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A Visual Method of Determining the Sex of Skeletal Remains Using the Distal Humerus*

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ABSTRACT: This study introduces a new method of determining sex based on four morphological features of the posterior, distal humerus. The technique was developed on a 20th century anatomy series, the University of Toronto Grant Skeletal Collection, and was tested on 35 known individuals from the University of New Mexico Documented Collection and 93 individuals from the William M. Bass Donated Skeletal Collection. Four statistically significant characteristics relating to the carrying angle of the arm are identified ($p < 0.05$). Together, they are capable of determining sex with 92% accuracy.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, sex determination, humerus, carrying angle

Humans do not exhibit marked sexual dimorphism. In fact, males and females share almost 95% of the total range of variation for most physical characteristics (1,2). The remaining 5% may be attributed to minor differences in robusticity and morphological differences relating to the female capacity for childbirth. Although these characteristics are subtle, it is possible to determine the sex of adult human skeletal remains with greater than 95% accuracy, provided the entire skeleton is present (3). Sex determination is less successful when sexually diagnostic elements, such as the pelvis and skull, are absent.

The sex of a skeleton can be established through either metric or visual means. The two methods are complementary and result in similar levels of accuracy (3–8). Metric analyses involve taking specific measurements to insert in existing formulae or for use in discriminant function analysis. Visual assessment of sex depends upon the observation of sex-specific differences in morphology, e.g., shape of the pubic bone, and robusticity, e.g., development of muscle markings.

Metric techniques result in few indeterminate cases, employ a broad range of elements, are easy to teach and are more precise than their nonmetric counterparts, but for most metric analyses, good preservation is essential (9–14). If bones are fragmentary, measurements must be estimated and if elements are absent, discriminant functions usually cannot be calculated (15–17). FORDISC 2.0 now makes it possible to overcome some of these limitations, since the program is capable of creating ''made-to-order'' discriminant functions using data from the Forensic Data Bank (18). One problem that FORDISC 2.0 cannot surmount is the shrinkage undergone by bones subjected to burning. Since size decreases when bones are burned, metric analyses should not be applied to cremated remains. In contrast, visual techniques prove quite effective on fragmented and/or burned bone (15–17).

To some degree, both metric and nonmetric analyses are population specific. Discriminant functions created on one sample cannot be applied unconditionally to other collections, due to population differences in size, robusticity and bodily proportions. Although some sex-specific morphological features cross-cut populations (19), others have proven less effective in samples that differ from the original test group (20). Morphological characteristics relating to robusticity exhibit varying degrees of expression and development, depending upon the population. As a result, investigators must become familiar with the range of variation found within each population before assessing attributes of this type (1).

Morphological techniques of determining sex based on differences in shape, rather than size or robusticity, are confined largely to the skull and pelvis. When these elements are absent, metric methods are usually given greater weight than visual assessments of postcranial robusticity. The results of metric analyses vary depending on the bone examined. The humerus, for example, has produced mixed results. Some describe it as a poor bone for sex estimation (21); others have found it extremely successful in discriminating sex (7,22). France (23) notes that while size measurements of the humerus may be used to identify sex, they will never be completely accurate in distinguishing a large female from a small male.

The purpose of this research was to develop a morphological method of determining sex from the humerus, to complement existing metric techniques. By maximizing the information provided by a single element, a better, more accurate determination of sex can be made. This is particularly important in cases of co-mingled and/or fragmentary remains, e.g., mass disasters such as airplane crashes.

The humerus became the focus of this study because of its relationship to the carrying angle of the arm. The carrying angle refers to the lateral deviation of the human forearm from the humeral axis. The carrying angle is approximately 10 to 15 degrees in males and 20 to 25 degrees in females (24). Females with Turner's Syndrome, or X monosomy, have an even higher carrying angle (25). Observation of the hard and soft tissues of the arm has revealed that the anterior fibers of the ulnar collateral ligament, which originate on the medial epicondyle of the humerus and insert on the medial aspect of the coronoid process of the ulna, are taut in extension and are well suited to prevent valgus angulation of the extended forearm (26–27). It has also been observed that the trochlea is rather eccentrically shaped and that the humero-ulnar joint

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has a screw axis, which is reported to change the carrying angle during elbow flexion so that the misalignment between the arm and forearm is decreased (24,27).

