ESTIMATING SEXUAL DIMORPHISM FROM STERNAL RIB ENDS

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Kristina Rhea Gavit, B.B.A.

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ESTIMATING SEXUAL DIMORPHISM FROM

STERNAL RIB ENDS

Committee Members Approved:

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Jerry Melbye, Chair

____
Kate Spradley

____
Kerrie Lewis

Approved:

____
J. Michael Willoughby
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Forensic anthropology is a branch of anthropology concerned with the application of anthropological knowledge and methods to the legal process. The identification of skeletal remains, badly decomposed, or otherwise unidentified human remains is important for both legal and humanitarian reasons. Forensic anthropologists apply standard scientific techniques developed in physical anthropology to identify human remains and assist in the medico-legal process. Frequently, forensic anthropologists work in conjunction with forensic pathologists, odontologists, and homicide investigators to identify a decedent, discover evidence of foul play, and/or the decedent’s postmortem interval. In addition to assisting in locating and recovering suspicious remains, forensic anthropologists create a biological profile, consisting of sex, age, ancestry, stature, and unique features, such as any antemortem pathology or postmortem trauma of a decedent from the skeleton (ABFA 1996).

Estimation of sex from the human skeleton is among the most important aspects of establishing the biological profile of unknown individuals in forensic anthropology (Patil and Mody 2005). The aim of the current research is to evaluate the reliability of the sternal end of the first and second ribs in estimating the sex of unidentified skeletal remains for a recent forensic population. When establishing the biological profile, it is typically important to first estimate sex and age, then ancestry and stature (White and

Folkens 2005). Humans are slightly sexually dimorphic, which is apparent in primary and secondary sexual characteristics of the soft tissue but far less obvious in hard tissue bones. Size and shape of bones in females and males overlap somewhat, but there are some slight differences that aid in estimating sex. For example, at the onset of puberty the female skeleton, and especially the pelvis, begins to change shape (Högler et al. 2008). During this time period, the pelvic outlet expands to allow females to more easily give birth. The male pelvic outlet does not expand and keeps a more narrow pelvic shape.

Estimation of sex via examination of sexually dimorphic features has focused primarily on the pelvic girdle, long bones, and the skull where size and morphology are arguably most variable. Numerous areas of the pelvis and skull are used in determining sex (Krogman 1962; Meindle et al. 1985; Phenice 1969; Purkait 2003; Steyn and Iscan 1997). Using 11 measurements of the skull, Giles and Elliot (1963) found that sex could be estimated correctly 85% of the time. When combined, these two areas have been argued to produce inter-observer accuracy rates of up to 97% when examined by a professional forensic anthropologist (Krogman 1962). However, in cases where the pelvis and skull are not always available for study, or are too damaged for examination, alternative methods of sex estimation are required. Other areas of the body, such as the long bones and ribs, may provide an alternative for estimating an individual's sex.

Sex can be estimated reasonably well using long bone measurements or visual estimations (Rissech et al. 2008; Steel 1972). Long bones have been found to be highly dimorphic, especially in areas such as the head and distal epiphysis of the femur, and proximal epiphysis of the tibia (Iscan and Miller-Shaivitz 1984). The maximum head diameter of the femur has been confirmed as a good indicator of sex, with classification accuracy reaching 92% for males and 95% for females (Purkait and Chandra 2004). Purkait and Chandra (2004), using a central Indian sample found that a maximum femoral head diameter value of less than 42.9 mm indicate a female bone, and measurements over 42.9 mm indicate a male bone. The sternal ends of fourth ribs have also given beneficial results for sex estimation.

In the absence of the pelvis and long bones, the fourth rib was chosen in most of the previous studies pertaining to ribs because the fourth rib was easily obtained during routine postmortem examinations and it made for easier comparison to later studies (Iscan 1985; Oettlé and Steyn 2000). Ribs have been analyzed using osteometric data, as well as chest plate roentgenograms and costal cartilage calcifications (Kocak et al. 2003; McCormick et al. 1985; Navani et al. 1970; Stewart and McCormick 1984). A roentgenogram is a radiograph that is made by exposing photographic film to X-rays. Unfortunately, all of these studies were conducted looking specifically at the fourth rib, which is difficult to identify when a skeleton is disarticulated.

