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Forensic anthropology population data

Discriminant function sexing of the mandible of Indigenous South Africans

Daniel Franklin [a,*], Paul O'Higgins [b], Charles E. Oxnard [a,c], Ian Dadour [a]

[a] Centre for Forensic Science, The University of Western Australia, 35 Stirling Highway, Crawley 6009, Western Australia, Australia
[b] Functional Morphology and Evolution Research Unit, The Hull York Medical School, Heslington, York Y010 5DD, United Kingdom
[c] School of Anatomy and Human Biology, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, Australia

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Abstract

South Africa currently has a high homicide rate. This results in a large number of unidentified bodies being recovered each year, many of which are referred to the forensic examiner. This situation has resulted in considerable growth of forensic anthropological research devoted to devising standards for specific application in South African medico-legal investigations. The standards suitable for Black South Africans now encompass a wide variety of skeletal elements (e.g. cranium, humerus, pelvis, femur, patella, talus, calcaneus), each with differing degrees of accuracy. Apart from a preliminary investigation of the Zulu local population, however, we note that there appears to be no established metric mandible discriminant function standards for sex determination in this population.

The purpose of the present study is to undertake a comprehensive analysis of sexual dimorphism in the mandible of Black South Africans, incorporating individuals from a selection of the larger local population groupings; the primary aim is to produce a series of metrical standards for the determination of sex. The sample analyzed comprises 225 non-pathological mandibles of Black South African individuals drawn from the *R.A. Dart Collection*. Nine linear measurements, obtained from mathematically transformed three-dimensional landmark data, are analyzed using basic univariate statistics and discriminant function analyses. All of the measurements examined are found to be sexually dimorphic; the dimensions of the ramus and corpus lengths are most dimorphic. The sex classification accuracy of the discriminant functions ranged from 70.7 to 77.3% for the univariate method, 81.8% for the stepwise method, and 63.6 to 84% for the direct method. We conclude that the mandible is a very useful element for sex determination in this population.

Keywords: Forensic anthropology; Mandible; Sex determination; Discriminant function analysis; Skeletal biology

1. Introduction

Alongside the determination of age, population affinity ('race') and stature, the diagnosis of sex from the analysis of human skeletal remains is a crucial element in forensic identification. There are a number of factors that facilitate the identification of sex in skeletal remains, among the most important being the efficacy of the available standards and their suitability for assessment of skeletal elements that are often poorly preserved or fragmentary [1]. With regard to sexing standards suitable for South African Blacks, a variety of skeletal elements have been assessed, each with differing degrees of accuracy: crania 68–82.5% [2], 90.6% [3]; viscerocranium 78–91% [4]; humerus 82–93% [5]; pelvis 72–94% [6], 56–87.5% [7]; patella 77.5–85% [8]; talus 80–89% [9]; calcaneus 64–86% [10]. A number of standards have also been devised for South African Whites (e.g. [5–7,11,12]).

In recent years there has clearly been a considerable increase in the number and variety of standards available for the identification of sex in South African individuals. The need for such standards is related to a large number of unidentified bodies being recovered each year in South Africa; the result of increasing violent activities [5,10,11,13]. Currently, however, there appears to be no established metric mandible standards for sex determination of South African Blacks. To this end, we undertook a preliminary investigation of the Zulu local population, which showed that the mandible, in terms of potential sex discriminatory power, is a practical element for forensic analysis [14].

The purpose of the present study, therefore, is to undertake a more comprehensive analysis of sexual dimorphism in the mandible of Black South Africans. By now incorporating

* Corresponding author. Tel.: +61 8 6488 1232; fax: +61 8 6488 7285.
E-mail address: daniel.franklin@uwa.edu.au (D. Franklin).

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individuals from a selection of the larger local population groupings (Zulu, Swazi, Xhosa, Sotho and Tswana), we aim to produce a series of metrical standards for the determination of sex in South African individuals that can be easily applied by forensic anthropologists and medical examiners alike. The samples studied are all drawn from the well-documented *Dart Collection* which was previously noted by Steyn and İşcan [5] to be an ideal source upon which to formulate forensic standards, as it represents a cross-section of a South African population.

2. Materials and methods

2.1. Materials

The skeletal material assembled for the present study is drawn from the *R.A. Dart Collection of Human Skeletons*, housed at the University of the Witwatersrand, Johannesburg. This collection is prepared from dissecting room samples; the sex, local population and a statement of age are thus documented for each skeleton [15]. We examine the mandibles of 225 individuals (120 male; 105 female) drawn from five local populations: Zulu [30♂, 29♀]; Swazi [20♂, 11♀]; Xhosa [25♂, 19♀]; Sotho [28♂, 25♀]; and Tswana [17♂, 21♀]. The stated age ranges are: male 18–69 years (mean 37 years); female 18–70 years (mean 36.5 years).

