Sex determination using humeral dimensions in a sample from KwaZulu-Natal: an osteometric study

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Abstract: The morphological characteristics of the humeral bone has been investigated in recent times with studies showing varying degrees of sexual dimorphism. Osteologists and forensic scientists have shown that sex determination methods based on skeletal measurements are population specific, and these population-specific variations are present in many body dimensions. The present study aims to establish sex identification using osteometric standards for the humerus in a contemporary KwaZulu-Natal population. A total of 11 parameters were measured in a sample of n=211 humeri (males, 113; females, 98) from the osteological collection in the Discipline of Clinical Anatomy, Nelson R. Mandela School of Medicine, University of KwaZulu-Natal, Durban, South Africa. The difference in means for nearly all variables were found to be significantly higher in males compared to females ($P<0.01$) with the most effective single parameter for predicting sex being the vertical head diameter having an accuracy of 82.5%. Stepwise discriminant analysis increased the overall accuracy rate to 87.7% when all measurements were jointly applied. We conclude that the humerus is an important bone which can be reliably used for sex determination based on standard metric methods despite minor tribal or ancestral differences amongst an otherwise homogenous population.

Key words: Sex determination, Osteometry standards, Humerus, Ancestral differences

Introduction

Determination of sex is an important first step in the identification process of an individual in a forensic examination. A biological profile which includes age, race, and stature when determined from the various human remains are amongst several other key parameters that need to be rapidly determined [1, 2]. Reports from previous studies have indicated that virtually every human bone has been used for sex determination with varying accuracy rates [3, 4]. Although studies have demonstrated both higher and more reliable accuracies using the pelvis and cranium [5, 6], recent studies have shown similarly high accuracy rates in postcranial long bones [6-8] foregrounding the relevance of the humeral bone for sex determination [9, 10]. The humerus has in fact received a lot of attention in recent forensic and anthropological literature with emphases being placed on its metric characteristics, in setting standards for sex determination [11, 12].

Despite previous literature predicting the maximum length

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(ML) of the humerus as a good predictor of sex [3, 9], the vertical head diameter (VDH) and epicondylar breadth (EB) of this bone have also been shown to be accurate predictors of sex [13, 14]. Furthermore, humeral metric assessment of sexual differences among the South Africans white and blacks using the Dart and Pretoria collection has indicated that the VDH and EB are the best predictor in whites, whereas VDH and ML are the best predictors in blacks [10].

Since variations have been reported to exist amongst different regional populations [15] with these population-specific variations being common in many body dimensions [16], it is important to note that humeral dimensions can vary distinctly from one geographic region to another [17-19].

However, in the South African context, it has been shown that although there are some regional differences amongst blacks, they still belong to a single homogeneous group [20-23]. In the study of black Africans, it is useful to generate certain specific body measurements for individuals from diverse geographical regions as it would be better to understand observed differences on a tribal basis. The present study aims to establish key metrics for the humerus derived from a contemporary South Africa population in the region of KwaZulu-Natal province. Comparison of these metrics with those from studies of other populations could broaden understanding and assist in various medico-legal, forensic, and anthropological discourses.

Materials and Methods

This study was conducted on 211 humeri (males, 113; females, 98) collected in the Discipline of Clinical Anatomy, Nelson R. Mandela School of Medicine, University of KwaZulu-Natal, Durban, South Africa. These bones were of people from South African black descent who died between the years of 1960 to 1996 and were donated to the department. Ethical approval was sought and obtained from the University of KwaZulu-Natal Biomedical Research Ethics Committee (BREC) with reference BCA356/14. The subjects were randomly distributed in the KwaZulu-Natal region. The ages for males ranged between 18 to 81 years with the mean of 48.5 (standard deviation [SD], 14.5) and females from 17 to 75 years with a mean of 45.4 (SD, 13.4). Eleven parameters were measured from each humeral bone using an osteometric board, vernier callipers and a flexible measuring tape (Table 1, Fig. 1). All measurements were done in accordance with standard osteometric techniques as recommended by Martin and Saller [24], Bass [25], and Devi et al. [26]. Transverse diameters were taken with the bones placed with their dorsal surfaces resting on the osteometric board (Fig. 1).

