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A Test of Sex Determination from Measurements of Chest Radiographs

ABSTRACT: Sexually dimorphic distinctions within the human thoracic area may include morphological as well as metric differences in the sternum and 4th rib. This research assesses the validity of a set of previously published measurements from chest radiographs and their use in contemporary forensic situations. The chest plates from 130 adult individuals of a known sample undergoing medico-legal post-mortem examination were examined at autopsy. Thoracic radiographs were taken using a Faxitron® cabinet X-ray machine at 40 kV using Kodak Diagnostic Film Ready Pack X-Omat TL. Measurements were taken to the nearest millimetre using a sliding calliper. Logistic regression analysis of measurements of the sternum and 4th rib was undertaken to determine sex. Using 4th rib width and sternal area, sex was predicted at an accuracy of 95.8% for males and 90.3% for females.

KEYWORDS: forensic science, forensic anthropology, radiographs, sex determination, logistic regression, metric, 4th rib, sternum

The human thoracic region is relatively important in biological and forensic anthropological studies as it is active between adolescent growth and adult maturational and degenerative periods. As such, it presents an opportunity to obtain information with respect to personal identification during much of an individual's life span and may be especially important when dealing with only partial remains, where sex determination and age estimation may become more difficult. Most anthropological methods for dealing with situations of questionable identity have been developed for use on dry bone and, at the very least, require a partially, if not totally, defleshed body. While all individuals requiring a forensic examination are in some stage of decomposition, in the majority of situations these bodies are relatively intact. In such instances it may be a straightforward procedure to initiate identification processes using fingerprints, visual confirmation, unique physical characteristics, dental records, or past medical procedures as corroborating evidence. However, on occasion, an individual may be too decomposed to successfully use these methods or ante-mortem medical and/or dental records may be inadequate, unavailable, or difficult to locate. Thus any technique that is able to facilitate a rapid, simple, and inexpensive determination of sex is extremely important (1). Of particular relevance to this study, is the determination of sex in forensic contexts from radiographs of the thoracic area.

Most quantitative studies of sex differences in the human skeleton have focused on producing sex discriminating statistics. While simple univariate methods that make use of mean values for each sex or a sectioning point have been proposed, more complex statistical explorations are common. These have been primarily in the form of discriminant function analysis (2), which classifies data into two or more clusters (in this case, a male and a female cluster) by determining the best linear combination of predictor variables. However, such an analysis can be problematic because it does not allow for direct prediction of group membership for the dependent variable (3,4). Logistic regression analysis is particularly well suited for this purpose, as it allows the investigator to estimate a probability function from an independent variable or a set of variables (e.g. metrics) that are known to best predict sex. Despite this, its application in forensic anthropology has been minimal (3,5–7).

The key to the successful determination of sex from metrics is the use of measurements that have shown consistently high replicability and accuracy in allocating both male and female sex. One of the first metric methods, Hyrtl's Law (8), has been using sternal size for over 170 years as an estimator of sex. According to Hyrtl, in females the manubrium generally exceeds half the length of the sternal body whereas in males the body of the sternum is usually twice as long as the manubrium. Numerous other investigators have used sternal or thoracic area measurements as useful predictors of sex (9–16). In 1983 Stewart and McCormick (16) re-examined 64 radiographs to determine if there was a relationship between sternal length and pattern of costal cartilage mineralization. They observed that manubrio-mesosternal length alone (>158 mm = male; <142 mm = female) predicted sex correctly in 40 of the 42 (95.2%) applicable cases with mineralization patterns accurately predicting sex in 38 of the 41 (92.7%) applicable cases. Using both methods, they achieved an accuracy rate of 96.4% on 87.5%, or on 56 of the 64 cases examined.