Many areas of the skeleton have been researched in regards to sex because estimation of sex is extremely important for the biological profile of an individual. In most cases, forensic anthropologists receive an incomplete skeleton. Although the pelvis, long bones, and skull have been shown to provide accurate estimates of sex, there are numerous occasions where these elements are not recovered or are rendered useless due to peri- or postmortem damage (Ubelaker 1997). It is important for alternate areas of the skeleton to be researched for sex estimation. One possible area that may aid in the estimation of sex is the sternal end of the first or second rib. The first and second ribs are more uniquely shaped making their identification much easier than the fourth rib, and are ideal when the pelvis and skull are absent. Visual estimates are based on basic sexual dimorphism, anticipating that males are normally larger in size than females.

The purpose of this research is to determine whether sexual dimorphism of the first or second rib is sufficient to be of value for sex estimation. This research is important and distinctive because it provides quantitative results. Data that contain quantitative results strengthen the reliability of ribs as potential sex estimators, especially in courtroom settings. The first important ruling regarding the admissibility of scientific evidence was issued in *Frye v. United States* (Christensen 2004). This rule became the standard for determining admissibility of scientific evidence in courts because it was easy to apply and little scientific knowledge was needed. Due to modifications or disregard of the *Frye* standard, the *Federal Rules of Evidence* was enacted, which was the first uniform set of evidentiary rules for trial in federal courts that specifically addressed expert witness testimony (Christensen 2004). Confusion still occurred in the courts concerning the admissibility of scientific evidence, which led to a set of factors referred to as the "*Daubert* guidelines". *Daubert* is a legal precedent set in 1993 by the Supreme Court of the United States regarding the admissibility of expert witness testimony during federal legal proceedings. *Daubert* requires forensic anthropologists to validate their claims with scientifically tested methods and, in particular, with probability assessments (Dirkmaat et al. 2008). The *Daubert* guidelines for determining whether evidence is scientific and therefore admissible under Federal Rule 702 are (U.S. Supreme Court 2003):

1. The content of the testimony can be (and has been) tested using the scientific method.

2. The technique has been subject to peer review, preferably in the form of publication in peer-reviewed literature.
3. There are consistently and reliably applied professional standards and known or potential error rates for the technique.
4. Consider general acceptance within the relevant scientific community.

Testifying as an expert witness has become an important and increasingly accepted role of the forensic anthropologist (Christensen 2004). In regard to the *Daubert* guidelines, publications in peer-reviewed literature and professional standards are few in number for the estimation of sex from the ribs. It is imperative for forensic anthropologists to continue conducting research and publishing quality data on biological profile methods and techniques. Research attempting to estimate sex from the first and second ribs is important to forensic anthropology because it gives supporting evidence of an unknown individual's sex. Given this, the potential to use a multitude of different bones to estimate sex could be of vital importance. Additionally, *Daubert* reinforces the need for modern forensic samples as a basis for testing traditional analytical methods as well as developing new methods.

CHAPTER II

LITERATURE REVIEW

Estimation of sex from the sternal ends of the fourth rib has been shown to hold promise (McCormick et al. 1985). The ribs were analyzed using chest plate roentgenograms, costal cartilage calcification, and osteometric analysis. McCormick and Stewart (1983) were among the first to examine the possibility that sex differences existed in the chest area. Their study consisted of over 650 chest X-rays of autopsied males and females. The results found that there was a difference among the sexes in the ossification patterns of most individuals. A later report by Stewart and McCormick (1984) expanded on particular patterns of costal-cartilage ossification and determined that there was a distinctive pattern found only in females. The distinctive pattern consists of a rounded or solitary ossified foci confined to the central portions of the costal cartilages. When this pattern is present, the individual can be identified as an elderly female. Although these results were useful when focusing on ossification patterns, there is no specific focus on the rib itself and it is specific to elderly females only.