To assess differences, measurements were subjected to standard statistical analysis using student's t test and a P-value of <0.05 was considered statistically significant. In addition, the demarking point for each variable was individually computed. The demarking point represents the average of the mean for males and females [27, 28]. A discriminant score (DS) higher than the demarking point indicates a male, while

Table 1. Definitions of humeral parameters measured

No.	Parameter	Abbreviation	Definition	Instrument used
1	Maximum length	ML	Straight distance from the most superior point on the head of the humerus to the most inferior point on the trochlea	Osteometric board
2	Vertical diameter of the head	VDH	Direct distance between the highest and the lowest point on the articular margin of the head measured	Electronic digital caliper
3	Circumference of the head	CH	Circumference of the humeral head along its articular surface	Flexible tape
4	Transverse diameter at the upper half of the shaft	TDUS	Distance between the medial and lateral margins at the middle of upper half of the humeral shaft	Electronic digital caliper
5	Transverse diameter at the middle of the shaft	TDMS	Distance between the medial and lateral margins of the humeral shaft at the middle	Electronic digital caliper
6	Transverse diameter at the lower half of shaft	TDLS	Distance between the medial and lateral margins of the humeral shaft at the middle of the lower half of shaft	Electronic digital caliper
7	Upper shaft circumference	USC	Circumference of humeral shaft at the middle of the upper half of shaft	Flexible tape
8	Mid-shaft circumference	MSC	Circumference of the humeral shaft at the middle	Flexible tape
9	Lower shaft circumference	LSC	Circumference of the humeral shaft at the middle of the lower half of shaft	Flexible tape
10	Upper epiphyseal breadth	UEB	Obtainable distance between the medial-most point on the articular surface of the head and the lateral-most point on the greater tubercle	Electronic digital caliper
11	Epicondylar breadth	EB	Distance between the most lateral point on the lateral epicondyle and the tip of medial epicondyle	Electronic digital caliper

a lesser score indicates a female bone.

Sexual dimorphism ratios were calculated to determine the level of differences between the sexes using the formula below [29, 30].

Sexual dimorphism ratio=(Male mean)/(Female mean)×100

To determine the variable that will provide the best discrimination between sexes, a stepwise discriminant function analysis was applied to all dimensions using Wilk's lambda. F=3.84 was used to enter and F=2.71 to remove variables. Wilks' lambda is a test statistics in multivariate analysis of variance (MANOVA). Like the F-statistic in ANOVA, it is used to establish whether there are differences between the means of groups of subjects on a combination of dependent variables. It provides an objective measure of the amount of variance that is accounted for by the independent grouping variable—in this case, sex, against the combination of dependent variables—in this case, the humeral metrics. In doing so it indicates how well the prediction model fits. Variables were also subjected to direct and stepwise discriminant function analysis to develop an equation for sex determination of the humeri from this geographic region. The original sample was cross-validated and a "leave-one-out" classification procedure applied to determine the final accuracy rates. In this procedure, each individual bone was correctly classified by the functions derived from all cases other than the case itself.
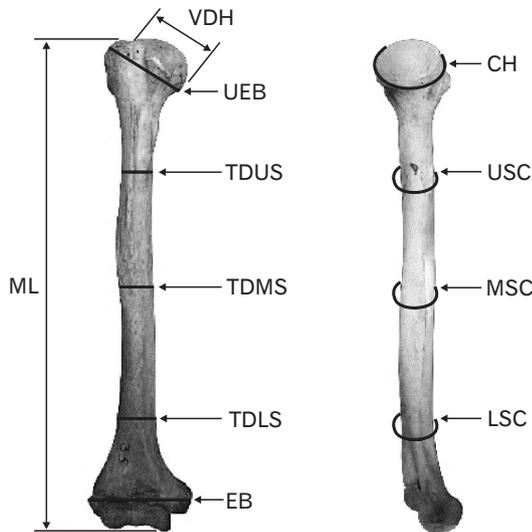
Assessment of inter and intra observer errors were evaluated using a sub-set of 30 males and 30 females done by two independent observers. Three measurements were taken by each observer and subject to intra-class correlation coefficient analysis in SPSS version 24.0 (IBM Corp., Chicago, IL, USA).

