NON-METRIC SEX DETERMINATION FROM THE DISTAL AND POSTERIOR HUMERUS IN BLACK AND WHITE SOUTH AFRICANS

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ABSTRACT

The successful identification of human skeletal remains relies on proven diagnostic techniques for sex determination. This research utilized 608 individuals from South Africa (420 males, 188 females) to conduct a blind non-metric determination of sex from three features of the distal humerus; olecranon fossa shape, angle of the medial epicondyle, and trochlear extention. A scoring system between males and females was implemented, and the aggregate score of the three features determined the estimated sex of the skeletal element in question. With all features combined, black and white South Africans were categorized successfully as either male or female 75.5% (77% accuracy rate for females, 74% accuracy rate for males). This classification rate is lower than what was found in previous studies, but suggests that characteristics of the distal humerus are still quite valuable when estimating skeletal sex. More research is needed to assess reasons for the differential expression of these traits in different populations, and to determine if the method is non-population-specific.

Key words: forensic science, forensic anthropology, sex determination, distal humerus, sexual dimorphism, South Africa

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Figure 1a: Triangular olecranon fossa shape observed in males. Fig 1b: The oval olecranon fossa shape in females.

Figure 2a: Angle of the medial epicondyle observed in males. The angle appears parallel to the table on which the humerus rests. Fig 2b: Angle of the medial epicondyle observed in females. The angle appears to project upwards from the table on which the humerus rests.

Figure 3a: Trochlear extension observed in males. The trochlea extends well past the margin of the capitulum. Figure 3b: Trochlear extension/ relative symmetry observed in females. The trochlea is more symmetrical with the margin of the capitulum.

Sexual dimorphism, or the characteristic physical differences expressed between males and females, can be used to further medico-legal (forensic) and osteological investigations (1-9). Non-metric (visual) differences between males and females manifest themselves in numerous arrangements throughout both the axial and appendicular skeleton with the cranium and pelvis being the most reliable indicators of skeletal sex. For example, when researchers recover remains that include an intact cranium and pelvis, visual morphological interpretation can be quite accurate for assigning a specific sex to the remains. Other post-cranial skeletal elements can be used as well, and are utilized consistently when cranial and pelvic bones are absent or fragmentary (10, 11, 12). New and innovative non-metric techniques in establishing skeletal sex of unknown remains continue to be a subject worthy of exploration, and researchers have continued to search for more comprehensive, precise and accurate methods of sex determination to augment existing practices.

The metric characteristics of the humerus have been studied frequently in order to set standards for the determination of sex (13-18), and have in general provided high classification accuracies. This indicates that size differences exist between male and female humeri. Morphological differences of the distal humerus have also been studied, but to a lesser extent (19-23). The elbow joint is known to be sexually dimorphic due to differences in the carrying angle of the articulated humerus, radius and ulna (24, 25, 26). The lateral deviation of the human forearm from the axis of the humerus is distinctive between males and females, and each sex forms deviating angles that can be construed as sexually dimorphic (10 to 15 degrees in males, 20 to 25 degrees in females, Rogers [19]).

The differences in the carrying angles between males and females imply that other observable differences may also exist in the distal humerus, which have been demonstrated in a recent study by Kranioti *et al.* (21). These authors used geometric morphometrics to study shape differences in the proximal and distal ends of the humerus. They found that in females, the greater tubercle of the humerus is smoother, with a less pronounced superior border. Females have a relatively squared distal epiphysis, whereas those of males are more rectangular. Males tend to have relatively shorter humeri with more voluminous distal epiphyses. They also have a relatively wider lateral trochlea and smaller capitulum.

Visual differences in the distal humerus have been used by Rogers (19) who ultimately employed four characteristics to develop a new method of determining sex, with average accuracies ranging from 74 to 91%. When using a combination of characteristics, accuracies of up to 94% were obtained. In addition, Rogers (20) assigned sex to juvenile and adolescent humeri with 80% accuracy in males and 82% accuracy in females. These results indicate that the carrying angle of the arm and its distinct features related to the distal humerus develop early and may be independent of activity level or occupational stressors, which could, in adulthood, modify the morphology of this portion of the humerus.