The hypothesis in this study is that morphological variation found in the distal humerus relates to the carrying angle of the arm and is, therefore, sexually dimorphic. It is proposed that this variation can be used to accurately determine the sex of skeletal remains. In order to accept this hypothesis the characteristics contributing to the carrying angle of the arm must demonstrate statistically significant sex differences. These features can then be used to formulate a technique for discriminating sex. Given the accuracy of existing methods of sex determination, this technique should provide at least 80% accuracy to be considered useful.

Materials and Methods

To identify potentially useful characteristics, a random sample of ten male and ten female humeri from the Grant Skeletal Collection of the University of Toronto's Department of Anthropology was observed. The Grant Collection consists of 202 skeletons from unclaimed bodies sent to the Department of Anatomy between 1928 and the early 1950s from local hospitals and welfare institutions, under the Anatomy Act of Ontario (and Revised Ontario Statutes of 1937, 1942, and 1946). Name, sex, age-at-death, and cause of death are known for each individual. Most are male (n = 175), over 40 years of age (n = 147), and many had been either transients, migrant workers or recent immigrants without family. All but one individual were white and of European origin. Known age was established through vital statistic records, hospital records or a personal history provided by the individual before death (28). The ages of the test sample ranged from 18 to 86 years.

Potentially sex-specific features of the trochlea, olecranon fossa and medial epicondyle were noted on the posterior aspect of the humerus. A blind test of three traits was then conducted on a hold-out sample of 20 males and 19 females, examined in no particular order.

The accuracy with which the individual features were capable of predicting sex ranged from 56 to 85%, both sexes combined (Table 1). Interobserver error between an experienced (author) and an inexperienced observer was quite high (21 to 32%). It was decided to pursue this research using a different skeletal collection and to redefine the features more clearly so as to increase precision.

One year later, the technique developed on the Grant Collection was tested on the Documented Collection at the Department of Anthropology, University of New Mexico. This is a modern collection of individuals of known sex, age, ancestry and cause of death [Stan Rhine, pers. comm.].

An initial sample of ten humeri was examined in order to review and revise the technique. At this point, two additional characteristics were added. Due to time constraints, a small random sample of 40 white individuals was selected by an assistant for a blind test of the technique. An interobserver error test was not possible.

TABLE 1—*Accuracy of sex determination using features of the distal humerus [Grant Collection (*n = *39)].*

Feature	Male and Female	Male (n = 20)	Female (n = 19)
Medial aspect trochlea	56%	50%	63%
Olecranon fossa depth/shape	69%	65%	74%
Angle of medial epicondyle	85%	80%	89%

FIG. 1—*Trochlear outline—The male trochlea is less spool-shaped (outlined area) and less constricted (arrows), while the female counterpart is constricted in the middle (arrows), producing a distinct spool-shaped trochlea (outlined area).*

Later, it was determined that sex had been estimated rather than known in five of the cases examined. These cases were excluded from the study. The final sample consisted of 35 white individuals, ages ranging from 20 to 90 years. Twenty-eight of the individuals were male, seven were female.

The features examined include:

1. *The orientation of the medial aspect of the trochlea relative to the shaft of the humerus*—in males this edge tends to run parallel to the shaft, in females it angles across the shaft (later discarded due to poor accuracy).
2. *Trochlear constriction*—in males the trochlea is less constricted, in females more constricted and spool-shaped (Fig. 1).
3. *Trochlear symmetry*—in males the trochlea is asymmetrical, in females more symmetrical (Fig. 2).