McCormick et al. (1985) examined sex differences on over 1,100 chest plate roentgenograms. The chest plate is defined as the anterior portion of the thoracic cage consisting of the complete, intact sternum, costal cartilages, sternal rib ends, and the associated soft tissues (McCormick et al. 1985). The five parameters used to evaluate sex are the: 1) manubrium-corpus, 2) fourth rib width, 3) corpus sterni, 4) manubrium-corpus area, and 5) pattern of costal cartilage ossification.

Although the study by McCormick et al. (1985) examined several parameters, the focus of this discussion is on the impact of the fourth rib width, which is defined as the transverse diameter measured by a line perpendicular to a tangent to the costal margin and immediately lateral to the fossa costae. According to the McCormick et al. (1985) study, it is determined that the fourth rib width exhibits sexual dimorphism. If a cutoff of 16 mm is used for male, an accuracy of 84.6% is obtained for the entire study population (McCormick et al. 1985). It was also found that in 196 cases reviewed, the fourth rib width was more predictive of sex than ribs II, III, or V. Although the fourth rib width measurement did not show strong sex differences by itself, the measurement is useful with the computation of the manubrium-corpus area estimate, which the authors found to be a better indicator of sex.

When looking specifically at the effectiveness of using the fourth rib, the McCormick et al. (1985) study does not give overwhelming support for sex estimation. As mentioned, fourth rib width measurements are most useful in conjunction with the computation of the manubrium-corpus area estimate. McCormick et al. (1985) focuses on sex estimation from the entire chest plate x-ray, which is not as useful in a “typical” forensic setting.

Torwalt and Hoppa (2005) also conducted research to test the accuracy given to sex estimation from chest radiograph measurements. This study used chest plates from 130 adult individuals of a known sample and looked at the fourth rib width and the sternal area as a whole. Results confirmed the accuracy of previous research and additionally found that the fourth rib width and sternal area used together were the best predictors of sex with rates of 95.8% for males and 90.3% for females (Torwalt and Hoppa 2005). Similar to the McCormick et al. (1985) study, this research is helpful only when the entire sternal area is available and is not appropriate for most forensic anthropological cases.

Navani et al. (1970) conducted a study to evaluate the prevalence of costal calcification in males and females to examine the influences of age and sex on patterns of costal cartilage calcification. The authors used 1,000 frontal chest roentgenograms from in-patients at the Boston City Hospital. The first rib was not used in this study because, according to the authors, sexual differences in patterns of costal cartilage calcification were not found in this rib. Costal cartilage calcification was divided into three broad categories and used when analyzing the results. These categories are: A. Type I (marginal), B. Type II (central), and C. Type III. Various patterns of calcification appear in males and females and are prevalent in Type I and Type II calcification.

Several findings have emerged from these data that suggest sex can be predicted with high accuracy from costal cartilage calcification patterns of the lower ribs (Navani et al. 1970). Type I calcification predominately occurs in males and Type II calcification predominately occurs in females. Another interesting finding is the infrequent occurrence of calcification of any kind in males under 20 years of age. Certain problematic issues arise with this study, however. For example, Navani et al. (1970) divide calcification into three categories but give no detailed description to further explain what each category encompasses. Figures are included, but are difficult for examination and discerning what is being viewed as “marginal,” “central,” or other. It would be beneficial in future studies to include more descriptive definitions of each category. Additionally, it is unlikely that a forensic anthropologist would benefit from these findings because of the lack of retrieval of costal cartilage in ribs in most instances.

Morphological estimation of sex specifically from sternal rib ends is a useful method**,** but few studies exist on this subject. Two previous studies by Iscan (1985) and Kocak et al. (2003) focus on osteometric analysis of sexual dimorphism. The Iscan (1985) study attempts to estimate sex from the sternal end of the fourth rib. A sample of 230 individuals of known age, sex, and race was obtained from a medical examiner's office. Iscan divided the sample into three groups, consisting of young (mean ages 14 to 28), old (mean ages 28 to 65), and combined total groups (mean ages 14 to 65) to control the effect of age on sexual dimorphism. Three measurements were taken at the costochondral junction of the rib: maximum superior-inferior height (SIH), maximum anterior-posterior breadth (APB), and maximum pit depth (MPD). The costochondral junction of the rib is the junction of the rib into cartilage in the anterior chest. SIH is the maximum distance between the most superior and inferior points at the end of the rib. APB is measured at the end of the rib between the most anterior and posterior points. MPD is defined as the maximum depth of the concavity at the medial articular surface of the rib and is taken with a depth caliper. Results from the study show that males are larger in all dimensions, and with the exception of MPD in the young group, the differences between the sexes is significant at a probability level of less than 0.001 (Iscan 1985). Average accuracy for classification of sex varied from 82% in the young group to 89% in the old group. Additionally, females were more accurately classified than males in the young group.