It is important to note that there is some apparent cranial variation between the local populations (see [16]). The subdivisions between these groups, however, is rapidly disappearing, and this, plus the fact that in forensic situations the local population is usually unknown, means that with regard to sexing criteria the pooled sample is the most appropriate to use. To further justify pooling the local populations, we used a series of regression analyses to test for interaction effects between sex and population in the cranial measurements; no significant interactions were found.

2.2. Methods

The measurements taken from each mandible were abstracted from a data set of 38 three-dimensional (3D) variables acquired using a *Microscribe G2X* portable digitizer; the 3D coordinates were then converted to linear measurements. The conversion formula is a simple extension in three-dimensions of the standard theorem of Pythagoras: $\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$, where $x_1 - x_2$ is the x coordinate difference between any two landmarks, and x, y and z are the three-dimensional landmark coordinates (see [17] for a critique of the validity of this technique).

Landmarks were chosen to correspond to those commonly used in the traditional metrical systems [18,19] and should thus be familiar to most physical and forensic anthropologists. Seven of the nine measurements used in this study employed standard anthropometric landmarks; the two non-standard measurements are symphysis breadth and maximum mandible length (see Table 1 and Fig. 1 for complete description and illustration). Following the calculation of normal descriptive statistics, the measurement data are subjected to a series of cross-validated discriminant function analyses. Statistical analyses are performed using the *Genstat 8.10* and *SPSS 13.0* software programs.

Table 1
Definitions of the landmarks used in the present study (from Franklin et al. [14])

Landmark	Definition
Bilateral landmarks	
Coronion (co)	The most superior point on the coronoid process
Condylion superior (cs)	The most superior point on the mandibular condyle
Condylion laterale (cdl)	The most lateral point on the mandibular condyle
Gonion (go)	The most lateral external point of junction of the horizontal and ascending *rami* of the lower jaw
Lateral infradentale (lid)	The mid-point of a line tangent to the outer margins of the cavities of the lateral incisor and canine teeth
Midline landmarks	
Gnathion (gn)	The middle point on the lower border of the mandible in the sagittal plane
Pogonion (pg)	The most projecting point of the chin in the standard sagittal line
Infradentale (id)	The mid-point of a line tangent to the outer margins of the cavities of the two mandibular central incisor teeth

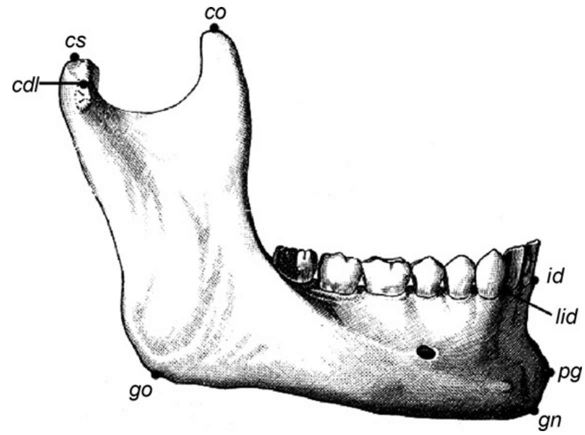

Fig. 1. Mandibular landmarks used in the present study; see Table 1 for key (from Franklin et al. [14]).

3. Results

3.1. Univariate comparisons

The mean and standard deviation for each of the nine measurements recorded in both sexes are presented in Table 2; ANOVA is used to compare mean measurement values. It is evident that males are larger in all dimensions than the females; all of the measurements compared are significantly different (Table 2). The F-statistic values indicate that the mandibular measurements expressing the greatest dimorphism are coronoid and ramus height, maximum length, and bi-gonion breadth (Table 2). A series of demarking points useful for sex differentiation were calculated using the mean of the male and female values for those four variables (Table 3); average accuracies are shown in decreasing order of correct classification.

