Morphological Variation and Sexual Dimorphism in the Skeletal Elements of the Human Elbow

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1. Introduction

Traditional methods of sex determination in the human skeleton include qualitative and quantitative analysis of the cranium, pelvis, and long bones. Qualitatively, sexual dimorphism is reflected by larger size in males than in females. Quantitatively, previous research has shown to varying degrees the effectiveness of long bones in determining the sex of an unknown individual. These studies have demonstrated the utility of estimating sex from the humerus, radius, and ulna individually [1-8]. Rather than examining the individual bones of the upper appendix, the present research explores the potential efficiency of improving sex estimation using the humerus, radius, and ulna by applying a composite of distal and proximal elements of the bones comprising the elbow.

2. Materials and Methods

The materials for the present research include 160 individuals from the Todd skeletal collection housed at the Cleveland Museum of Natural History. The data comprises measurements and observations from both right and left humerii, ulnae and radii of forty skeletally mature adult Black and White males, and forty-one Black and forty White females. Individuals that exhibited pathology or other damage were not used. Only the White sample is discussed here.

The measurement protocol was developed at the Wichita State University Biological Anthropology Laboratory using the WSU-BAL cadaver collection. Ultimately, the protocol comprised thirty-one traditional and non-traditional measurements designed or selected by the authors to test how well, if at all, any of them measure sexual dimorphism. Thus, the majority of measurements focused on the quantification of size and shape specific to the elbow segment of the distal humerus and the proximal ulna and radius.

All measurements were taken with standard equipment including sliding and coordinate calipers, an osteometric board, and a fiberglass tape. Only bones of the left side were used in the calibration of the result of the study presented here. Multivariate statistical procedures (PROC CANDISC [9]) were used to discern any evidence of sexual dimorphism in and among the bones of the arm and to illustrate the relative contribution of individual variables. Model selection for optimal discrimination, and the calibration of correct classification calculated, was carried out using a PROC STEPWISE [9] procedure with a MAXR option. A test of the efficiency of the discriminating models calibrated for White males and females were tested on an independent sample (n=26) of White males and females from the WSU-BAL cadaver collection.

Because the models for estimating sex are derived from, and thus aimed at, bones of the left arm only, the authors decided to test the potential application of the same models to bones of the right arm. To examine the effect of side asymmetry, all models calibrated for the bones of the left side were tested on measurements taken on bones of the right arm from all individuals of the calibration sample.

3. Results

A canonical discriminant analysis of our White sample demonstrated a pair-wise squared distance of approximately 21.24 between sexes. A significant canonical variate with a correlation of 0.84, and a corresponding F-value of 8.43 ($P<.0001$) illustrates the contribution of individual variables to the observed pattern variation. Of the thirty-one variables along the canonical axis, thirteen exhibited loadings of 0.80 or above. Based on a separate examination of individual variable means, it is evident that the observed difference is one of size.

A PROC STEPWISE procedure applied to our white sample produced a best single variable model for sex estimation using the radius head circumference. The model is associated with an R-square of 0.67, and sex estimation that correctly classifies 90% of males and 92.5% of females for the calibration sample. The model correctly classified 80% of males and 92.86% of females in the test sample of bones from the WSU-BAL collection. The model classified 92.5% of both males and females in the additional test sample of bones of the right side. The

best two-variable model for estimating sex includes the radial head circumference and the minimum circumference of the humerus. The two-variable model is associated with an R-square of 0.71 and a correct classification of 90% of males and 95% of females in the calibration sample, 93.33% of males and 100% of females in the WSU-BAL test sample, and 95% of both males and females in the test sample of bones of the right side. The best three-variable discriminant function model is associated with the radius head circumference, the minimum circumference of the humerus, and the maximum diameter of the radius head. An R-square of 0.73 is associated with a correct classification of classification 90% of males and 97.5% of females in the calibration sample, a correct classification of 93.33% of males and 100% of females in the WSU-BAL test sample, and 92.5% in both males and females in the test sample of the right bones.

4. Discussion and Conclusion

The current study presents data indicating that together, the bones of the arm are highly useful in determining the sex of an adult human. The classification results of the discriminant analysis demonstrate an improvement of sex estimation when applying one, two, and three variable models to the sample of White males and females. For males in the WSU-BAL test sample, correct classification improved from 80% with a single variable model to 93.33% for both two and three variable models. Likewise for females in the test sample of WSU-BAL bones, classification results improved from 92.86% to 100% when both two and three variable models are used. In the test sample of right bones, the classification results of the single variable model classifying 92.5% were improved to 95% with the addition of the second variable. Notably, the further improvement in classification of sex in both test samples using two and three variable models lends support to our initial suggestion that a composite of measurements from at least two of the bones comprising the elbow, namely the humerus and radius, successfully improves sex estimation in White males and females generally from 80% to 100%.

Our test of bones from the right sides has shown that these bones classify comparably well as the WSU-BAL test sample. Therefore, the effect of asymmetry in the Todd sample is considered minimal.It is evident from the present study that the bones of the upper appendage reflect sexual dimorphism between human males and females when considered either individually or jointly. Further, the combination of the proximal radius and the distal humerus offers optimal classification in White males and females. This study raises further questions that may better assess the morphometric variation of the upper appendage, particularly concerning age and how it reflects sexual dimorphism in humans. Our ongoing research will test the effectiveness of using multiple bones of the arm to determine sex of unknown Black individuals. Overall, our results offer a consistent and reliable method for the purpose of sex determination and it is hoped that this procedure will eventually lend itself useful across diverse populations and provide a reliable and consistent means of identification.

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6. References

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