In 1985 McCormick, Stewart, and Langford (1) again examined sex differences in chest plate radiographs of 698 males and 435 females over the age of 20 years. As in their previous study, they were concerned primarily with providing an accurate methodology that would facilitate timely, simple, and inexpensive sex determination when assessing complete, decomposed, or partial human remains. Their proposed technique required only bones of the thoracic area, a section often removed during autopsy and almost always available in a decomposing or a completely skeletonized body. Sex determination would be made directly from high-resolution chest plate radiographs, thus eliminating the need to de-flesh the individual. Six measurements were taken generating five criteria that were to be used to metrically evaluate the chest plate roentgenograms (Fig. 1). Criteria included: 1. maximum manubrium and 2. manubrium-body length (outside of the midline if necessary). The width of the

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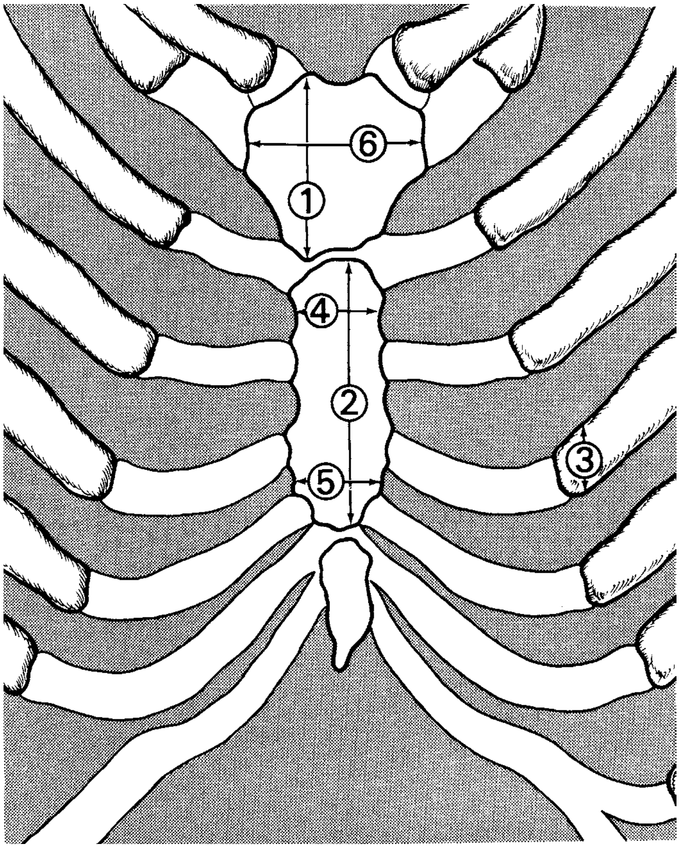

FIG. 1—*Measurements of the sternum and 4th rib reproduced with permission from McCormick et al., AJPA, V 68, 1985, page 174, Fig. 1. 1. Length of the manubrium, 2. Length of the body of the sternum, 3. 4th rib width, 4. Corpus width midway between second and third costal notches, 5. Corpus width midway between fourth and fifth costal notches, and 6. Manubrium width at first costal notch midpoint.*

4th rib 3. was taken by measuring the transverse diameter of a perpendicular line tangent to the costal margin and immediately lateral to the costochondral junction (McCormick et al., 1985). All measurements were taken from the left side. According to McCormick and colleagues, either side may be used. However, if the sides are not identical the measurement closest to the indecisive zone between larger male and smaller females should be used. Width was taken at the midpoint of the insertion of the 1st costal cartilage 6., midway between the 2nd and 3rd costal cartilage 4., and midway between the 4th and 5th costal cartilage 5. Sternal area was estimated by using the average of the three width measurements; 4, 5, and 6 and the total of the manubrium and sternal body lengths; measurements 1 and 2.

In the study conducted by McCormick et al. (1985) sternal length fell outside of the grey zone of 143 to 157 mm in 761 of the 1133 cases sampled, or 67.2%. Sex was predicted correctly in 718, or 94.3% of those cases. With a sectioning point of 148 mm, ($\geq$148 mm is male) an overall accuracy of 85.2% was observed for the entire sample. McCormick and colleagues (1) also noted that the width of the 4th rib was sexually dimorphic, supporting results found by Iscan (15) who had quantified these age-related changes using component and phase analysis on male and female individuals. McCormick et al. (1) found if they used a point of 16 mm ($\geq$16 mm is male) for 4th rib width an accuracy of 84.6% was achieved for the entire sample. Corpus width at the second intercostal interspace also reflected the sexual dimorphism seen within the other morphometric parameters, however alone it was a weak sex predictor because of the large indeterminate range (20–27 mm). Sternal area was also sex predictive, generating accuracy rates of 93.0% when the grey zone of 4976–6041 mm^2 was excluded (766 cases). If these were included the accuracy rate for sex prediction dropped to 67.6%.

