each of the measurements using the Lin's concordance correlation of reproducibility (Pc) (Table 2).

2.1. Data analysis

The obtained data were described and analysed statistically using SPSS version 23 software program. To establish significant differences between the means of these data for both males and females the Student's *t*-test was used. An analysis of variance was performed to assess variation between males and females. As described by Bidmos and Asala [35], these data were subjected to univariate, stepwise and direct discriminant function analysis. The validity of the functions generated was assessed using the "leave-one-out" classification procedure.

Table 4
Discriminant function coefficients, constants and classification rates for humeri.

Function	Variables	Unstandardized coefficient	Centroids	Sectioning point	Average Accuracy (%)	
					Original classification	Cross validation
1	maxlhum	0.072	−1.133	−0.177	85.2	85.2
	constant	−21.832	0.779			
2	maxlhum	0.047	−1.367	−0.214	85.2	84.3
	circhum	0.124	0.940			
	constant	−21.845				
3	circhum	0.173	−1.168	−0.183	85.2	82.4
	mldhum	0.202	0.803			
	apdhum	−0.083				
	penfhum	0.018				
	constant	−15.927				
4	circhum	0.146	−1.157	−0.181	84.3	80.6
	penfhum	0.017	0.795			
	apdhum	0.208				
	constant	−15.752				
5	penfhum	0.013	−1.123	−0.176	83.3	83.3
	circhum	0.208	0.772			
	constant	−14.703				
6	circhum	0.235	−1.136	−0.1775	83.3	81.5
	mldhum	−0.090	0.781			
	penfhum	0.014				
	constant	−14.920				
7	circhum	0.212	−1.060	−0.166	81.5	81.5
	constant	−12.731	0.729			
8	circhum	−0.046	−1.063	−0.166	80.6	79.6
	mldhum	0.226	0.731			
	constant	−12.744				
9	circhum	0.196	−1.063	−0.166	80.6	78.7
	apdhum	0.055	0.731			
	constant	−12.825				
10	apdhum	0.538	−0.813	−0.127	76.9	75.0
	constant	−10.354	0.559			

maxlhum = maximum length of humerus, penfhum = length of proximal end of humerus to nutrient foramen; circhum = circumference at nutrient foramen of humerus, apdhum = anteroposterior diameter at nutrient foramen of humerus; mldhum = mediolateral diameter at nutrient foramen of humerus.

3. Results

The results of intra-observer reliability of measurements for each observer are shown in Table 2. The range of the majority of the values for the concordance correlation coefficient of reproducibility obtained for each observer fell within the internationally accepted standards of 0.90 to 0.99.

The descriptive statistics of all measured variables for both sexes are displayed in Table 3. Males consistently displayed higher mean values for all variables compared to females. Statistically significant differences were observed between male and female mean measurements at $p \leq .05$ for all measurements.

The five humeral measurements were analysed using a stepwise discriminant function (Table 4). Two measurements namely maxlhum and circhum were selected in these analyses (Function 2) with an average accuracy of correct classification of 85.2%. Individual measurements were separately entered in a discriminant function analysis, the measurements with the highest average accuracies in correct sex classification were maxlhum (85.2%), circhum (81.5%) and apdhum (76.9%). The average accuracies for various combinations of the humeral measurements ranged between 80.6% and 83.3% (Functions 3–6,8 and 9).

Table 5 shows the various combinations of measurements of the radius with reasonably high discriminating ability. Using the radii the average accuracy in correct classification ranged between 77.5% and 89% (Table 5). The highest average accuracy in correct sex assignment was obtained in function 1 using all measurements. Individual measurements with the best discriminating ability were maxlrad (Function 2), apdrad (Function 5) and circrad (Function 10) with average accuracies of 85.6%, 81.1% and 77.5% respectively. Various combinations of measurements also presented with acceptably high average accuracies, which ranged between 80.2% and 83% (Functions 3, 4, 6–9).

A combination of maxluln and mlduln with an average accuracy of 83.5% were selected in the stepwise analysis of ulna measurements (Function 2, Table 6). The maxluln, circuln and mlduln were respectively the best individual measurements with high classification rates (Functions 3, 4 and 8). Various combinations of measurements of the ulna also yield high average accuracies in correct sex classification. These ranged between 81.7% (Functions 6 and 7) and 84.4% (Function 1).

To derive discriminant function scores from each of the functions presented in Tables 4 to 6, the dimension of the measured variable is multiplied with the unstandardised coefficient, and the provided constant for the function is added to this product to obtain a discriminant function score. This score is then compared to the sectioning point. If the discriminant function is greater than the sectioning point, the individual should be classified as male and *vice versa* for females.

