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ORIGINAL ARTICLE

Sex discrimination from the glenoid cavity in black South Africans: morphometric analysis of digital photographs

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Abstract Given that skeletal material recovered from medicolegal contexts is often incomplete or damaged, forensic anthropologists need to have a variety of techniques at their disposal in order to correctly determine the sex of unidentified human remains. The purpose of the present study, therefore, was to produce practical standards for discriminating the sex of black South Africans using measurements of the glenoid cavity of the scapula. Standardized digital photographs of the left glenoid fossa were taken for 60 males and 60 females drawn from the Pretoria Bone Collection. An image analysis software program was then used to collect height, breadth, area, and perimeter data from each digital photograph. All four dimensions of the glenoid cavity were highly sexually dimorphic in this population group ($p<0.0001$). Univariate logistic regression analysis yielded overall sex prediction success rates ranging from 88.3% for area of the glenoid fossa to 85.8% for glenoid fossa breadth. Multivariate procedures did not provide increased accuracy over those using only a single variable. Classification sex biases were below 5.0% for all equations. These results demonstrate that the analysis of glenoid cavity size provides a highly accurate method for discriminating the sex of black South Africans.

Keywords Sex determination · Scapula · Glenoid cavity · Logistic regression analysis · South Africa

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Introduction

Human skeletal material recovered from medicolegal contexts is often incomplete or damaged due to numerous taphonomic processes, such as dismemberment, burning, and carnivore activity. Forensic anthropologists, therefore, need to have a variety of techniques at their disposal in order to correctly determine the sex of unidentified remains. In South Africa, population-specific osteometric standards for sex determination have been developed for the cranium [1, 2], mandible [3, 4], pelvis [5], humerus [6], radius and ulna [7], femur [8, 9], patella [10], talus [11], and calcaneus [12] of indigenous (black) South Africans with varying rates of accuracy. Currently, however, there is no established technique for estimating sex from scapular dimensions in this ancestral group, although previous studies have shown that metrical analysis of this bone provides an effective method for discriminating sex in diverse populations.

As recently summarized by Dabbs [13, 14], Dwight [15] was the first to report on the sex discrimination potential of the scapula. In that study, Dwight suggested that both maximum length of the scapula and glenoid fossa height can be utilized in sex estimation, although he did not provide statistical analyses to support his assertions. Subsequently, Hanihara [16] applied multivariate discriminant function analysis to modern Japanese scapulae and found that between 94.1% and 96.8% of the study population could be sexed correctly using varied combinations of glenoid and scapular blade dimensions. More recently, Di Vella et al. [17] examined scapular measurements among contemporary southern Italians and achieved a maximum classification accuracy rate of 95.0%, while Dabbs and Moore-Jansen [14] reported a similar value of 95.7% for a sample of late nineteenth and twentieth century white and black Americans from the Hamann-Todd collection. Additional studies for other disparate populations, including prehistoric New Zealand Polynesians [18], contemporary indigenous Guatemalans [19], and medieval Anatolians [20], have also provided sex prediction success rates for the scapula ranging from 82.9% to 95.0%, utilizing both multivariate and univariate discriminant function analysis.

Given the success of the abovementioned studies, the purpose of the present investigation was to produce practical standards for discriminating the sex of black South Africans using measurements of the glenoid cavity of the scapula. The glenoid fossa in particular, and not the entire bone, was selected for analysis given that this structure is more likely to survive in an undamaged condition than the thinner scapular blade [21–23]. In addition, previous studies have demonstrated that dimensions of the glenoid fossa are highly sexually dimorphic for diverse population groups [14, 19, 20, 22]. Furthermore, height or breadth of the glenoid cavity is often selected in stepwise discriminant function analyses [14, 17, 20], indicating that these dimensions are among the most diagnostic scapular variables for sex assessment. Finally, glenoid surface area is correlated with humeral head size, which has been shown to be one of the most accurate non-pelvic skeletal structures for estimating sex in black South Africans [6].