Kocak et al.'s (2003) study also looks at sex estimation from the sternal end of the rib by osteometric analysis. In this study, 251 right fourth ribs of known age, sex, and race from Izmir, Turkey are used to establish a sample group from this population. Three measurements taken in this study are the superior-inferior height (SIH), anterior-posterior breadth (APB), and medial pit depth (MPD), the same measurements as used by Iscan. Differences between Kocak et al. and Iscan's studies include the population and the total age range used. Kocak et al. (2003) separate ages into a young group (15-32 years), old group (33-89 years), and total group (15-89 years). Despite the minor differences, this study gives similar results as achieved by Iscan (1985). SIH is found to be the most effective parameter to estimate sex; APB is the second most effective measurement in sex estimation. Accuracy rates vary slightly depending on the age group used, but using SIH of the total group yields an accuracy of 85.5% for males and 87.2% for females.

Cologlu et al. (1998) conducted a study using the sternal end of the fourth rib of almost 300 autopsied Turkish individuals to determine sex. The focus of their research was to use measurements of the superior-inferior (SIH) edge and anterior-posterior (APB) edge of the rib to estimate the usefulness of this bone. Using both dimensions together, Cologlu et al. (1998) reported accuracy results of 86% to 90% with the SIH being the most dimorphic dimension.

Osteometric analysis of sexual dimorphism was also conducted on a West African population. Wiredu et al. (1999) carried out a study specifically looking at sex estimation from the height and width of the sternal end of the fourth rib. As seen in studies by Iscan (1985) and (Kocak et al. 2003) mentioned above, Wiredu et al. divided their sample into three groups: young (<30 years), old (≥30 years), and total sample (total group). Their analysis showed that accuracy of sex estimation varied between the young and old groups, with the total group yielding 78% accuracy rates. An important issue with the

Kocak et al. (2003), Cologlu et al. (1998), and Wiredu et al. (1999) studies is that they use samples from Turkish and West African populations respectively. Results obtained by these three studies are for specific populations, and are not representative of North American populations. Rib size has been found to be population-specific, affected by environmental and climatic differences (Kocak et al. 2002). Therefore, the Kocak et al. (2003), Cologlu et al. (1998), and Wiredu et al. (1999) studies are not applicable for North American populations.

While these previous investigations are extremely useful, Iscan (1985), Kocak et al. (2003) and Wiredu et al's (1999) studies focus more specifically on the sternal end of the fourth rib, which is an element that forensic anthropologists may recover from a scene and use in estimating age and sex of an individual. Issues arise though when the skeletal remains are not found in articulation or when remains are very badly damaged. Although the adult fourth rib can be reliably used to estimate sex by discriminant function analysis, the fourth rib is difficult to identify when the skeleton is disarticulated because it resembles most other ribs in the human body. In a typical human body, the ribs increase in length from the first through the seventh rib and decrease from the eighth through the twelfth rib. This information is useful when all of the ribs are recovered, but is of little help when only a few ribs are found.

The first and second ribs are more easily identifiable in comparison to the fourth rib due to their unique shape and structure. Fourth ribs are less easy to identify because morphologically, they are very similar to the third, fifth, sixth, and seventh ribs. When ribs are not recovered, determining which rib is the fourth can be difficult. In contrast, both the first and second ribs are more morphologically distinct. The first rib is the broadest, short, tightly curved, and almost flat. It also has a relatively long neck in relation to its overall size. The second rib is longer than the first and is also strongly curved. The present study evaluates the success of using first and second sternal rib end measurements for sex estimation.