FIG. 2—*Trochlear symmetry—The medial edge of the male trochlea extends further distally than does the lateral edge, making the trochlea appear asymmetrical (highlighted by angled bar), while the distal extension of the medial and lateral edges of the female trochlea are almost equal (highlighted by less angled bar). Olecranon fossa shape and depth—The male olecranon fossa is uniformly shallow and roughly triangular in shape (outline). The female olecranon fossa is primarily a deep oval (center female example), but in some cases it may exhibit a shallow proximal extension in addition to the deep oval (right female example).*

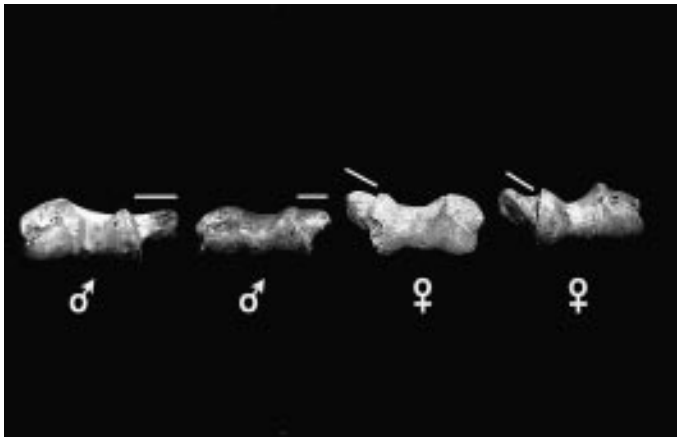

FIG. 3—*Medial epicondyle—With the humerus placed on a table, posterior surface facing upward, the male medial epicondyle remains parallel with the tabletop or slightly raised when viewed from the distal end (highlighted bar). In the same position, the female medial epicondyle angles upward, away from the tabletop (highlighted, angled bar).*

4. *Olecranon fossa shape and depth*—in males the fossa is a shallow triangle, in females it is a deep oval; shape is more important than depth (Fig. 2).
5. *Angle of the medial epicondyle*—in males the epicondyle is flat or slightly raised, in females it is distinctly raised (Fig. 3).

Two years after the UNM sample was examined, the technique was tested on the William M. Bass Donated Skeletal Collection at the Department of Anthropology, University of Tennessee, Knoxville (UTK). The methodology was identical to that used on the UNM sample. The UTK skeletons are a modern collection of individuals of known age, sex ancestry and, in many cases, cause of death [Murray Marks, pers. comm.]. The test sample consists of 93 white individuals, ages ranging from 25 to 89 years. Seventy-four of the individuals were male, 19 were female.

Results

Fisher's exact probability tests conducted on the UNM material ($n = 35$) indicate that sex-specific variation observed on the posterior distal humerus is significant in all cases except for the orientation of the medial aspect of the trochlea relative to the shaft ($p = 0.534$). This trait was eventually eliminated from the method due to its poor performance. The remaining characteristics produced the following results: trochlear constriction $p = 0.003$, trochlear symmetry $p = 0.02$, olecranon fossa shape and depth $p = 0.00001$, angle of medial epicondyle $p = 0.0017$. The statistically significant traits are presented in Figs. 1–3.

The accuracy with which each trait could predict sex (both sexes combined) ranged from 42 to 91% (Table 2). The traits were approximately as accurate for males as for females.

By utilizing all five traits in combination, 88.6% accuracy was achieved. Each characteristic was scored as male or female and the final sex assessment was made on the basis of the majority. When the orientation of the medial aspect of the trochlea was omitted (since it proved both inaccurate and not statistically significant), accuracy dropped to only 80% because of a greater number of indeterminate cases (two features indicating male and two features indicating female). In five of the six indeterminate cases, the olecranon fossa shape and depth accurately reflected sex, while the remaining traits proved inconsistent or ambiguous. If the olecranon shape and depth is given more weight in the indeterminate cases, accuracy is increased to 94%.