Results

Comparison of mean values for all parameters (Table 2)

Table 2. Mean values of variables of humerus in males and females (Students t test)

Variable	Males (n=113) (mm)	Females (n=98) (mm)	P-value
ML	320.81±1.79	294.63±1.55	<0.01
VDH	43.63±0.35	37.82±0.28	<0.01
CH	133.47±3.30	116.01±0.77	<0.01
TDMS	20.89±0.25	17.96±0.19	<0.01
TDUS	23.15±2.03	18.28±0.20	0.028
TDLS	23.52± 0.29	20.00±0.25	<0.01
USC	66.10±0.64	60.74±0.56	<0.01
MSC	62.95±0.53	58.99±0.54	<0.01
LSC	64.00±0.58	59.84 ±0.58	<0.01
UEB	49.51±0.43	43.43±0.30	<0.01
EB	61.36± 0.50	54.40±0.40	<0.01

Values are presented as mean±SEM. ML, maximum length; VDH, vertical head diameter; CH, circumference of the head; TDMS, transverse diameter at the middle of the shaft; TDUS, transverse diameter at the upper half of the shaft; TDLS, transverse diameter at the lower half of shaft; USC, upper shaft circumference; MSC, mid-shaft circumference; LSC, lower shaft circumference; UEB, upper epiphyseal breadth; EB, epicondylar breadth.

Fig. 1. Posterior and mediolateral views of the left humerus showing the parameters used. VDH, vertical head diameter; UEB, upper epiphyseal breadth; TDUS, transverse diameter at the upper half of the shaft; TDMS, transverse diameter at the middle of the shaft; TDLS, transverse diameter at the lower half of shaft; EB, epicondylar breadth; ML, maximum length; CH, circumference of the head; USC, upper shaft circumference; MSC, mid-shaft circumference; LSC, lower shaft circumference.

Table 3. Demarking points separating males from females, sexual dimorphism ratio, F ratio, and statistical significance in KwaZulu-Natal study population

Variable (mm)	Demarking point	Sexual dimorphism ratio	Wilks' lambda	F-ratio	P-value
ML	F<307.72<M	108.89	0.638	118.164	<0.01
VDH	F<40.73<M	115.36	0.565	160.160	<0.01
CH	F<114.74<M	115.05	0.901	22.950	<0.01
TDMS	F<19.43<M	116.31	0.707	86.251	<0.01
TDUS	F<20.72<M	126.64	0.977	4.898	0.028
TDLS	F<21.72<M	117.60	0.725	78.868	<0.01
USC	F<63.42<M	108.82	0.847	37.535	<0.01
MSC	F<60.92<M	106.71	0.887	26.512	<0.01
LSC	F<61.92<M	106.95	0.892	25.272	<0.01
UEB	F<46.47<M	114.00	0.625	124.758	<0.01
EB	F<57.88<M	112.79	0.652	111.162	<0.01

ML, maximum length; VDH, vertical head diameter; CH, circumference of the head; TDMS, transverse diameter at the middle of the shaft; TDUS, transverse diameter at the upper half of the shaft; TDLS, transverse diameter at the lower half of shaft; USC, upper shaft circumference; MSC, mid-shaft circumference; LSC, lower shaft circumference; UEB, upper epiphyseal breadth; EB, epicondylar breadth.

showed males to be statistically significantly higher than those of females for transverse diameter at the upper half of the shaft (TDUS) ($P<0.05$) with $P<0.01$ for all other variables.