Materials and methods

The present study examines the left scapula of 120 black South Africans (60 males, 60 females) obtained from the Pretoria Bone Collection, housed in the Department of Anatomy, School of Medicine, Faculty of Health Sciences at the University of Pretoria. The specimens in this documented skeletal series mainly derive from unclaimed bodies at public hospitals which were used in medical training and research [24]. The age-at-death for the selected sample ranged between 22 and 68 years, with a mean age of 41.9±11.4 years for males and 44.7±12.2 years for females (Table 1). The dates of death for these individuals ranged from 1994 to 2001 in males and 1961 to 2001 in females. Only specimens with an intact and well-preserved glenoid fossa were included in the investigation.

The process of measuring photographs (photogrammetry) has been routinely used in odontological studies of fossil and modern humans for several decades, and is now being employed in bioarchaeological and forensic investigations concerning other anatomical structures as well. This methodology, for example, has been used in sex determination studies of the hyoid bone [25], acetabulum [26], and most recently the sacrum [27]. The abovementioned analyses have demonstrated that it is possible to use photogrammetry to collect linear measurement data comparable to that obtained using conventional anthropometric instruments. In addition, photogrammetric analysis allows for precise measurement of sexually dimorphic variables, such as area and perimeter dimensions, not easily acquired using traditional metric methods [27].

Table 1 Sex and age-at-death distribution of the utilized sample

	n	Mean	SD	Median	Minimum	Maximum
Male	60	41.9	11.4	40.0	26	65
Female	60	44.7	12.2	42.5	22	68

In this study, standardized high-resolution photographs of the glenoid cavity were obtained for each specimen using a digital camera (Nikon Coolpix S610). In order to photograph the bone, the vertebral (medial) border of the scapular blade was placed in a bed of fine sand with the glenoid process facing upwards. Thus positioned, the glenoid cavity was oriented so as to maximize the projected area as seen by the camera. A 10-mm scale, resting within the glenoid fossa, was included in each photograph for calibration. The camera was mounted on a tripod with the lens at a distance of approximately 250 mm from the glenoid surface, and a leveling device was used to maintain a consistent camera angle (Online Resource 1). The camera's LCD monitor was used to compose the image and control for camera parallax.

The digital photographs were subsequently uploaded to a personal computer, calibrated, and measured on-screen using NIH ImageJ, a public-domain image analysis software program distributed freely by the National Institutes of Health, USA (http://rsb.info.nih.gov/ij/). Calibration was accomplished by using the program's set scale function and the millimeter scale present in each image. The following four measurements were then recorded from the digital photographs utilizing the polygon, straight line, and freehand line tools within the NIH ImageJ program (Fig. 1):

- Height of the glenoid cavity: maximum distance across the glenoid cavity perpendicular to the anteroposterior axis, recorded to the nearest tenth of a millimeter (0.1 mm).
- Breadth of the glenoid cavity: maximum distance across the glenoid cavity measured at a right angle to the axis of the length of the glenoid cavity, recorded to the nearest tenth of a millimeter (0.1 mm).
- Area of the glenoid cavity: total area within the enclosed profile of the glenoid fossa, recorded to the nearest tenth of a square millimeter (0.1 mm^2).
- Perimeter of glenoid cavity: length of the enclosed profile of the glenoid fossa, recorded to the nearest tenth of a millimeter (0.1 mm).

