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**TECHNICAL NOTE**

**ANTHROPOLOGY**

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# A Method for Estimating Sex Using Metric Analysis of the Scapula*

**ABSTRACT:** The most accurate and precise methods for the assessment of age and stature often require knowledge of sex. Thus, being able to correctly identify sex from skeletal remains is critical in the forensic context. The presence of the os coxae or skull can never be guaranteed, making the development of reliable methods of sex estimation using other skeletal elements necessary. Using a 724 individual calibration sample from the Hamann-Todd collection, this study identifies sexual dimorphism in the human scapula, and presents a new five-variable discriminant function for sex estimation. The overall accuracy of this method proved to be 95.7% on the cross-validated calibration sample, 92.5% on an 80 individual test sample from the Hamann-Todd collection, and 84.4% on a 32 individual test sample from the skeletal collection of the Wichita State University Biological Anthropology Laboratory. Additionally, a slightly less accurate two-variable model was developed and has cross-validated accuracy of 91.3%.

**KEYWORDS:** forensic science, forensic anthropology, sex estimation, biologic profile, metric analysis, scapula

Identification of the sex of an individual is of paramount importance to establishment of the biologic profile, because methods for establishing stature and age at death are often sex dependent. Traditionally, the human os coxa and cranium provide the most accurate assessments of sex, and are widely used when available in the medico-legal context (1,2). However, taphonomic processes such as carnivore activity and decomposition often result in the loss of vital information because of the destruction or loss of ox coxae and/or crania. To complement sex estimation, alternative methods involving elements other than the cranium and the pelvis should be devised. Recent inquiries have focused on determining sex from various elements of the skeleton, including the calcaneus (3–6), clavicle (7), femur (8–15), humerus (10,12,15,16), metatarsals (17), patella (3,6), radius (10,12,15), ribs (18), scapula (7,19–24), talus (25–27), tibia (10,12,15,28–31), and ulna (10,12,15,31). It has been noted that the application of methods developed on one population have limited use on populations other than the original (2); hence, developing methods for many different skeletal elements based on different populations is required.

Quick examination of many forensic anthropology or human osteology texts demonstrate that if sex estimation based on the scapula is mentioned at all, the simple metric analysis of Thomas Dwight is most often reported (32,33). In 1894, Dwight reported on the potential use of the human scapula in the context of sexual dimorphism, suggesting both the glenoid fossa height and maximum scapula length can be utilized in sex estimation. According to Dwight (19) females are characterized by maximum scapula length <140 mm, while males generally have scapula lengths over 170 mm; values between 140 and 170 mm cannot be assessed. When applied to an independent sample of 803 individuals from the Hamann-Todd collection the low precision of Dwight's maximum length technique quickly became evident. When falling above or below the demarcation points, Dwight's method of sex estimation using maximum length of the scapula proved 96.81% accurate on the Hamann-Todd sample. Two hundred fifty-one individuals fell either above or below the given demarcation points. Of these, 141 were females and 110 were males. All females were correctly identified, but only 92.73% (102/110) of the males were correctly identified. The true measure of any sex estimation technique lies not only in its ability to accurately assess sex of individuals, but also in its ability to provide an estimation for most individuals. In this regard, Dwight's method fails. Of the 803 individual samples, 552 individuals (68.74%) were indeterminate using Dwight's method, because the maximum length of the scapula fell between 140 and 170 mm. The overwhelmingly larger number of individuals that fall within the indeterminate category demonstrates the desperate need for new, easy, accurate methods for sex estimation from the scapula (34). Working with the Hamann-Todd collection, a sample of late 19th–early 20th century White and Black Americans, this study examines sexual dimorphism of the human scapula and presents a new, simple, accurate method for estimation of sex using metric analysis.

## Materials and Methods

The protocol for this study was developed on the Wichita State University (WSU), Biological Anthropology Laboratory's cadaver collection. This collection consists of both males and females of known age, sex, and group affiliation, ranging in age from 45 to 99 years. To maximize the number of scapula measured during the protocol development stage, all complete scapulae were measured, regardless of age, sex, ancestry, or side. The methods outlined in this paper were also tested on this population.

Data were collected on the Hamann-Todd collection at the Cleveland Museum of Natural History (CMNH). The total sample consists of the left scapulae of 804 individuals (169 black females, 139 white females, 194 black males, and 302 white males).