The validity of the functions was assessed using the leave-one-out classification. The average accuracy in correct sex classification for most of the presented functions remained unchanged after cross-validation (see Tables 4–6). The drop in average accuracy for a few of the functions ranged between 1.5% and 3.7% (Function 1, Table 6), which indicates the validity of these functions.

4. Discussion

Through analyses of measurements obtained from upper limb bones of mixed ancestry South Africans discriminant functions were created and show with high accuracy that they can correctly estimate sex. All osteometric dimensions showed statistically significant differences between males and females. The maximum length measurement was the

Table 5
Discriminant function coefficients and constant and classification rates for radii.

Function	Variables	Unstandardized coefficient	Centroids	Sectioning point	Average Accuracy (%)	
					Original classification	Cross validation
1	maxlrad	0.056	−1.313	−0.408	89.0	88.3
	apdrad	0.497	0.497			
	constant	−18.309				
2	maxlrad	0.080	−1.119	−0.149	85.6	85.6
	constant	−18.293	0.822			
3	penfrad	0.030	−1.123	−0.149	83.0	82.0
	apdrad	0.516	0.825			
	circrad	0.131				
	constant					
4	penfrad	0.034	−1.141	−0.152	82.0	80.2
	apdrad	0.597	0.838			
	mldrad	−0.165				
	circrad	0.158				
	constant	−13.340				
5	apdrad	0.915	−0.960	−0.128	81.1	81.1
	constant	−9.873	0.705			
6	penfrad	0.037	−1.048	−0.139	81.1	80.2
	apdrad	0.791	0.770			
	constant	−11.528				
7	cirdrad	0.255	−0.994	−0.132	81.1	80.2
	penfrad	0.036	0.730			
	constant	−13.286				
8	apdrad	0.833	−0.965	−0.128	81.1	80.2
	mldrad	0.087	0.709			
	constant	−10.213				
9	cirdrad	0.155	−1.063	−0.142	80.2	78.4
	apdrad	0.558	0.780			
	constant	−12.357				
10	circrad	0.298	−0.918	−0.122	77.5	77.5
	constant	−12.189	0.675			

maxlrad = maximum length of radius; penfrad = length of proximal end of radius to nutrient foramen, circrad = circumference at nutrient foramen of radius; apdrad = anteroposterior diameter at nutrient foramen of radius, mldrad = mediolateral diameter at nutrient foramen of radius.

Table 6
Discriminant function coefficients and constant and classification rates for ulnae.

					Average Accuracy (%)	
Function	Variables	Unstandardized coefficient	Centroids	Sectioning point	Original classification	Cross validation
1	circuln	0.144	−1.005	−0.1495	84.4	80.7
	penfuln	0.018	0.706			
	mlduln	0.179				
	apduln	0.074				
	constant	−11.858				
2	maxluln	0.050	−1.156	−0.1715	83.5	83.5
	mlduln	0.336	0.813			
	constant	−17.111				
3	maxluln	0.072	−0.985	−0.146	82.6	82.6
	constant	−17.841	0.693			
4	circuln	0.234	−0.931	−0.138	82.6	82.6
	constant	−10.744	0.655			
5	penfuln	0.021	−0.981	−0.1455	82.6	82.6
	circuln	0.221	0.690			
	constant	−12.181				
6	circuln	0.218	−0.933	−0.1385	81.7	81.7
	apduln	0.050	0.656			
	constant	−10.712				
7	circuln	0.153	−0.971	−0.1445	81.7	80.7
	mlduln	0.254	0.682			
	constant	−10.669				
8	mlduln	0.614	−0.87	−0.129	78.0	78.0
	constant	−8.746	0.611			

maxluln = maximum length of ulna; penfuln = length of proximal end of ulna to nutrient foramen, circuln = circumference at nutrient foramen of ulna; apduln = anteroposterior diameter at nutrient foramen of ulna, mlduln = mediolateral diameter at nutrient foramen of ulna.

best predictor of sex, except for on the ulnae, where the circumference at the nutrient foramen was an equally powerful predictor.

Discriminant function analysis produced correct sex classification accuracies for the humeri ranging from 76.9–85.2%. Overall, combining humeral maximum length and its circumference gave an accuracy of 85.2%. The single most accurate measurement on its own was maximum humeral length, which also had an average classification accuracy of 85.2%. These findings were similar to Mokoena et al. [25], in the humeri of the South African Africans and South African Europeans, with an average accuracy of 85%. In the radii, the average classification accuracy ranged from 77.5–89% and the combination of maxlrad and apdrad produced the highest average accuracy for this bone (89%). Similar to the humeri, maximum length of the radii was the best individual predictor of sex with an average accuracy of 85.6%. Similar average accuracies were reported in the radii of South African Africans and South African Europeans; however, apdrad was reported as the single best predictor of sex in these groups [25]. High classification accuracies were also observed in the ulnae, ranging from 78 to 83.5% and the best combination of variables included maxluln and mlduln. As individual variables, maxluln and circuln were equally powerful in predicting sex, both generating an average accuracy of 82.6%. This is slightly lower than what was reported in South African Africans (86%) and South African Europeans (88%) [25]. Moreover, the circumference of the ulnae was the single best predictor of sex in these populations, predicting sex with an average accuracy of 82% [25].