In order to determine the accuracy of the measurements obtained from the digital photographs, the values for height

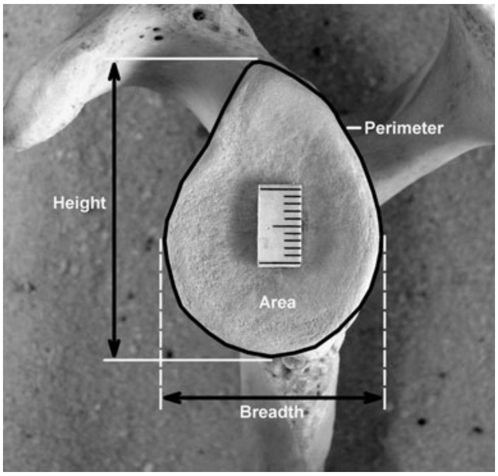

Fig. 1 Image of the glenoid cavity illustrating the four dimensions recorded from digital photographs (*scale bar* in millimeters)

and breadth of the glenoid cavity recorded from the digitized images were compared to those taken directly on the specimens using sliding calipers. The results of paired-sample t tests demonstrate that there is no significant difference between the two measurement techniques (height: $t=-0.982$, $p=0.328$; breadth: $t=-0.168$, $p=0.867$). To assess measurement precision associated with the photogrammetric process (specimen orientation, image capture, calibration, and measurement), the entire data recording procedure was repeated five times for five randomly selected specimens from the study sample. There was no indication of systematic methodological errors in recording glenoid dimensions from digital images, as revealed by repeated-measures ANOVA (height: $F=0.583$, $p=0.680$; breadth: $F=0.320$, $p=0.860$; area: $F=2.051$, $p=0.135$; perimeter: $F=1.298$, $p=0.313$).

Subsequent to data collection, the correlation between age-at-death and glenoid dimensions within each sex was evaluated, as it is possible that the size of the glenoid fossa may change during the aging process in either males or females, thus influencing the degree of sexual dimorphism exhibited by this skeletal structure in this population group. A recent study, for example, has demonstrated that several long bone dimensions in black South Africans exhibit an increase in size with advancing age [28]. In the current study, Pearson correlations between age-at-death and all glenoid dimensions were not significant ($p>0.05$) for either males or females and ranged from $r=0.019$ (height in females) to $r=0.185$ (area in males). This suggests that any sexual dimorphism observed in the utilized sample is independent of age-at-death, and thus it is not necessary to include age as a variable in the logistic regression analyses (see below).

Descriptive statistics including the mean and standard deviation, as well as maximum and minimum values, were then computed for each dimension. After establishing that highly significant differences exist between male and female mean values for all four variables, binary logistic regression analysis was performed with SPSS Version 14.0 for Windows. Binary logistic regression analysis, like discriminant function analysis, can be used to predict a dichotomous dependent variable (e.g., group membership) from a set of continuous independent variables [29], such as osteometric data. Logistic regression analysis was employed in the current investigation as this method generally performs as well as or better than discriminant function analysis with fewer statistical assumptions when predicting sex, and the resulting score used to classify an unknown individual also provides a probability value for the allocation [30–35]. Initially, a binary logistic regression procedure utilizing the direct method and incorporating all four glenoid dimensions was conducted. In direct analysis, each of the predictor variables (measurements) is entered into the model at the same time. Next, a forward stepwise approach, also considering all four glenoid dimensions, was performed in order to define a model that best discriminates between males and females. In forward stepwise analysis, all predictive variables are systematically added one at a time. The process starts by defining a model with a single variable that aids in prediction of the dependent variable (i.e., the p value of its regression coefficient is <0.05). Then a second model is generated by adding another variable which is retained if it aids in prediction ($p<0.05$). Subsequently the first variable may be removed if deemed no longer important ($p>0.10$). This process of additions, and if necessary removals, continues until all variables have been explored and the final best model is defined. Finally, univariate logistic regression equations were generated, through the direct method, for each of the measurements included in the study.

Results

The descriptive statistics for measurements of the glenoid cavity for both males and females are provided in Table 2. As mentioned above, results of independent-sample t tests show that the difference between male and female mean values for all dimensions are highly significant ($p<0.0001$), indicating the presence of strong sexual dimorphism in the size of the glenoid fossa for this population group.