The aim of this study was to use morphological characteristics of the distal humerus in order to test their usability to determine the sex of unknown skeletal remains from South Africa. Because post-cranial elements such as the humerus tend to survive in the field quite well, the understanding of sexually dimorphic characteristics in this element would benefit forensic anthropologists and osteologists alike. Thus, if the morphology of the distal humerus can be used to determine sex, it would compliment the already existing standards for osteometric determination of sex with this skeletal element.

Methods and Materials

The skeletal sample in this study originated from the Pretoria Bone Collection at the Department of Anatomy, University of Pretoria (27) and the Raymond Dart Collection at the University of Witwatersrand (28). Ages within the sample ranged from 19 to 94 (mean age for males 56 years, mean age for females 53 years). The humeri of 420 adult males and 188 adult females were used in this study. Unfortunately this uneven sex distribution is typical of many modern skeletal collections obtained from cadavers (27). The sample included a random collection of both white and black South Africans of all socio-economic backgrounds.

Three visual indicators of sex in the distal and posterior humerus were used to determine skeletal sex. They were previously defined by Rogers (19) as “angle of the medial epicondyle” “olecranon fossa shape”, and “trochlear extension” (Table 1, Figures 1 – 3). Trochlear constriction, a fourth characteristic used by Rogers, was discarded early on in this analysis as it was difficult to score consistently and yielded poor results. Data on left humeri were used for analysis.

A 5-graded scoring system was employed to categorize individuals as either “male” or “female” in morphology. The designation of a [1] or a [2] indicated a male specimen, with [1] being clearly male and [2] being cautiously male. A score of [3] was considered ambiguous, and [4] as cautiously female and [5] as distinctly female. The combined total of the numerical values were used to make an estimation of sex as a whole. A particular humerus could therefore have a maximum score of 15, being hyper feminine. A total score of 3 through 8 was diagnosed as male, 9 as ambiguous, and 10 to 15 as female. The percentage of males and females correctly classified, incorrectly classified and ambiguous were then calculated.

An independent observer was utilized to determine if the non-metric characteristics of the distal humerus were apparent enough to reproduce accurate statistical results. The intra-observer subject was tasked assess 11 male specimens and 20 female specimens, using the physical characteristic criteria of the distal and posterior humerus provided.

Results

Table 2 documents the overall accuracy of skeletal sex determination from the distal and posterior humerus. All specimens exhibiting a majority of male characteristics were placed in the table under scores 3-8 (M). Specimens with scores indicating female characteristics were categorized as female and placed in the table under scores 10-15 (F). Some specimens exhibited an equal number of male and female characteristics, and were ultimately categorized as score 9, or ambiguous.

Table 3 shows the detailed performance of each of the three characteristics, using the original 5 point scale. When taken in isolation, the angle of the medial epicondyle was seen as the most accurate trait with 70% classification accuracy in males (scores of 1 and 2 combined) and 55% in females (scores of 4 and 5 combined). The olecranon fossa shape was the next most accurate trait (57% accuracy in males, 61% accuracy in females), while trochlear extension proved the least accurate of the three traits observed (45% accurate in males, 56% accurate in females). Clearly a combination of the characteristics gave better results than any single characteristic. Females were scored more accurately in all traits, and male specimens were more often misclassified as females than their female counterparts were misclassified as males.

Originally, trochlear constriction was also included in the assessment. When this trait was incorporated, males were classified with an accuracy rate of 62% (in contrast to 74% with three characteristics), and female estimated sex was accurate at 72% (in contrast to 77% with three characteristics). The removal of the trait trochlear constriction from the data thus allowed for the correct assignment of a total of 60 otherwise ambiguous or misclassified cases. The three remaining humeral traits resulted in the classification of skeletal sex being equivalent to other anthropological methods used for non-metric sex determination.