CHAPTER III

MATERIALS AND METHODS

The present study includes 87 females and 236 males of known age and sex. Ages of the measured individuals range from 22 to 101 years and are predominately of American White and American Black ancestry. The data samples were collected in the summer of 2008 from two existing skeletal collections, the William Bass Donated Skeletal Collection at the University of Tennessee and the Maxwell Museum's Documented Skeleton Collection at the University of New Mexico. The two collections were chosen because both consist of well-documented individuals with accurate and detailed biological profile information. Additionally, both collections consist of individuals from recent forensic populations.

The Bass Collection currently houses over 700 individuals in separate boxes with all available biological profile information on the side for easier viewing. The contents of each box are sorted in a systematic manner, with the ribs conveniently located at the top of the disarticulated skeleton. Ribs are typically separated into right and left sides and bound together with string or Velcro. To avoid observer bias throughout the data collection stage, multiple precautions were taken. Crania, innominate, and long bones were not removed from the box unless they were specifically obstructing the path to the ribs. This was done to ensure that the observer would not have other visual methods available to estimate sex.

In this study, measurements were taken in rounds, consisting of more than one box being placed on a research table at a time. Each "round" of measurements consisted of up to three separate boxes brought simultaneously to the research table and turned around so as to hide the biological information on the side of the boxes. First and second left and right ribs were taken out of each box and placed in close proximity to their respective box to ensure the correct rib was recorded with the corresponding individual. Each rib, totaling up to four ribs per individual (right first, left first, right second, left second), was measured with a Titan digital caliper and the results were recorded to the nearest tenth of a millimeter on a spreadsheet. After all ribs from the three boxes were measured and recorded on the spreadsheet, the University of Tennessee identification number given to the individual was recorded and the boxes were returned to their specific shelves. This process was repeated and measurements were taken with the time available. A total of 221 individual observations were collected at this location.

Unlike the Bass collection, boxes from the Maxwell Museum Collection did not contain biological profile information on the outside. Therefore, only one box was brought to the table at a time. All other procedures performed were similar to the procedures outlined for the Bass collection. One hundred and two individual observations were collected at this location. Both the Bass and Maxwell Museum collections graciously supplied complete biological profile information (including the individual's sex) after all of the observations had been collected and recorded. Individual observations and measurements are noted in Appendix A.

To account for observer bias, the individual's sex was unknown until measurements for all samples had been completed from each collection. Both collections house more males than females. Subsequently, the number of males greatly outnumbered the number of females measured for in this research. It is important to obtain a large sample of both males and females, and this was accomplished despite the number of male observations outweighing the number of females.

The right and left first and second ribs were collected from samples of known age and sex. For all analyses, the right rib was used unless it was missing or too badly damaged. The right rib was chosen to keep consistent with previous studies that focus their analyses on this side (Iscan 1985; Kocak et al. 2003; Wiredu et al. 1999). Additionally, the difference in overall descriptive statistics between the left and right side was negligible. If damage was present or the right rib was not available, the left rib was used in analysis, and is documented in Appendix A. Two measurements taken for each rib were superior-inferior height (SIH) and anterior-posterior breadth (APB). All measurements were taken in accordance with the procedure described by Iscan and associates (Iscan et al. 1984). Although not given in precise detail, Iscan et al. took the SIH and APB measurements at the costochondral junction of each rib, the method followed by the present study. The costochondral junction is defined as the junction of the rib into cartilage in the anterior chest. All of the measurements were taken with a digital sliding caliper calibrated to the nearest 0.1 mm. These measurements are defined as:

1. Superior-Inferior Height (SIH) (Figure 1): the maximum distance between the most superior and inferior points at the end of the rib; and
2. Anterior-Posterior Breadth (APB) (Figure 2): the maximum distance between the most anterior and posterior points at the end of the bone.