The logistical regression equations derived from both stepwise and direct methods, as well as associated correct classification accuracies, are presented in Table 3. The sex of a specimen can be determined from these formulae by multiplying the value of each dimension with its corresponding coefficient (β) and adding the products together along with the appropriate constant. For example, for the regression equation incorporating all four glenoid dimensions the logistic regression score (y) is calculated

Table 2 Descriptive statistics for measurements of the glenoid cavity taken from digital photographs

Variable	Males (n=60)				Females (n=60)				t values*
	Mean	SD	Min	Max	Mean	SD	Min	Max	
Height	38.21	1.90	34.2	41.7	33.87	1.92	30.1	38.7	12.465
Breadth	27.02	1.82	21.5	30.3	23.59	1.45	19.7	27.4	11.370
Area	759.76	76.91	550.6	888.3	595.81	60.40	469.9	767.2	12.987
Perimeter	103.04	5.38	89.4	112.2	91.13	4.73	80.9	103.5	12.890

*All significant at $p<0.0001$

as follows: $y = (-0.572 \times height) + (-0.292 \times breadth) + (-0.026 \times area) + (0.217 \times perimeter) + (24.352)$. Individuals with scores greater than the 0.5 sectioning point are classified as male, while individuals with scores less than 0.5 are classified as female. The closer the value is to 1, the greater the probability that the specimen is male, while a value closer to 0 indicates a greater probability of the specimen being female.

The overall classification accuracies for the univariate regression equations ranged from 88.3% for area of the glenoid cavity to 85.8% for glenoid cavity breadth. Intermediate values were obtained for height and perimeter measurements (87.5% and 86.7%, respectively). Allocation accuracy rates did not improve when multiple dimensions were incorporated into the logistic regression analysis. For example, the inclusion of height, breadth, and perimeter in combination with area of the glenoid cavity yielded the same prediction percentage (88.3%) as that of area when used in isolation. Likewise, in the stepwise approach only area of the glenoid cavity was selected, thus producing a classification accuracy rate (88.3%) identical to that obtained for the univariate analysis. The sex biases of these regression formulae are low (0.0% to 5.0%) with slightly greater accuracy in females than in males for the majority of functions.

Discussion and conclusion

In the present study, digital photogrammetric methods were utilized to collect height, breadth, area, and perimeter measurements of the glenoid cavity for a black South African sample. The resulting dataset was then subjected to logistic regression analyses in order to develop population-

Table 3 Logistic regression equations and classification accuracies for glenoid cavity dimensions

Variable(s)	ß coefficient	Standard error	Sectioning point	Correctly classified (%)			Sex bias (%)[a]
				Males	Females	Overall	
Stepwise[b]							
Area	−0.031	0.006	0.5	86.7	90.0	88.3	−3.3
Constant	21.012	3.783					
Direct							
Height	−0.572	0.586	0.5	88.3	88.3	88.3	0.0
Breadth	−0.292	0.512					
Area	−0.026	0.035					
Perimeter	0.217	0.479					
Constant	24.352	21.956					
Height	−1.032	0.179	0.5	86.7	86.7	86.7	0.0
Constant	37.164	6.419					
Breadth	−1.196	0.215	0.5	83.3	88.3	85.8	−5.0
Constant	30.101	5.393					
Area	−0.031	0.006	0.5	86.7	90.0	88.3	−3.3
Constant	21.012	3.783					
Perimeter	−0.411	0.073	0.5	85.0	90.0	87.5	−2.5
Constant	39.758	7.063					

[a] Sex bias%=% males correctly classified−% females correctly classified

[b] Variables not selected: height, length, and perimeter of glenoid cavity

specific standards for discriminating sex. The derived univariate regression equations yielded correct classification accuracy rates ranging from 85.8% for glenoid fossa breadth to 88.3% for area of the glenoid fossa. A multivariate model incorporating all four scapular dimensions also achieved an overall sex prediction success rate of 88.3%. However, the sex bias ratio for this equation is zero (males and females were equally well classified), which is a slight improvement over the value observed for area alone (3.3%). The results of this study, therefore, demonstrate the high discriminatory value of the glenoid cavity for determining the sex of an unknown individual in this population.