The goal of this study was to evaluate the determination of sex using radiographic features of the thorax as proposed by McCormick and colleagues (1).

Materials

The chest plates from 130 subjects with documented manner and cause of death, age, population affinity, and sex were removed during post-mortem investigation of the chest cavity. The area removed and subsequently X-rayed consisted of the entire sternum with its associated soft tissue, the costal cartilage, and when available 2 to 6 cm of the terminal ends of the first through seventh ribs. In 28 of the cases, assessed rib width was not an available measurement. All radiographs collected over a 10-month period (August 2000 to March 2001) were from individuals who were undergoing medicolegal investigation by the Office of the Chief Medical Examiner (OCME) at the Health Sciences Centre, Winnipeg, Manitoba, Canada. The sex, age, and population affinity of the individuals comprising the study (89 males and 41 females, all over the age of 18 years) was unknown to the investigator at the time of analysis. Figures 2 and 3 present the age distribution of the sample.

Table 1 summarizes the distribution of this sample by population affinity. Independent samples t-tests between the two largest

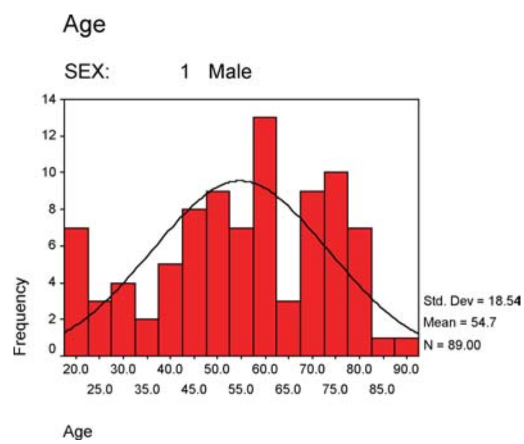

FIG. 2—*Age distribution of male OCME sample.*

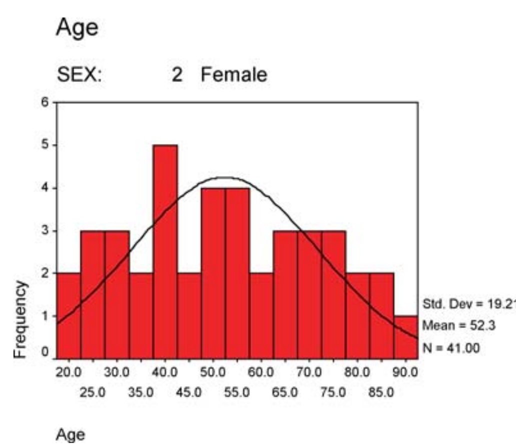

FIG. 3—*Age distribution of female OCME sample.*

TABLE 1—*Distribution of OCME sample by population affinity.*

Ethnic Affiliation	Male	Female
Caucasian	40	14
Native American	16	8
Negroid	1	0
Mongoloid	1	1
Unknown	31	18
Total	89	41

TABLE 2—*Independent samples t-test of means for Caucasian and Native American groups.*

Sex	*t*	*df*	*p*	Mean Diff.	s.e.
Male					
Manubrium Length	1.3424	54	0.185	2.487	1.853
Body Length	−0.8787	54	0.383	−2.461	2.801
Sternum Length	0.0076	54	0.994	0.026	3.366
4th Rib Width	0.6985	38	0.489	0.578	0.828
Costal II and III Width	−0.2925	54	0.771	−0.356	1.218
Manubrium Width	−0.2116	54	0.833	−0.409	1.935
Costal IV and V Width	−0.1871	54	0.852	−0.438	2.342
Area	−0.1961	54	0.845	−57.352	292.505
Female					
Manubrium Length	−1.5753	20	0.131	−3.406	2.162
Body Length	−0.3322	20	0.743	−1.548	4.660
Sternum Length	−0.9487	20	0.354	−4.954	5.222
4th Rib Width	−0.1639	15	0.872	−0.137	0.839
Costal II and III Width	0.0473	20	0.963	0.079	1.681
Manubrium Width	−1.2652	20	0.220	−3.779	2.986
Costal IV and V Width	0.5441	20	0.592	1.361	2.501
Area	−0.8437	20	0.409	−282.895	335.304