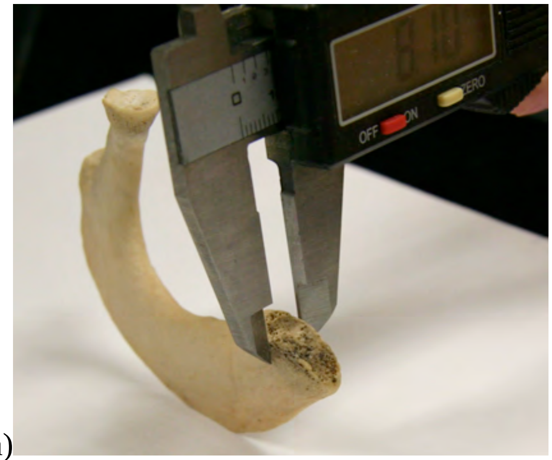
a)  b) 

Figure 1. Superior-inferior height (SIH) measurement: a) first rib; b) second rib.

a) 

b) 

Figure 2. Anterior-posterior breadth (APB) measurement: a) first rib; b) second rib.

Iscan et al. (1984) also took measurements of the maximum pit depth (MPD), but it was not used in this study because it was found to be ineffective for results in previous studies (Kocak et al. 2003).

The superior-inferior height was defined as the maximum distance between the most superior and inferior points at the end of the rib. This measurement was taken by holding the rib in anatomical position. The fixed arm of the sliding caliper was held parallel to the inferior side of the sternal end of the rib and the caliper's moving arm was adjusted to meet the most superior point on the sternal end of the rib. It should be noted that the shape and position of the sternal end of the rib is variable, so the calipers will not always lie perfectly across the height of the sternal end. The measurement was always taken at the maximum distance.

The anterior-posterior breadth was defined as the distance between the most anterior and posterior points at the end of the bone. This measurement was taken by holding the rib so that it faced perpendicular to anatomical position. The sliding caliper was held parallel to one edge of the rib and adjusted to meet the maximum breadth point of the sternal end of the rib. As noted for the superior-inferior height, the measurement was always taken at the maximum distance.

Previous studies, including Iscan et al. (1984) and Kocak et al. (2003), assigned a rib to an age group based on its metamorphic phase. Iscan and Loth (1986) found the sternal rib to be one part of the skeleton in which dimorphism increased with age throughout most of the adult life span, although in their study, the average percentage of correct prediction of the different age groups did not differ significantly. Due to the slight differences in average percentage correct between age groups, age was considered negligible for the present study and not taken into account when analyzing the data. In addition, age estimation is increasingly difficult to determine without additional skeletal material, such as the pelvis. Age, nevertheless, was obtained for each individual for future studies and is documented in Appendix A.

Although age was not considered in the data analysis, the sternal end of a rib exhibits certain changes with advancing age. Iscan et al. (1984) studied the sternal end of the fourth rib and found that changes occur in form, shape, texture, and overall quality. They created a 9-phase model standard for both males and females, illustrating each phase by both a picture and description. Early phase characteristics of the sternal end of the fourth rib contain ribs that have a more regular, rounded rim with the bone smooth and solid. Middle phase characteristics show some pit depth and thinner walls. Late phase characteristics include more visible pit depth, thin walls, and an irregular rim with brittle projections of bone at the superior and/or inferior margins of the rib.

Early and middle phase characteristics did not affect the SIH and APB rib measurements taken. Projections of bone that were present in the late phase of rib development presented an obstacle when trying to keep measurements consistent. Whenever a rib was encountered that exhibited this extra bone projection, the measurement was still taken at the maximum height and breadth, and the projection was documented during collection and is noted in Appendix A. This was done to keep all measurements consistent, even if the measurement with the projection slightly misrepresented the sternal end's true dimensions.

For each collection used, race was available, but not taken into account in this study. Individuals with known or observable pathology affecting the integrity of the sternal end of the rib were not used in this study. If an individual's rib was measured and the individual had a noted pathology, the information was documented during data collection and can be found in Appendix A. When an individual's rib was fractured or cracked, it was only measured if the integrity of the rib's sternal end was not compromised or altered. The measurement taken adhered to previously stated guidelines. Any measurement taken on a fractured rib was documented during data collection and noted in Appendix A.