The results also suggest, however, that osteometric data, such as area and perimeter dimensions, derived from digital photographs may not be necessary for accurate sex prediction from the glenoid cavity in black South Africans. As mentioned, the most effective logistic regression equation developed in the present investigation was for area of the glenoid fossa. In addition to the measured value employed in this study, area of the glenoid cavity can also be calculated as the product of linear height and breadth dimensions ($area = height \times breadth$) for a given specimen. This calculated variable was subsequently computed for each individual in the study sample, and a univariate logistic regression procedure was conducted for the additional set of values. As can be observed in Table 4, the new regression equation produced an identical classification accuracy rate as that reported for measured area of the glenoid cavity (Table 2). Given that equivalent height and breadth (and thus area) dimensions can be obtained using conventional measuring techniques, such as sliding calipers, this result indicates that digital photogrammetry is not required to make use of the sex discriminatory ability of the glenoid fossa in this ancestral group.

The classification accuracies for dimensions of the glenoid cavity obtained in the present study are comparable to the results provided in the literature for disparate populations. For a southern Italian sample, Di Vella et al. [17] demonstrated a sex prediction success rate of 90.0% for the combination of height and breadth dimensions using multivariate discriminant function analysis. Frutos [19] reported an identical value in his study of indigenous Guatemalans, with univariate discriminate function equations yielding 90.0% classification accuracy for both height and breadth of the glenoid fossa. Likewise, Özer et al. [20] examined the scapulae of medieval Anatolians and achieved an accuracy of 90.0% for glenoid height and 88.0% for glenoid breadth, employing univariate discriminant function analysis. Murphy [18] obtained similar results for a prehistoric Polynesian sample from New Zealand, with multivariate discriminant functions based on height and breadth dimensions of the glenoid fossa yielding classification accuracy rates of 86.5% and 93.6% for the left and right scapula, respectively. The abovementioned results clearly demonstrate that the glenoid cavity of the scapula is sufficiently dimorphic to provide an effective method for discriminating sex, not only in black South Africans, but in other geographically and ethnically diverse groups as well.

It should be mentioned that in addition to logistic regression analysis, the dataset utilized in the present investigation was also subjected to discriminant function analysis (not reported) as this statistical method has most often been used in metric sex determination studies, including those of the scapula. The discriminant functions derived in this study yielded higher overall classification accuracies compared to those provided by the regression analysis for four out of the six equations listed in Table 2; however, the difference between allocation rates was less than 1.0%. In addition, the discriminant functions were associated with larger classification sex biases, ranging from 1.6% to 13.3% (an average increase of 5.1%). Therefore, based on these results, logistical regression analysis appears to be the better method for the present dataset given its ability to make sex determinations that have both high classification accuracy rates and low sex bias ratios.

In conclusion, the results of the present study demonstrate that the analysis of glenoid cavity size, utilizing digital photogrammetry or conventional measuring techniques, provides a highly accurate method for discriminating the sex of black South Africans. Univariate and multivariate logistic regression analyses yielded overall sex prediction success rates ranging between 85.8% and 88.3%, with sex biases below 5.0% for all equations. These standards may be

Table 4 Logistic regression equation and classification accuracy for calculated area of the glenoid cavity

Variable	ß coefficient	Standard error	Sectioning point	Correctly classified (%)			Sex bias (%)[a]
				Males	Females	Overall	
Area[b]	−0.022	0.004	0.5	86.7	90.0	88.3	−3.3
Constant	19.805	3.576					

[a] Sex bias%=% males correctly classified−% females correctly classified

[b] $Area = height \times breadth$ of the glenoid cavity

particularly useful in forensic cases in which the skeletal remains of an individual are incomplete or damaged and thus more accurate bones such as the pelvis or cranium are absent. However, until additional studies have demonstrated their applicability, the sex discriminating formulae devised in this investigation should only be applied to the indigenous South African population.

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Conflict of interest The authors declare that they have no conflict of interest.

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