subgroups, White and Native American, showed no significant differences in any of the metrics under study (Table 2). It should be noted however that sample sizes were not large, and therefore true differences between these groups might not be detectable. Nevertheless, within the current sample, ethnicity does not appear to be a confounding factor (17). The impact of height and weight as assessed at the time of autopsy was also examined. While some of the variables showed statistically significant correlations with height (and occasionally with weight), this was not surprising. However, partial correlation analysis showed that all variables continued to be significantly correlated with sex even when controlling for height and weight ($p < 0.05$). In addition, when included as a covariate in the logistic regression analysis, both height and weight had coefficients that were not significantly different from zero. That is, height and weight did not contribute to the prediction of sex when included with any of the models tested.

Methods

Chest plate radiographs were taken using a Faxitron® cabinet X-ray machine at 40 kV using Kodak Diagnostic Film Ready Pack X-Omat TL. According to McCormick and colleagues (1) less than 1% magnification occurs because the chest plate is placed directly onto the film, and while the chest plate is not perfectly flat, the areas measured for sex determination are those closest to the film. As a result, the magnification of the area being measured is negligible. All measurements were taken to the nearest millimeter with the use of a sliding caliper (accurate to ± 0.05 mm).

Eight variables from six different measurements of the sternum, as proposed by McCormick et al. (1), were tested for significant differences between sexes (Fig. 1). All were found to be sexually dimorphic (Table 3).

The accuracy of sex determination using sectioning points and ranges for measurements that McCormick and his colleagues (1) found to be sexually dimorphic (using metric criteria alone), were assessed (Table 4). Finally, logistic regression models were generated from the OCME sample to evaluate the predictive power of these measures.

Logistic regression equations are of the form

$$L_i = \beta_0 + \beta_1 X_i + \beta_2 X_i$$

where the logit (L_i) is a linear function of the independent variable(s) X_i. Values for the constant (β_0) and variable coefficients

TABLE 3—*Independent samples t-tests of mean measures between the sexes.*

Sex	*N*	Mean	s.d.	s.e.	*t*	*df*	*p*
Manubrium Length							
Male	89	54.431	6.101	0.647	5.188812	128	<0.001
Female	41	48.793	4.917	0.768			
Body Length							
Male	89	109.406	12.479	1.323	7.303871	128	<0.001
Female	41	93.551	8.981	1.403			
Sternum Length							
Male	89	163.837	14.826	1.572	8.288952	128	<0.001
Female	41	142.344	10.969	1.713			
4th Rib Width							
Male	71	18.515	2.145	0.255	8.807103	100	<0.001
Female	31	14.760	1.532	0.275			
Costal II and III Width							
Male	89	29.826	5.655	0.599	5.76533	128	<0.001
Female	41	24.267	3.626	0.566			
Manubrium Width							
Male	89	57.184	5.907	0.626	7.016168	128	<0.001
Female	41	49.050	6.631	1.036			
Costal IV and V Width							
Male	89	35.957	7.674	0.813	4.680486	128	<0.001
Female	41	29.616	5.942	0.928			
Area							
Male	89	6716.517	963.562	102.137	10.47697	128	<0.001
Female	41	4901.526	808.097	126.204			

TABLE 4—*Accuracy of sex prediction of the OCME sample using McCormick et al.'s (1985) sectioning points and ranges.*

Variable Name	Sectioning Point (mm)	Accuracy		Range Indeterminant	Accuracy	
		Male	Female		Male	Female
Sternal Length	148	89.89%	73.17%	143–157	70.79%	56.10%
4th Rib Width	16	88.73%	80.65%			
Corpus Width				200–277	75.28%	12.20%
Sternal Area	5400	89.89%	80.49%	4976–6041	75.28%	65.85%

TABLE 5—*Regression coefficients and accuracy for sex allocation for each measurement. Accuracy is calculated using the leave-one-out (LOO) mathod.*