An independent observer was utilized to determine if the non-metric characteristics of the distal humerus could be scored consistently. This observer's accuracy rate with each trait in isolation was consistent with that of the original researcher; the independent observer categorized the angle of the medial epicondyle correctly more often than the other two traits used (olecranon fossa shape and trochlear extension). When asked to ascertain a final determination of sex from the distal humerus based on the combination scoring for all three traits, the independent observer was 91% accurate with male humeri and 75% accurate with female humeri.

Discussion

In this study, traits from the distal and posterior humerus were used to determine sex. Morphology of the elbow joint has shown sexually dimorphic traits due to more distinct valgus angulation in females in comparison to males (26). The lateral deviation of the human forearm from the axis of the humerus is distinctive between males and females, being about 10 to 15 degrees in males and 20 to 25 degrees in females (19). The soft tissue anatomy of the ulnar collateral ligament (which originates on the medial epicondyle and inserts on the medial aspect of the coronoid process of the ulna) as well as the hard tissue anatomy of the trochlear spool changes this carrying angle during elbow flexion. Hard tissue morphology relating to the ulnar collateral ligament and the trochlear spool should therefore exhibit differences between males and females which have been presented here. The medial epicondyle is obviously the origin of ligaments that preserve the carrying angle; the olecranon fossa shape is the receptacle for the olecranon process superiorly, and is connected to the coronoid process inferiorly; and trochlear extension is an expansion of the trochlear spool and the articulation between the trochlea and the coronoid process. All of these anatomical soft tissue characteristics correlate to hard tissue characteristics, and should be sexually dimorphic.

Average accuracies of 75.5% obtained in this study were lower than those reported by Rogers ([19], average 88.6% accuracy), and also those found in the study by Wanek ([23], average 84% accuracy). Similar to both previous approaches, the features of the distal and posterior humerus were combined in order to obtain the best possible results. The Rogers (19) study found 100% accuracy for females and 85.7% accuracy for males (average 88.6%) when using a combination of characteristics. These accuracies increased to 94% (93% for males) when the olecranon fossa shape was used in indeterminate cases. When employing geometric morphometrics to assess differences in the distal humerus, Kranioti *et al.* (21) found 74.2 – 89.7% accuracy in sex determination for a Cretan population. However, shape differences alone provided a 74.2% accuracy which is comparable to the results from this study.

Generally speaking, methods yielding accuracies above 80% are regarded as usable (19). Results from our study thus indicate that shape differences in the distal humerus may be usable but would not be a method of choice if other remains are available. Regardless, traits of the humerus were expressed as reasonably sexually dimorphic and comparable with other anthropological methods used for visual or metric sex classification (19, 23, 29-32).

Several possible reasons exist for the observed differences in accuracies. As the sample size in this study is quite large, the variation present increased and thus ultimately resulted in lower classification accuracies. It is possible that the South African population may be less sexually dimorphic in this anatomical location, but it may also simply be that these characteristics are not so consistent in this particular population, and may be influenced by genetics, hard labour, osteoporosis and general body build. In addition, Wanek's study (23) employed humeri from seven different biological populations; accuracy in sex determination ranged from 78% (American Blacks) to 94% (Aleutians, Chinese). These results indicate that features seen in the distal humerus exhibit distinct differences between males and females, populations vary in the discernible expression of these traits, and the traits may be considered non-population-specific. Finally, white South Africans have shown unusual and variable results (such as the misclassification of white males as females) in research conducted on distinctly sexually dimorphic skeletal elements such as the os coxae (33). More research on additional populations is necessary to better assess the possibilities of using this feature solely for sex determination.

Conclusions

Allocation of sex based on the percentage of correct assignments showed the delineation between male and female morphology in the distal humerus. Examination of features from the distal and posterior humerus resulted in reasonably accurate classification rates with both males and females when utilizing a suite of three visual traits (angle of the medial epicondyle, olecranon fossa shape, and trochlear extension). All of these characteristics in isolation were not particularly accurate in predicting sex on their own. However, when used in conjunction with each other as an amalgamated recognition of sex, all males were classified with a 74% accuracy rate, while all females were classified accurately 77% of the time. This was accurate enough (and statistically significant enough) to deem these characteristics sexually dimorphic, indicating that visual traits of the distal humerus may be used in conjunction with other non-metric and metric techniques for sex determination.