The sexual dimorphism ratio, demarking points (points separating males from females), F-ratio and their corresponding significance levels is presented in Table 3. A higher demarking point indicates a male with females having a lower value. The result of stepwise discriminant function analyses was reported in Table 4. Of the eleven variables entered into the function, only four were ultimately selected as 'critical.' These were VDH, ML, transverse diameter at the lower half of shaft (TDLS), and mid-shaft circumference (MSC) in that relative order. The table also present the unstandardized discriminant function coefficients and the sectioning points (average of the male and female centroids) in the original samples [31]. To determine the sex of an individual, the DS can be obtained from specified function. Each humeral dimension is multiplied by its corresponding raw (unstandardized) coefficient and then added to the constant, if the score is greater than the sectioning point, then the individual is male, whereas a score less than the sectioning point indicates a female [10]. For example, a black individual with VDH (43.63),

ML (320.81), TDLS (23.52), and MSC (62.95), the calculation will be as following.

DS=0.175×VDH+0.028×ML+0.133×TDLS−0.048×MSC−15.761=0.964

As this value (0.964) is greater than the sectioning point (−0.0675), the individual is a male.

The classification accuracy for the humeral dimensions (Table 5) indicate VDH to be the most effective single dimension or the best predictor for sex using stepwise discriminant analyses with an average accuracy of 82.5% ($r=0.868$). The results also indicate that the percentage accuracy is increased

Table 4. Summary of stepwise discriminant function analyses, unstandardized discriminant function coefficients, and the sectioning points

Variables entered	Wilks' lambda	F-ratio	d.f	Unstandardized coefficients	Sectioning points
VDH	0.565	160.160	1,208	0.175	−0.0675
ML	0.522	94.849	2,207	0.028	
TDLS	0.507	66.843	3,206	0.133	
MSC	0.495	52.380	4,205	−0.048	
Constant				−15.761	

VDH, vertical head diameter; ML, maximum length; TDLS, transverse diameter at the lower half of shaft; MSC, mid-shaft circumference.

Table 5. Classification accuracy on humeral dimension in KwaZulu-Natal population

| Variable | Predicted group membership | | | | | |
| | Original group | | | Cross-validated | | |
	Males	Females	Average	Males	Females	Average
ML	72.6	82.7	77.3	72.6	82.7	77.3
VDH	82.3	82.7	82.5	82.4	82.7	82.5
CH	92.9	62.2	78.7	92.9	62.2	78.7
TDMS	75.0	77.7	76.2	73.2	77.6	75.2
TDUS	100.0	2.00	54.5	100	2.00	54.5
TDLS	72.6	75.5	73.9	72.6	75.5	73.9
USC	68.1	62.2	65.4	68.1	62.2	65.4
MSC	74.3	50.0	63.0	74.3	50.0	63.0
LSC	71.7	57.1	64.9	71.7	57.1	64.9
UEB	85.0	82.7	83.9	85.0	82.7	83.9
EB	85.0	79.6	82.5	85.0	79.6	82.5
VDH+ML+ TDLS+MSC	90.3	84.7	87.7	89.4	84.7	87.2
All variables	89.3	85.7	87.6	85.7	83.7	84.8

Values are presented as percentage. ML, maximum length; VDH, vertical head diameter; CH, circumference of the head; TDMS, transverse diameter at the middle of the shaft; TDUS, transverse diameter at the upper half of the shaft; TDLS, transverse diameter at the lower half of shaft; USC, upper shaft circumference; MSC, mid-shaft circumference; LSC, lower shaft circumference; UEB, upper epiphyseal breadth; EB, epicondylar breadth.