Model	Beta	s.e.	Wald	*df*	*p*	Male	Female	Overall
1 Sternal Body Length	−0.146	0.028	21.600	1	<0.001	92.1	68.3	84.6
Constant	14.014	2.801	25.038	1	<0.001			
2 Manubrium Length	−0.171	0.040	18.626	1	<0.001	91.0	41.5	75.4
Constant	8.044	2.026	15.763	1	<0.001			
3 Sternal Length	−0.129	0.023	30.395	1	<0.001	92.1	68.3	84.6
Constant	18.902	3.530	28.667	1	<0.001			
4 4th Rib Width	−1.033	0.203	25.944	1	<0.001	90.1	71.0	84.3
Constant	16.229	3.283	24.431	1	<0.001			
5 Costwone	−0.342	0.066	26.880	1	<0.001	87.6	56.1	77.7
Constant	8.373	1.730	23.411	1	<0.001			
6 Manubrium Width	−0.219	0.044	24.973	1	<0.001	91.0	51.2	78.5
Constant	10.912	2.325	22.031	1	<0.001			
7 Sternal Area	−0.002	0.001	12.551	1	<0.001	95.8	90.3	94.1
4th Rib Width	−0.850	0.263	10.441	1	0.001			
Constant	26.002	6.212	17.524	1	<0.001			

(β_1, β_2) are presented. The model is estimated using a maximum likelihood estimation (MLE) technique. The MLE then expresses the probability of obtaining the observed sample as a function of the model parameters (18). The probability function is of the form:

$$\hat{P} = \frac{1}{1 + e^{-\hat{L}}}$$

and represents the so-called S-curve. In the present context, the probability closer to 1 is that a given value predicts being female. An inverse of 1-*p* or closer to zero, is that the given value is predictive of being not female or in this case male. Visually, the S-shaped probability curve should have a steep and narrow vertical rise with quickly flattening tails at both ends that are near to 1 and zero. This would represent a measure that has high predictive power for both groups with a relatively narrow range of uncertainty (the transition between $p = 1$ and $p = 0$).

How well the model predicted sex was gauged by goodness of fit statistics and cross-validation. Cross validation of accuracy for this analysis was undertaken by leave-one-out analysis. The accuracy of prediction from the model based on the analysis sample tends to result in an over-estimation of true prediction. Alternatively a hold out sample or subset of the sample can be removed from the data set used to develop the logistic regression models. This is impractical for relatively small sample sizes such as the current analysis. As a result, the leave-one-out analysis re-calculates logistic regression models n-1 times, each time excluding one case for which prediction will be estimated. The result is a distribution of predicted values that are unbiased. Coefficients and their standard errors can be averaged over the n-repeated models.

The issue of external validity of the models was a separate matter. In this study, logistic regression was utilized in order to independently evaluate the sex discriminating power of McCormick and colleagues' previously published set of measurements. We have presented our models here for diagnostic and critical assessment by readers. We do not suggest that these models are broadly applicable to other populations. Before making such a statement, further external validation of the models, on a variety of different documented samples would be required.

Results

Independent samples t-tests demonstrate significant differences in the means of each measurement between the sexes in the OCME sample (Table 3). Table 4 presents the accuracy of sex determination in the OCME sample using McCormick et al.'s (1) sectioning points and ranges.

Logistic regression analysis was undertaken on the OCME sample for each of the metric variables that McCormick and colleagues (1) found to be significant with respect to determining sex. Probability curves for each of the univariate models are presented in Fig. 4 and the regression model coefficients and predictive accuracy are presented in Table 5. Accuracy of the model prediction is estimated based on a leave-one-out analysis.

A multivariate model using two variables accurately predicted sex between 90.3% for females and 95.8% for males in the OCME sample (Table 5, Model 7). As noted by Saunders and Hoppa (3) logistic regression models are still affected by multicollinearity among independent variables. Thus, some degree of correlation exists between measurements of the thorax, given that they are all a function of skeletal growth. This results in the standard error of the variable coefficients being greater in the multivariate model as compared to the univariate models.