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Table 1: Non-metric distal humerus characteristics for males and females (based on Rogers, 1999)

Characteristic	Male	Female
Olecranon Fossa Shape	The fossa appears roughly triangular	The fossa appears oval
Angle of the Medial Epicondyle	The medial epicondyle extends parallel to the table (or exhibits a slight angle) when placed posterior side up	The medial epicondyle clearly angles upwards away from the parallel plane of the tabletop surface when placed posterior side up
Trochlear Extension	Medial edge of the trochlea extends further distally than does the lateral edge	Distal extension of the medial and lateral edges of the female trochlea is almost equal; more symmetrical in shape

Table 2: Distribution of classification, all males and females, estimated sex.

							Total
		Male Score 3-8		Ambiguous Score 9		Female Score 10-15	
SEX	Male	310 **(74%)**		24 (6%)		86 (20%)	420
	Female	33 (17%)		10 (5%)		145 **(77%)**	188
Total		343		34		231	*N*= 608

Pearson's chi square value=182.593, df=2, sign. (2-sided) p=0.000<0.05

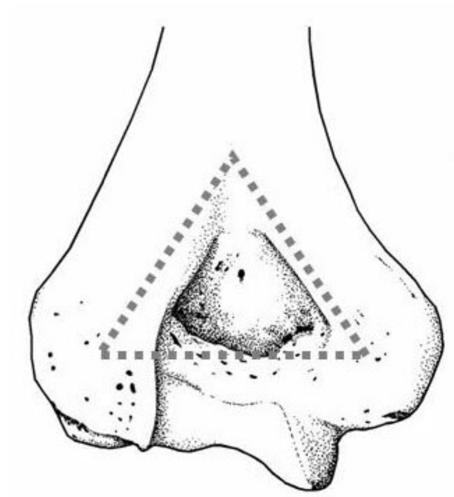
Table 3: Distribution of classification and chi square significance, all males and females (total *N* = 608). Estimated sex under "1 (M)" and "5 (F)" represents a total of the [1] and [2] "estimated sex" determinations for males, and [4] and [5] "estimated sex" determinations for females.

	Males (*n*=420)					**Females (*n*=188)**					Pearson's Chi Square	df	Sig. (2-tailed)
	1 (M)	2	3	4	5 (F)	1 (M)	2	3	4	5 (F)			
Epicondyle angle	153	144	22	76	25	24	49	12	64	39	69.388	4	**0.000***
	(36%)	(34%)	(5%)	(18%)	(6%)	(6%)	(26%)	(6%)	(34%)	(21%)			
Olecranon fossa shape	70	170	79	86	15	4	36	34	67	47	110.370	4	**0.000***
	(17%)	(40%)	(19%)	(20%)	(4%)	(2%)	(19%)	(18%)	(36%)	(25%)			
Trochlear extension	55	135	77	137	16	12	40	31	79	26	32.994	4	**0.000***
	(13%)	(32%)	(18%)	(33%)	(4%)	(6%)	(21%)	(16%)	(42%)	(14%)			
Estimated sex	310		24		86	33		10		145	182.593	2	**0.000***
	(74%)		(6%)		(20%)	(18%)		(5%)		**(77%)**			

***Significant at <0 .05**

Figure 1a: Triangular olecranon fossa shape observed in males. Fig 1b: The oval olecranon fossa shape in females.

a.