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Individuals included in the sample range in age from 19 to 93 years old, with the main selection criteria requiring the scapula be complete and undamaged. Additionally, all secondary centers of ossification must be fused to the main body of the scapula. From the larger sample of 804 individuals, the authors withheld a test sample of 80 individuals similar to the larger sample in demographic distribution and date of entrance into the Hamann-Todd collection. The remaining 724 individuals (447 males and 277 females) served as the calibration sample. Additionally, 32 individuals collected from the cadaver collection at Wichita State University were used as a second, independent test sample. There are 18 males and 14 females, ranging in age from 45 to 97 years old in this sample.

One author (GRD) measured 23 dimensions depicting the size and shape of the scapula. Of these 23 measurements, six were defined previously (35–39), and 17 are original for this study. Table 1 provides the sex specific mean values, standard deviations, and between sex *p*-values for all 23 measurements, and Table 2 briefly outlines the five variables used in the model to be presented. The data collected at CMNH was examined using SPSS version 14.0. Initially, the descriptive statistics of mean, maximum, minimum, and standard deviation were computed. This allowed the authors to identify any erroneous values. SPSS was then used to calculate an independent samples *t*-test to identify differences between the male and female groups. For this study, statistical significance was accepted at a level of $p \leq 0.01$. To develop the sex estimation model, a multivariate linear regression of the variables was first run using a stepwise model to identify which variables and variable combinations are the best predictors of sex. The probability of F required to enter was 0.050 and 0.100 was required to remove. The independent variable for this procedure was sex, coded as one for females and two for males. The 23 variables collected were used as independent variables. This procedure identified the combination of the five variables

TABLE 1—*Sexually dimorphic variables.*

| Variable | Measurement Name | Male (mean) | Male (SD) | Female (mean) | Female (SD) | Sexual Dimorph[†] |
|---|---|---|---|---|---|---|
| BXB | Breadth of infraspinous body | 104.68 | 5.62 | 93.01 | 5.08 | 1.09 |
| XBS | Maximum breadth of the scapula | 106.89 | 6.16 | 95.08 | 5.26 | 1.03 |
| XLS* | Maximum length of the spine | 141.33 | 7.88 | 125.22 | 6.96 | 1.09 |
| XHS* | Maximum length of the scapula | 162.49 | 9.65 | 140.20 | 8.72 | 1.21 |
| LIL | Length of infraspinous line | 118.47 | 8.71 | 102.30 | 8.06 | 0.96 |
| LSL | Length of supraspinous line | 57.47 | 5.87 | 48.94 | 5.20 | 0.77 |
| LXC | Length of infraspinous lateral margin | 130.12 | 8.13 | 114.53 | 7.04 | 1.03 |
| LML | Breadth of mid-body | 64.42 | 5.47 | 54.52 | 4.62 | 0.98 |
| TSB | Thickness at superior border | 3.76 | 1.14 | 3.47 | 0.95 | 0.14 |
| TMN | Thickness at medial notch | 2.23 | 0.85 | 1.99 | 0.72 | 0.16 |
| TLB* | Thickness at lateral border | 10.23 | 1.43 | 7.87 | 1.11 | 0.93 |
| TIB | Thickness at inferior border | 8.36 | 1.22 | 7.00 | 0.89 | 0.64 |
| TMB | Thickness at medial border | 3.41 | 0.95 | 2.83 | 0.72 | 0.35 |
| LLC | Length of coracoid process | 46.23 | 3.47 | 40.51 | 3.05 | 0.88 |
| DCH | Height of coracoid process | 11.11 | 1.57 | 9.23 | 1.23 | 0.67 |
| LIM | Length between inferior border and medial notch | 149.12 | 8.78 | 129.90 | 7.75 | 1.16 |
| LII | Length between inferior border and inferior notch | 145.81 | 8.45 | 127.25 | 7.15 | 1.19 |
| CILA | Curvature between inferior border and medial notch 1/4 | 16.32 | 2.68 | 13.64 | 2.44 | 0.52 |
| CILB | Curvature between inferior border and medial notch 1/2 | 13.56 | 2.86 | 11.26 | 2.51 | 0.43 |
| CILC | Curvature between inferior border and medial notch 3/4 | 8.92 | 2.61 | 7.56 | 2.21 | 0.28 |
| CSV* | Lateral curvature | 6.40 | 2.64 | 4.55 | 2.27 | 0.38 |
| HAX* | Height of glenoid prominence | 41.09 | 3.24 | 34.44 | 1.98 | 1.27 |
| BCB | Breadth of glenoid prominence | 27.07 | 2.26 | 22.92 | 1.81 | 1.02 |

Group mean values, SD and sexual dimorphism scores for males ($n = 447$) and females ($n = 277$) for the 23 variables used in this study. All measurements are in mm, and all *p*-values are $\leq 0.0001$.