The current study shows similarities in the sex estimating potential of the three upper limb bones in mixed ancestry South Africans. This is demonstrated by similarities in the average classification accuracies of each bone (Function 1 and 2 of Tables 4–6). It is worth noting that the contribution of various dimensions relating to the nutrient foramen in estimating sex, differ between the bones. For example, the most accurate combinations of variables were maxlhum and circhum for humeri; maxlrad and apdrad for radii; maxluln and mlduln for ulnae. This may be explained by morphological variations in the shape of the bone shaft, or difference in the position of the nutrient foramen in each bone. Maximum length was significant in discriminating between the sexes, it was consistently selected as the best individual predictor of sex. This has been demonstrated in both upper and lower limb long bones in South African Africans and South African Europeans [18,25] and in the forearm bones of Turkish individuals [11,36]. However, the current findings are incongruent with other South African population based studies, which depict the width dimensions to be the best predictor of sex when compared to length measurements [26,27,37]. Limb breath measurements are influenced by several factors including muscle attachments, physical activity, torsional forces, climatic adaptation (for heat loss), genetic variation and socioeconomic status [38–41].

The mixed ancestry South African population have the highest intra-population variation in comparison to South African Africans and South African Europeans [28]. The variation is higher in males and is expressed as size variation [28]. The mixed ancestry South African population also display the highest level of intra and inter-continental genetic admixture compared to the rest of the world [42,43]. With regard to genetic composition of the mixed ancestry South African population being diverse from Europe, Bantu-speaking South Africans, Khoesan people and people of Asia (Malaysians and Indonesians) [43]. The high intra-population variation may be responsible for variant sex estimation results reported on the same population [15,27,28]. Due to the historical peopling of South Africa, the genetic contribution varies in this population group between sexes, at individual levels, and in different geographical areas within South Africa [44]. Therefore, intra-population variation in this group can affect the contributing elements to sexual dimorphism.

Although the maximum length measurement was found to be the best predictor of sex, importantly the combination of maximum length with dimensions related to the nutrient foramen had high classification accuracies. Moreover, when maximum length cannot be obtained, possibly due to damage or fragmentation, the dimensions related to the nutrient foramen can be used as good predictors of sex for humeri (Table 4, function 3), radii (Table 5, function 3) and ulnae (Table 6, function 3). Therefore, the nutrient foramen of upper limb long bones is equally important for sex estimation in mixed ancestry South Africans. This is similar to the findings described in upper limb long bones of other South African populations [25].

The mixed ancestry South African sample showed marginally higher accuracies in the humeri and radii when compared to South African Europeans but were markedly higher than those of South African Africans [25]. Krüger et al. [27], identified a similar pattern regarding postcranial elements of mixed ancestry South Africans, estimated as more sexually dimorphic in comparison to South African Africans and South African Europeans. In comparison to the findings of Mokoena et al. [25], the bony elements that contributed to the sexual dimorphism of each bone differed between the three South African populations. For example, maximum length of the radii in South African Europeans provided the highest average accuracy, which was not observed in South African Africans nor mixed ancestry radii. Thus, despite sharing a geographic location, variations are observed in both the degree and the specific traits contributing to sexual dimorphism in these population groups. As such these findings further corroborate the significant role of defining population-specific discriminant functions for sex estimation [15]. Inter-population osteological variations are influenced by the genotype (*i.e.* genetic variation), which effects phenotype (*i.e.* morphological changes such as shape and size) and the impact of environmental factors (*e.g.* physical activity and diet) [15]. The latter is quite important in South Africa due to the socio-political history experienced by different population groups [32].

5. Conclusions

The current study demonstrates the utility of measurements related to the nutrient foramen and bone length on upper limb long bones of mixed ancestry South African population for sex estimation. When combined with bone maximum length measurements, the dimensions around the nutrient foramen produce high sex estimation percentages. In comparison to other studies, population differences were observed in the degree and scope of sexual dimorphism in these bones. The current study further emphasises the need for population-specific standards in sex estimation, with specific reference to the mixed ancestry South Africans. These results will measurably improve service delivery of forensic anthropologists in South Africa to Forensic Pathology Services and South African Police Service forensic laboratories – restoring the identities of those who may otherwise have been lost to justice and history.

Conflict of interests

None declared.

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Declarations of interest

None.

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