Discussion

In McCormick and coworkers' (1) study, an indeterminate range of 143 to 157 mm was found for sternal length. They observed that males less than 25 years of age had statistically shorter sternal lengths while older males had sternal lengths much closer to the male mean (161.6 mm). They noted that females 20 to 21 years of

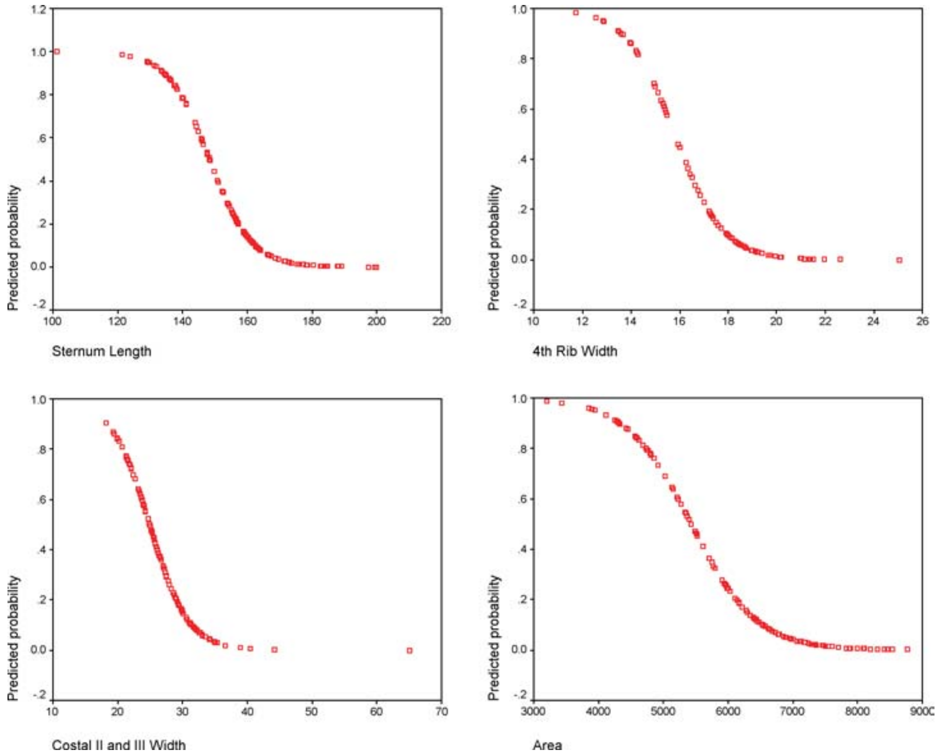

FIG. 4—*Probability curves for sex allocation (1 = female, 0 = male) based on the logistic regression models presented here using measurements noted by McCormick et al. (1985).*

age also had significantly shorter sternal lengths while older females showed no significant difference statistically. Within the OCME sample there was no age-related trend with any of the measurements except for manubrium length. Analysis of variance demonstrated a significant difference in manubrium length when the sample was grouped by decades of age for both males ($F = 3.346$; $df = 88$ $p = 0.004$) and females ($F = 2.39$; $df = 40$; $p = 0.043$). However, the trend was only weakly linear with middle-aged males having longer manubriums than males of other ages. For females, the trend was less clear, although suggestive of middle-aged females having shorter manubrium lengths than the youngest and oldest females in the sample.

Consistent with previously published work (1, 16), accuracy for all the univariate models was consistently higher, and often at acceptable levels, for males rather than for females. McCormick and colleagues (1) also observed that sternal length, 4th rib width, and sternal area when used alone were the stronger sex predictors of their variables. In the present study, it was observed that the 4th rib width and sternal area used together were the best predictors of sex with accuracy rates of 95.8% for males and 90.3% for females. In addition, the multivariate model resolves the issue of asymmetry in the accuracy of prediction for males.

Conclusion

As previously stated, sex determination of unknown individuals is not always a straightforward procedure, especially when confronted by badly decomposed or severely traumatized remains. This becomes even more challenging when only partial remains are available. While the majority of techniques and standards have been developed for use on dry bone and require defleshed remains in order to assess morphological landmarks and generate accurate measurements, the technique presented here may be successfully utilized on completely intact, decomposed, or partial remains. Accurate determination of sex from metric analysis of the sternum is facilitated by using only a few very simple and rapidly taken measurements (1,16,17). These are easily taught and reproduced and require little or no special processing of remains or unique equipment. For those individuals who do not have access to a Faxitron® unit, measurable radiographs may be obtained utilizing conventional x-ray equipment operated at a target distance of approximately one meter or more from the breast plate with the latter in contact with the film.

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