3.2. Discriminant analysis

3.2.1. Pooled population

In a stepwise analysis of all nine variables, coronoid height, maximum mandible length, and bi-gonion breadth were selected; the accuracy of correct sex classification is 81.8% (Table 4). Five direct discriminant functions were then calculated; discriminant equations, group centroids, sectioning

Table 2
Descriptive statistics and comparisons of mean mandibular measurements

Measurement	Landmarks[a]	Male		Female		*F*-statistic	*P*-value
		Mean	S.D.	Mean	S.D.		
Ramus height	cs–go	56.66	4.94	50.96	3.66	94.20	***
Symphysis height	gn–id	32.91	3.43	30.61	2.87	29.31	***
Coronoid height	co–go	58.50	4.70	52.46	3.66	113.31	***
Bi-gonion breadth	go–go	93.54	5.69	87.06	5.68	72.66	***
Bi-condylar breadth	cdl–cdl	113.67	6.04	108.66	5.84	39.72	***
Symphysis breadth	lid–lid	20.18	1.69	19.47	1.61	10.28	**
Bi-coronoid breadth	co–co	93.16	6.22	87.88	4.40	52.46	***
Corpus length	go–pg	91.63	4.35	87.16	4.42	58.12	***
Maximum mandible length	cs–pg	120.89	4.65	114.85	4.73	92.86	***

Significance: $^{***}P < 0.001$, $^{**}P < 0.01$, $^{*}P < 0.05$, NS: not significant.
[a] Definition of landmarks in Table 1.

Table 3
Demarking points (in mm) for sex differentiation

Measurement	Demarking points	Expected accuracy
Maximum mandible length	♀ < 117.87 < ♂	77.3%
Ramus height	♀ < 53.81 < ♂	73.8%
Coronoid height	♀ < 55.48 < ♂	73.3%
Bi-gonion breadth	♀ < 90.30 < ♂	70.7%

points and cross-validated classification accuracies are shown in Table 5. Discriminant scores are obtained by multiplying each variable with its *unstandardised coefficient*, summing them and adding in the constant; scores greater than the sectioning point are classified as male—smaller values as female.

From Table 5 it is evident that the direct analysis of all nine variables provided the highest accuracy of correct sex classification (84%). Function 2, employing the four variables that in combination contribute the most to sex discrimination, was the next best (82.7%). The remaining functions are designed to be applied in cases of fragmentary bones; it is evident that expected classification accuracy ranges from 79.6% (unilateral) to a relatively low 63.6% (symphysis only).

3.2.2. *Individual local populations*

To assess the degree of variation in mandibular dimorphism between the five local populations comprising the pooled sample, each individual population was subjected to a stepwise analysis of all nine measurements; the variables selected and the classification accuracy for each function are shown in Table 6. The accuracy of correct sex classification ranges from 77.3% (Xhosa) to 90.3% (Swazi). It is evident that different combinations of variables are selected in each function; coronoid height was the best sex discriminator in three out of the five populations (Table 6).

4. Discussion

The determination of sex is one of the first, and most crucial, steps in the identification of unknown remains. In this study we used a documented Black South African sample to formulate a series of metrical sexing standards for this population. We selected the mandible for analysis for two simple reasons: firstly, there appears to be a paucity of standards utilizing this element (see Section 1); and secondly, this bone is often recovered largely intact (or complete enough to yield diagnostic fragments) compared to other more porous and less dense elements (e.g. scapula, sternum, vertebrae and foot bones) [20–22].

All of the nine variables examined were significantly different between the sexes; the most dimorphic measurements were coronoid height, ramus height and maximum length. The variables of least use for discrimination were the breadth and height measurements of the symphysis (Table 2). In one of the most comprehensive studies of sexual dimorphism in Black South African populations, de Villiers [18,23] similarly found that coronoid and ramus heights expressed the greatest univariate dimorphism; symphyseal height was the second least dimorphic measurement out of the 15 mandibular variables examined.

In considering the relative dimorphism of different regions of the mandible, it was demonstrated in an extensive study of

Table 4
Stepwise discriminant function analysis[a]

Step	Variables	Unstandardised coefficient	Standardised coefficient	Wilk's lambda	Structure point	Group centroids	Sectioning point	Correctly assigned
1	crh	0.136	0.578	0.578	0.758	♂ 0.875	−0.0625	81.8%
2	ml	0.096	0.450	0.450	0.687	♀ −1.000		
3	gogo	0.073	0.417	0.417	0.607			
	Constant	−25.533						

[a] Key to measurements in Table 5.