*Used in the five-variable model; [†]sexual dimorphism = $(x_1 - x_2)/(s_1 + s_2)$, where $x$ = mean, $s$ = SD, 1 = male, 2 = female.

TABLE 2—*Measurement descriptions.*

| Code | Measurement Name | Measurement Description |
|---|---|---|
| XLS* | Max length of spine | Use sliding calipers to measure from the medial margin of the scapula at the spinous axis to the most lateral point on the scapular spine (36–39) |
| XHS*[†] | Max length of scapula | Use sliding calipers to measure from most superior point on the superior angle to the most inferior point on the inferior angle (36–39) |
| XBS[†] | Max breadth of scapula | Use sliding calipers to measure from the lateral surface of the glenoid dorsal cavity to the spinous axis (36–39) |
| HAX* | Height of glenoid prominence | Use spreading calipers to measure from the superior margin of the glenoid prominence to the inferior margin of the glenoid prominence (35) |
| CSV* | Lateral curvature | Use coordinate calipers to measure the distance from parallel at the midpoint between the inferior margin of the glenoid fossa prominence and the spinous axis (35) |
| TLB* | Thickness of lateral border | Use sliding calipers to measure the thickness of the border at the midpoint between the inferior margin of the glenoid prominence and the inferior angle. The measurement should be taken perpendicular to the scapular body (35) |

Descriptions of measurements used in the two- and five-variable models outlined in this article.

*Five-variable model.

[†]Two-variable model.

indicated in Table 2 as the most predictive of sex. Once these variables were identified, a discriminant function (with SPSS default of equal priors) analysis with Fisher's coefficients was used to develop the equation in Table 3 by subtracting the female values of Fisher's coefficients from the male values.

Using the same procedure, a two-variable discriminant function was developed for use in situations where one of the five variables indicated above is not available. This two-variable model uses the maximum length and breadth of the scapula (XBS and XHS). A similar two-variable model has been published in Fordisc 3.0, with high levels of accuracy; however, not all researchers have access to this program.

## Results

All 23 variables measured in this study showed statistically significant differences between the male and female group mean values (Table 1). The *p*-value listed is either assuming equal variances or assuming unequal variances, depending on the significance of Levene's test for that particular value. In this case, the aforementioned point is moot; all 23 variables showed statistical significance at the level of $p \leq 0.001$, regardless of the equality of variance. Additionally, this table lists the value of sexual dimorphism calculated as the difference between means over the sum of the standard deviations.

The multivariate linear regression with Fisher's coefficients provided a five-variable model useful for estimating sex. Table 3 illustrates the equation necessary for sex estimation using the scapula. For this method, the value of "sex" is calculated by substituting the individual values for the variable code. The demarcation point is zero, with males having sex values larger than zero, females smaller. For the calibration sample, this method proved accurate in 95.8% of cases, with no bias against either sex. Leave one out cross-validation resulted in an accuracy rate of 95.7%. Testing this method on an 80 individual holdout sample from the Hamann-Todd collection produced an overall accuracy of 92.5%. The six individuals assessed incorrectly span across both sexes and groups and have widely varying ages. Thus, the five-variable model has validity across all groups in this study. Additionally, the same method was used to estimate sex in the WSU cadaver collection of 32 individuals. The overall accuracy of this sample was 83.4%, still high (Table 4). In this sample, all of the incorrectly assessed individuals were over 75 years old, suggesting a potential tendency for misclassification with advancing age. Other methods of sex estimation have shown that older individuals, especially females, may often be misclassified (cf. 39–41).

Table 5 outlines the two-variable model for sex estimation, and Table 6 demonstrates its accuracy in sex estimation. As was mentioned previously, a similar model is available in Fordisc 3.0, and its overall accuracy is 92–94%. Our model has slightly lower accuracy, but is publicly available.

## Discussion and Conclusion

The results of this analysis make it evident that metric analysis of the human scapula is useful for determining sex of an individual. The utility of models such as the one presented here are self-evident. Methods of sex estimation utilizing skeletal elements other than the crania and os coxae increase the likelihood of positive identification in forensic situations, and improve the accuracy of demographic profiles created by osteologists on archaeological samples. Additionally, the use of metric analysis reduces the subjective aspect of sex determination. This not only reduces the learning curve for newly trained forensic anthropologists, who may not have yet had the opportunity to observe hundreds of crania or os coxae as a basis for subjective sex estimation, but also is easily understandable by lay people, an important consideration for legal testimony.