The goal of the current research is to provide forensic anthropologists with another means of estimating sex through discriminant function analysis (DFA). This research uses four measurements from the first and second right ribs from individuals contained in the William Bass Donated Skeletal Collection housed at the University of Tennessee and the Maxwell Museum's Documented Skeleton Collection housed at the University of New Mexico. The ratio of males to females is approximately 3:1 due to the availability of samples at the collections used and the manner in which the measurements were taken. Although it is ideal to have an equal representation of males and females in any study dealing with sexual dimorphism, it is not always feasible. The greater proportion of males to females does not impact the final results negatively.

A DFA was performed to classify observations into groups defined by sex using Statistical Analysis Software (SAS) for Windows version 9.1.3. The left-side rib was used only when the right-side rib was missing or too damaged to measure and is recorded in Appendix A. Descriptive statistics were calculated, including the minimum, maximum, mean, and standard deviation, for all variables. Because not all skeletal elements are recovered in a forensic anthropology case, each measurement was run separately to see how well it estimated sex. Next, a stepwise DFA was performed for all four measurements in order to determine whether all of the measurements or a subset is best at discriminating sex. Then, a DFA was run using the stepwise selected measurements in order to arrive at cross-validated classification rates and linear discriminant function scores.

CHAPTER IV

RESULTS

Descriptive statistics for each measurement are found in Tables 1 and 2. Table 1 is broken down specifically by the variable, while Table 2 separates the data further into males and females. The number of individuals reported in Tables 1 and 2 reflects all individuals in the study sample, mostly referring to the right-side rib. The stepwise selection method did not remove any measurements for the purpose of discrimination; therefore all variables were run in the DFA.

Table 1. Descriptive statistics for total sample observations and all variables.*

Variables	N†	Minimum	Maximum	Mean	Standard Deviation
First Right SIH	323	4.16	21.68	12.71	3.44
First Right APB	323	12.06	33.20	20.45	3.15
Second Right SIH	323	2.56	19.21	8.44	2.17
Second Right APB	323	10.45	23.21	14.55	1.97

*All measurements shown in millimeters.
†Sample includes a total of 87 females and 236 males.

Table 2. Descriptive statistics for females and males.*

Variables	Females (N = 87)		Males (N =236)	
	Mean	SD	Mean	SD
First Right SIH	10.54	2.77	13.51	3.31
First Right APB	18.69	2.41	21.09	3.15
Second Right SIH	7.16	1.55	8.90	2.18
Second Right APB	12.88	1.35	15.16	1.81

*All measurements shown in millimeters.

Table 3. Summary of stepwise selection process.

Variables	F Value	Wilks' Lambda	P-value
*First Right SIH	36.32	0.661	<.0001
First Right APB	5.10	0.651	0.0246
Second Right SIH	3.92	0.643	0.0486
*Second Right APB	115.15	0.736	<.0001

*No variables were selected for removal.

Cross-validated classification rates for each individual measurement are reported in Table 4. These rates suggest that, when analyzed by specific rib, the second rib has a slightly better ability to correctly classify skeletons by sex. Using the first rib's SIH, approximately 77% of females and 65% of males were accurately classified into their corresponding sex. The first rib's APB yielded results of approximately 74% for females and 62% for males correctly classified. Approximately 71% of females and 75% of males were classified correctly using the second rib's SIH only and approximately 77% of females and 75% of males were classified correctly using the second rib's APB.

Table 4. Individual variable cross-validation classification results.

Variables	Females (%) (N=87)	Males (%) (N=236)	Pooled (%)
First Right SIH	77	65	71
First Right APB	74	62	68
Second Right SIH	71	75	73
Second Right APB	77	75	76

Results of the discriminant analysis using all four variables are presented in Table 5. When using all four variables, approximately 89% for female and 78% for male are correctly classified. The best functions in the ribs require all four measurements. These discriminant functions are provided in Table 6.

Table 5. Percentage of correct classification by the discriminant functions.*

Variables	Females (%) (N=87)	Males (%) (N=236)	Pooled (%)
All Four Variables*	89	78	84

*Four variables include: 1st SIH, 1st APB, 2nd SIH, and 2nd APB.