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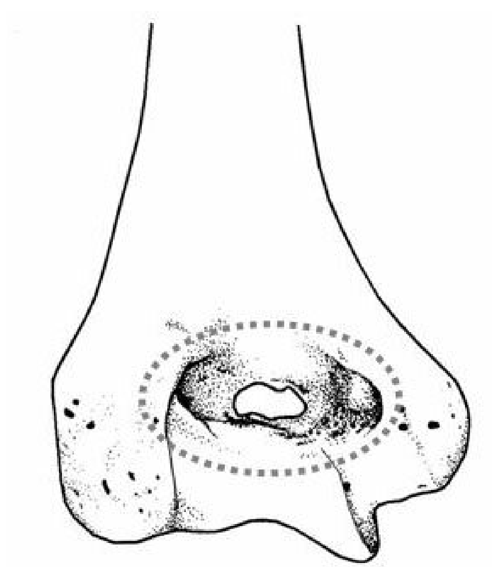
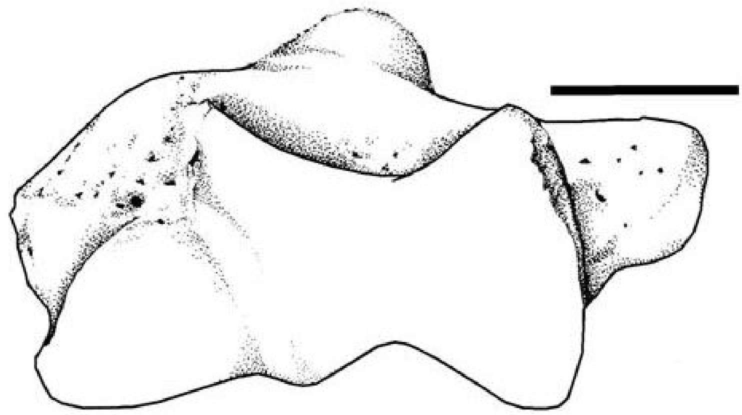


Figure 2a: Angle of the medial epicondyle observed in males. The angle appears parallel to the table on which the humerus rests. Fig 2b: Angle of the medial epicondyle observed in females. The angle appears to project upwards from the table on which the humerus rests.

a.



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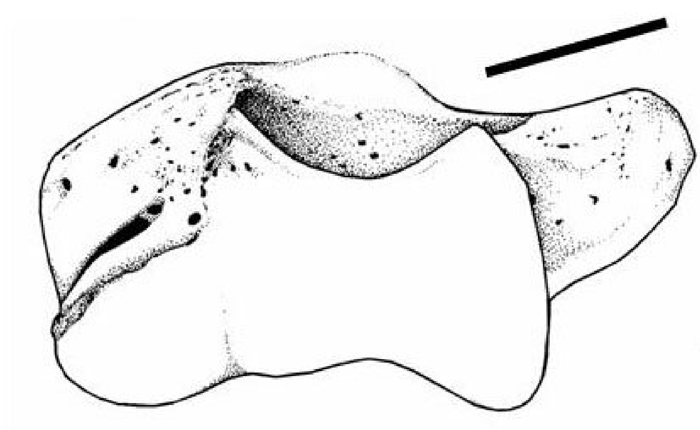

Figure 3a: Trochlear extension observed in males. The trochlea extends well past the margin of the capitulum. Figure 3b: Trochlear extension/ relative symmetry observed in females. The trochlea is more symmetrical with the margin of the capitulum.

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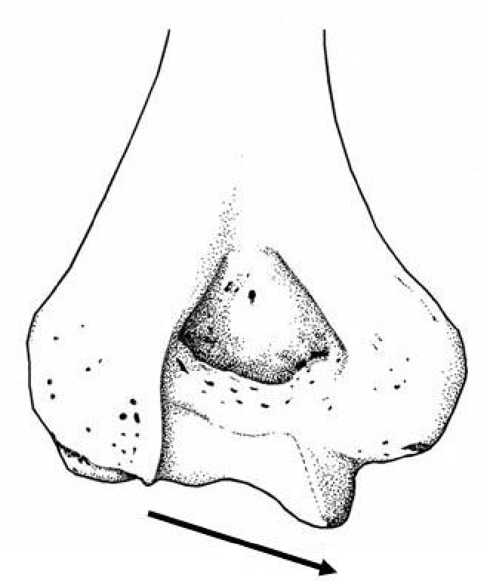

b.