Table 6. Variables selected by the stepwise discriminant function analysis, the best discriminatory variable for group assessment, and the percentage of accuracy for several different populations

Study	Population	No.	Variables selected (stepwise)	Accuracy (%)	Best variable	Accuracy (%)
Steyn and Işcan [10]	South Africans whites (Dart and Pretoria)	104	EB/VDH	92.5	EB	94.7
Steyn and Işcan [10]	South Africans blacks (Dart and Pretoria)	88	VDH/ML	93.1	VDH	96.0
Işcan et al. [32]	Chinese	87	ML/VDH/EB/MSC	86.6	VDH	80.5
Işcan et al. [32]	Japanese	90	EB/VDH/MMSD/MSC	92.4	EB	89.9
Işcan et al. [32]	Thais	104	EB/VDH/MMSD	97.1	EB	93.3
Lee et al. [33]	Koreans	175	ML/VDH	87	VDH	87.0
Ríos Frutos [34]	Guatemalans	118	MDH/MMSD/EB	98.5	MDH	95.5
Mall et al. [9]	Germans	143	ML/VDH/EB	93.2	VDH	90.4
Kranioti and Michalodimitrakis [3]	Cretans	178	ML/VDH/MMSD/EB	92.9	VDH	89.9
Present study (2017)	KwaZulu-Natal's	211	VDH/ML/TDLS/MSC	87.7	VDH	82.5

EB, epicondylar breadth; VDH, vertical head diameter; ML, maximum length; MSC, mid-shaft circumference; MMSD, minimum midshaft diameter; MDH, maximum diameter of the head; TDLS, transverse diameter at the lower half of shaft.

Table 7. Comparison of demarking points with other studies

Study	Population	ML	VDH	MSC
Işcan et al. [32]	Chinese	F<298.65<M	F<42.30<M	F<61.10<M
Işcan et al. [32]	Japanese	F<287.15<M	F<41.60<M	F<61.40<M
Işcan et al. [32]	Thai	F<289.75<M	F<41.20<M	F<57.15<M
Lee et al. [33]	Koreans	F<289.50<M	F<42.70<M	-
Steyn and Işcan [10]	South African whites (Dart and Pretoria)	F<322.20<M	F<46.04<M	-
Steyn and Işcan [10]	South African blacks (Dart and Pretoria)	F<311.35<M	F<40.74<M	-
Kranioti and Michalodimitrakis [3]	Cretans	F<307.39<M	F<43.79<M	F<62.03<M
Present study (2017)	KwaZulu-Natal's	F<307.52<M	F<39.95<M	F<60.92< M

ML, maximum length; VDH, vertical head diameter; MSC, mid-shaft circumference; F, female; M, male.

for both sexes when the four variables VDH, ML, TDLS, and MSC (selected by the stepwise discriminant analyses procedure) are combined giving a combined average accuracy value of 87.7%.

All the variables selected by the stepwise discriminant function analysis were reported (Table 6). The best discriminatory variables and the percentage accuracy for several different populations as well as that of the present KwaZulu-Natal study population is given in Table 6. The demarking points from other studies is also given for comparison (Table 7).

The mean inter-observer correlation coefficient for all parameters combined is 0.982 with the mean intra-observer correlation coefficient for researchers 1 and 2 being 0.989 and 0.987, respectively. All classes of observer errors were much greater than 0.7 indicating a very high degree of correlation. No significant intra and inter-observer errors were found necessitating removal of any of the measured parameters.

Discussion

It is posited that there is no significant ethnic differences in humeral metrics necessitating the use of an entirely new formula for blacks in South Africa. However, it is conceivable that tribal differences will lead to minor variation in certain metrics requiring modification to the existing formulas. This study aimed to investigate the local KwaZulu-Natal population with view to confirming or disproving this. In order to assess if any sex differences exist within a contemporary South Africa population in the region of Kwazulu-Natal province, key metrics for sex discrimination using osteometric standards for the humerus was employed. All of these parameters (ML, VDH, circumference of the head, transverse diameter at the middle of the shaft [TDMS], TDUS, TDLS, upper shaft circumference, MSC, lower shaft circumference, upper epiphyseal breadth, and EB) were investigated as listed in Table 2. The differences in mean of these variables were sig-

nificantly higher in males when compared to females. These findings confirm previous studies on the humerus as reported by several authors [32, 33, 35, 36]. This could be attributed to a more variable lifestyle and differential patterns of physical labour expected of males versus females [37]. Another contributing factor may be as a result of early maturity of females thereby giving males two or more additional years to develop physically [36].