Table 5
Direct discriminant functions

Equation[a]	Group centroids and sectioning point	Correctly assigned
Function 1: all variables		
(rh × 0.095) + (h^1 × 0.059) + (crh × 0.080) + (gogo × 0.050) + (w^1 × −0.004) + (syb × 0.045) + (crcr × 0.037) + (cl × 0.093) + (ml × −0.019) + −25.805	♂ 0.928, [−0.066], ♀ −1.061	♂ 100/120; ♀ 89/105 [84%]
Function 2: four 'best' variables[b]		
(crh × 0.141) + (gogo × 0.067) + (ml × 0.069) + (cl × 0.042) + −25.876	♂ 0.883, [−0.063], ♀ −1.009	♂ 98/120; ♀ 88/105 [82.7%]
Function 3: unilateral		
(rh × 0.091) + (h^1 × 0.068) + (crh × 0.112) + (cl × 0.120) + (ml × −0.005) + −23.381	♂ 0.864, [−0.062], ♀ −0.988	♂ 94/120; ♀ 85/105 [79.6%]
Function 4: ramus only		
(rh × 0.104) + (crh × 0.155) + −14.243	♂ 0.713, [−0.051], ♀ −0.815	♂ 83/120; ♀ 86/105 [75.1%]
Function 5: symphysis only		
(h^1 × 0.272) + (syb × 0.320) + −15.016	♂ 0.398, [−0.028], ♀ −0.455	♂ 75/120; ♀ 68/105 [63.6%]

[a] rh: ramus height, h^1: symphysis height, crh: coronoid height, gogo: bi-gonion breadth, w^1: bi-condylar breadth, syb: symphysis breadth, crcr: bi-coronoid breadth, cl: corpus length, ml: maximium mandible length.
[b] Assessed using MANOVA; minimization of Wilks' lambda as selection criteria.

Table 6
Sexing accuracy for population specific stepwise discriminant function analyses

Population	Variables[a]	Correctly assigned
Zulu	crh; gogo; cl; ml	♂ 26/30; ♀ 26/29 [88.1%]
Swazi	w^1; cl	♂ 18/20; ♀ 10/11 [90.3%]
Xhosa	crh; gogo	♂ 18/25; ♀ 16/19 [77.3%]
Sotho	rh	♂ 22/28; ♀ 20/25 [79.2%]
Tswana	crh; b^1	♂ 14/17; ♀ 17/21 [81.6%]

Key to measurements in Table 5.
[a] Listed in relative order of contribution to sex discrimination.

human and great ape mandibles [24] that the sites associated with the greatest morphological changes in size and remodelling during growth (the condyle and ramus in particular) are generally the most dimorphic. Further, the relative development (size, strength and angulation) of the muscles of mastication is also known to influence the expression of mandibular dimorphism [25,26]. The primary masticatory muscles (e.g. *masseter*, *temporalis*, *medial* and *lateral pterygoids*) all have insertion points on the ramus, condyle and coronoid process; muscles in the region of the symphysis (e.g. *mentalis*, *orbicularis oris*) are considerably less powerful and have only auxiliary roles (e.g. positioning of food) in mastication (see also [14]).

In the stepwise discriminant analysis, three variables were selected from the nine entered, with an expected accuracy of 81.8% (Table 4); those three variables are amongst the best sex discriminators (Table 2). Subsequent direct discriminant functions showed that the mandible can be used to predict sex with expected classification accuracy ranging from 63.6 to 84% (Table 5). In general, the sex classification accuracy of the functions presented in this study are comparable to similar studies made on different populations: e.g. Giles [27] 83–87%; Steyn and İşcan [28] 81.5%; Hanihara [29] 85%. The level of sex classification accuracy of the present study is slightly higher than what we achieved using 8 cranial measurements on the same sample population (68–82.5%) [2]; de Villiers [23] similarly found the mandible to be more dimorphic than the cranium in this population.

With regard to the individual local populations, it is evident that classification accuracy, and the combinations of discriminating variables selected, varies between each (Table 6). This demonstrates a degree of variability in the relative expression of sexual dimorphism between the local populations, a phenomenon also observed in the crania of the same basic population sample [30]. In comparison to our preliminary study, stepwise classification accuracy of the Zulu population has dropped from 92.5 to 88.1%, albeit still high, and with a sample now comprising 19 extra individuals. Clearly, however, both the Zulu and Swazi exhibit particularly strong mandibular dimorphism compared to the other local populations (Table 6). The lowest classification accuracy of the local populations is for the Xhosa; this population also had the lowest classification accuracy based on cranial data (Xhosa 76%; Sotho 82%; Zulu 82.5%, Franklin et al. [2] p. 223).

5. Conclusion

Although there are clearly a wide variety of South African standards for sex determination, their applicability is dependent upon the accuracy of the available standards and the preservation of the recovered material. This study has outlined strong evidence suggesting that the mandible is a suitable element, both in terms of resistance to damaging taphonomic processes, and potential sex discriminating power, for forensic analysis in Black South African populations. Although some degree of variation was found between the individual local populations, the subdivisions within South African populations are rapidly disappearing. Also, in forensic cases, the local population of a recovered individual is usually unknown, thus the pooled sample functions are the most appropriate to use.

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