The authors suggest that the difference in accuracy observed between the two test samples may have four explanations. First, the WSU cadaver test population consists of only white individuals, while the CMNH experimental sample was comprised of both black and white individuals. Unpublished data demonstrates small, but significant differences ($p \leq 0.05$) between black and white males and females for some of the variables used in this method. However, examination shows an equal number (19 each in calibration sample; three each in CMNH test sample) of blacks and whites were misclassified using this method, suggesting that while statistically significant variation may be present between blacks and whites for *some* of the variables used, it does not cause bias in sex estimation for either group.

Additionally, the calibration sample had wider age dispersion than the WSU sample, which has higher mean and absolute ages. The observed loss of accuracy in the WSU test sample may suggest that, like other sex estimation methods, this five-variable model may lose some of its predictive power as the individual ages. Previous research has shown significant ($p \leq 0.05$) variation in one of the variables (XHS) used with advancing age in adult

TABLE 3—*Five-variable model for sex estimation.*

$$\text{Sex} = 0.136 \times \text{XLS} + 0.117 \times \text{XHS} + 0.541 \times \text{HAX} + 0.296 \times \text{CSV} + 0.904 \times \text{TLB} - 66.186$$

Sex, >0 individual is male, <0 individual is female.

TABLE 4—*Accuracy of the five-variable method.*

| | CMNH Calibration | CMNH Test | WSU Cadaver |
|---|---|---|---|
| Males | 417/439 (94.9) | 44/49 (89.8) | 16/18 (88.9) |
| Females | 269/277 (97.1) | 30/31 (96.8) | 11/14 (78.6) |
| Total | 686/716* (95.8)† | 74/80 (92.5) | 27/32 (84.4) |

Values presented in parentheses are percentages.

Number and percentage of individuals correctly identified as either male or female using the five-variable model presented in Table 3.

CMNH, Cleveland Museum of Natural History.

*Eight individuals excluded from calibration sample because of missing variable values.

†Unvalidated-leave one out cross-validation results in 95.7% accuracy.

TABLE 5—*Two-variable model for sex estimation.*

$$\text{Sex} = 0.212 \times \text{XBS} + 0.201 \times \text{XHS} - 51.425$$

Sex, >0 individual is male, <0 individual is female.

TABLE 6—*Accuracy of the two-variable method.*

| | CMNH Calibration | CMNH Test | WSU Cadaver |
|---|---|---|---|
| Males | 398/446 (89.2) | 45/49 (91.5) | 16/18 (88.9) |
| Females | 262/277 (94.6) | 29/31 (93.6) | 10/14 (71.4) |
| Total | 660/723* (91.3)† | 74/80 (92.5) | 26/32 (81.3) |

Values presented in parentheses are percentages.

Number and percentage of individuals correctly identified as either male or female using the two-variable model presented in Table 5.

CMNH, Cleveland Museum of Natural History.

*One individual excluded from calibration sample because of missing variable value.

†Unvalidated-leave one out cross-validation results in 91.3% accuracy.

white males, which may affect the accuracy of the given model. The calibration sample consists of only left scapulae, while the WSU sample includes left and right scapulae. This was performed to maximize the number of individuals included in the WSU test sample. Consequently, the reduction in sex estimation seen in the WSU test sample may result from bilateral asymmetry in scapular size and shape.

Finally, the observed variation in accuracy may have resulted from a secular increase in scapula size. The CMNH samples are derived from a larger sample with birth dates mainly in the 19th century. The WSU population consists of individuals with slightly later birth dates, in the early 20th century. The misclassification of a greater number of females from the WSU sample as males supports this idea. However, the sample size is far too small to firmly assert this as the sole cause of the decreased accuracy of this method for the WSU sample. At this point, further testing is necessary to identify the exact contribution of each of these potential causes to the overall accuracy of the scapular method of sex estimation.

Over the last 100 years, many researchers have developed methods for estimating sex using various measures and characteristics of the human skeleton. It has been demonstrated that these population specific measures are necessary because the accuracy of any method decreases if it is applied to a population other than the one for which it was developed. Additionally, taphonomic processes such as decomposition and carnivore modification often damage, or even remove, sexually dimorphic skeletal elements, thus necessitating a variety of sex estimation techniques.

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