Our results point to the VDH of the humerus as the best single parameter in predicting sex. This agrees with findings from other populations such as the South Africa blacks from the Dart and Pretoria [10], the Chinese [32], the Germans [9], the Cretans [3], and the Koreans [33].

In comparison, the EB of the humerus serves as the better predictor of sex from findings obtained from populations such as the South African whites in Dart and Pretoria [10], the Japanese and Thai [32] populations.

The combined accuracy of variables selected by the discriminant function and the accuracy of the best predictor of sex using the humeral bone is lowest in the present study, and also for the Chinese [32] when compared with other population groups (Table 6). This suggests that patterns of variations exist in humeral dimensions amongst different tribal groups within and amongst the various population groups [15, 38, 39]. However, the variations that occur in parameters investigated in Steyn and Işcan [10] study show for example the demarking point for ML=311.35 and VDH=40.75 (amongst blacks) while this present study shows a demarking point of ML=307.52 and VDH=39.95. This differences appears insufficient similar to making the KwaZulu-Natal a distinct subpopulation within South Africa.

The classification rate for this study using single variables (ML, VDH, MSC, and EB) ranges from 77.3%–83.9%. For comparison, the classification rate is 76.8–81.8%, 79.8%–92.4%, and 87.5%–97.1% in Chinese, Japanese, and Thai populations respectively [32], 84.0%–89.7% and 88.55%–90.95%

in South African whites and black in Dart and Pretoria population respectively [10], 80.6%–90.4% in Germans [9], 86.6%–95.5% in Guatemalans [34], 83.3%–92.90% in Cretans [3], and 74.7%–87.0% in Koreans [33].

The demarking point of the South African whites was higher than that of all other populations compared in two of the selected variables (ML and VDH) as shown in Table 7. The Cretan population has the highest MSC demarking point when compared with other populations.

However in the present study, similarities in the ML demarking point were observed with that of the Cretans (307.52 vs. 307.39) and the South African blacks (307.52 vs. 311.35). Referring to Table 7, the VDH demarking point (present study) is also similar to other studies of South Africa blacks (Dart and Pretoria, 39.75 vs. 40.74). In addition, the Thai and Japanese study show VDH demarking point of 41.20 and 41.60 which is similar to the VDH demarking point of the present study (39.95). The MSC demarking point (present study) is similar to that of the Chinese and Japanese (60.92 vs. 61.10 and 61.40, respectively). We observed a smaller ML demarking point in our study compared with those of South Africa whites (307.52 vs. 322.20) while our ML demarking point appears bigger than those of the Japanese (287.15), Korean (289.50), Thai (289.75), and Chinese (298.65) populations. The differences observed in demarking points may be due to changes in environmental factors that affect bone growth such as lifestyle, nutrition, and extreme division of labour as well as genetic constitution. Experimental variability (sample measurements) is also a possible source or variation although shown to be quite small for most parameters in this study. This study shows a high degree of intra and inter-individual correlation between all the variables in the sample dataset.

Overall however, the changes to the new formula were minor as it incorporated new parameters not investigated by others. Using the new parameters, the overall accuracy rate was increased to 87.7% by stepwise discriminant analysis when all measurements were jointly applied. However, this improvement does not warrant an entirely new formula but minor corrections to the existing ones. The value of this modified formula is that it incorporates these new parameters which may prove useful when presented with fragments of the humerus bone which have only these parameters.

It is clear that population differences affect sexual dimorphism as reflected in humeral dimensions. However, a specific standard for sex determination in the KwaZulu-Natal population in South Africa has been explored which may be useful in forensic investigations.

It should be noted however that less commonly measured parameters (TDUS, TDMS, and TDLS) were used to expand the scope of this study which may bring minor conflicts with the results of other researchers. The value of this study demonstrates that the humerus is a useful bone which can be used for the determination of sex for forensic and other purposes. However in a fragmentary state, its accuracy is limited as at least four of the eleven parameters are needed for satisfactory classification accuracy rates.

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