TABLE 2—*Accuracy of sex determination using features of the distal humerus [UNM Collection (*n *= 35)].*

Feature	Male and Female	Male ($n = 28$)	Female ($n = 7$)
Medial aspect trochlea	42%	50%	14%
Olecranon fossa depth/shape	91%	89%	100%
Angle of medial epicondyle	86%	82%	100%
Trochlear constriction	74%	75%	72%
Trochlear symmetry	74%	75%	72%
Combined	88.6%	85.7%	100%
Combined (olecranon used as guide in indeterminate cases)	94%	93%	100%

TABLE 3—*Accuracy of sex determination using features of the distal humerus [UTK Collection (*n *= 93)].*

Feature	Male and Female	Male ($n = 74$)	Female ($n = 19$)
Olecranon fossa depth/shape	82%	81%	84%
Angle of medial epicondyle	86%	89%	74%
Trochlear constriction	88%	92%	74%
Trochlear symmetry	69%	66%	79%
Combined (olecranon used as guide in Indeterminate cases)	91%	91%	95%

TABLE 4—*Number of males and females exhibiting each trait form (UNM and UTK combined).*

Trait Form	Males ($n = 102$)		Females ($n = 26$)	
Olecranon fossa				
Shallow triangle	85*	83%*	3	12%
Deep oval	15	15%	23*	88%*
Indeterminate	2	2%	0	0%
Medial epicondyle				
Flat/slightly raised	89*	87%*	5	19%
Marked angle	13	13%	21*	81%*
Indeterminate	0	0%	0	0%
Trochlear constriction				
Less constricted	89*	87%*	6	23%
More constricted	9	9%	19*	73%*
Indeterminate	4	4%	1	4%
Trochlear symmetry				
Asymmetrical	70*	69%*	4	15%
Symmetrical	31	30%	20*	77%*
Indeterminate	1	1%	2	8%

* Asterisked values indicate number/percentage correct.

The results from the UTK sample were similar (medial epicondyle), slightly better (trochlear constriction) or slightly worse (olecranon fossa and trochlear symmetry) than was observed in the UNM sample. Table 3 provides the accuracy of each trait for males, females and the sexes combined. Using all four traits in combination, giving greater weight to the olecranon fossa shape and depth in indeterminate cases, the accuracy of this method was 91% for the UTK sample.

Since both the UNM and UTK samples were obtained from modern, documented collections using the same methods, the data were pooled to increase the sample size. The combined results are reported in Tables 4 and 5. The accuracy of this method is 92%.

TABLE 5—*Accuracy of sex determination using features of the distal humerus [UNM and UTK Collections Combined (*n = *128)].*

Feature	Male and Female	Male (n = 102)	Female (n = 26)
Olecranon fossa	84%	83%	88%
Medial epicondyle	86%	87%	81%
Trochlear constriction	84%	87%	73%
Trochlear symmetry	70%	69%	77%
Combined	92%	89%	96%

Discussion

The results reported here suggest that it is possible to determine the sex of skeletal remains using morphological characteristics of the posterior distal humerus. The olecranon fossa shape and size, orientation of the medial epicondyle and shape of the trochlea all contribute to the carrying angle of the arm—a feature that is sexually diagnostic in living individuals.

This technique relies upon differences in shape to determine sex and is, therefore, complementary to existing metric procedures which depend upon size and robusticity. The combination should prove particularly useful in cases of mass disasters or disarticulated remains, where bony elements are co-mingled or found in isolation, since the distal humerus tends to remain intact in situations where other bones may become fragmented (22). The fact that this method depends upon shape, rather than size, means that there is a greater likelihood that it can be applied across populations. This method has been used successfully by the author on single individuals from the following groups: black, Native, South Asian (India) and Hispanic. Clearly, further research into the applicability of this method to nonwhite populations is warranted.

It is recommended that investigators using this technique restrict observations to the four statistically significant characteristics which were capable of discriminating sex: trochlear constriction, trochlear symmetry, olecranon fossa shape and depth, and angle of the medial epicondyle (as demonstrated in Figs. 1–3). For those cases in which two features are scored male and two are scored female, greater weight should be given to the results obtained from the olecranon fossa, since this feature tends to be more consistent in ambiguous cases.

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