Table 6. All variables discriminant functions. *,†,§

Variable	Metric 1	Metric 2	Metric 3	Metric 4	Constant
All Four Variables	-0.22494(1st SIH)	-0.12207(1stAPB)	-0.16399(2ndSIH)	-0.68339(2ndAPB)	-16.034

* Four variables include: 1st SIH, 1st APB, 2nd SIH, and 2nd APB.

†Sectioning Point = 0. Values greater than zero indicate female, values less than zero indicate male.

§Formula: Metric 1 product + Metric 2 product + Metric 3 product + Metric 4 product + Constant.

CHAPTER V

DISCUSSION

The goals of this study were to: (1) determine if the first or second rib is useful for estimating sex in a forensic context, and (2) provide a new method of sex estimation in North American populations via metric analysis. Previous studies on sex estimation have mainly looked at the pelvis, long bones, and the cranium (Krogman 1962; Meindl et al. 1985; Purkait and Heeresh 2004; Rissech et al. 2008). Few studies have been conducted on ribs, and most of these studies focused on the fourth rib and patterns of calcification of the costal cartilage (McCormick and Stewart 1983; Navani et al. 1970). Observations of sexual dimorphism led to studies more focused on osteometric analysis of the sternal end of the rib (Iscan 1985; Kocak et al. 2003). Iscan (1985) studied sexual dimorphism of the fourth sternal rib and obtained correct classification results as high as 89%. Despite producing good classification rates, this and other studies focusing on the fourth rib have a crucial limitation. The fourth rib is very similar morphologically to other ribs in the human body and is difficult to distinguish when not in articulation. Additionally, it is often common that not all elements will be found in a recovery scene. When only a few of the ribs are found, it is difficult to classify the specific location of the rib.

This study is imperative when dealing with the above difficulties faced by forensic anthropologists. The present study specifically focuses on the first and second ribs, both of which are morphologically more distinctive than the fourth rib. Overall, this study discovered that accurate sex estimation from the first and second sternal rib could be as high as 84%. This percent correct classification is comparable to such highly dimorphic areas as the tibia, which produce average sex estimation accuracy of 87% for whites, and the skull, which yield accuracy results of 85% (Giles and Elliot 1963; Iscan and Miller-Shaivitz 1984). Results of this study indicate that sexual dimorphism from the sternal end of a first or second rib can be measurable with much reliability.

Examining each variable individually, the second right APB measurement produces the best results, correctly classifying 77% of the individuals. The second right SIH measurement produces the next best overall results, correctly classifying 73% of the individuals. These results demonstrate that when looking at the variables individually, the second rib measurements demonstrate a slightly greater ability to correctly classify. More convincing results are obtained when two measurements are used together. The accuracy of sex estimation increases to 82% for individuals when using the second rib APB and first rib SIH measurements. Combining all four measurements produces accuracy rates of 84%, which is positively comparable to rates of the tibia, femoral head, and skull.

It is apparent from this study that the method of measuring height and breadth of the sternal end of the first and second rib can produce high standards of accuracy when assessing sex. Possible factors not considered in this study that may affect future results include age, population, stature, occupation, and numerous others. Differing opinions have been offered regarding the affect age has on sex differences in the morphology of the rib. Results supporting the importance of age find that age is necessary to obtain accurate results when estimating sex (Iscan 1985; Kocak et al. 2003; Wiredu et al. 1999). Iscan (1985) does concede, though, that while a rib’s morphology changes with age, metric analysis can successfully categorize males and females for the majority of their adult life without knowing a specific age.

The population that was measured in the present study may also affect the reliability results obtained. Wiredu et al. (1999) compared the means of various rib measurements in their study with mean measurements in Iscan's (1985) study and found that rib sizes were much larger for both sexes in Iscan's study population. This is an area for future research, taking into consideration such elements as ancestry, environment, nutrition, and the generation of the population being used.

Additional factors that may influence the reliability of sex estimation from the sternal end of the first and second ribs are factors that affect the size of an individual. It is found that males as a whole are larger in several chest dimensions than females (Semine and Damon 1975). The present study has shown that sexual dimorphism can be assessed with reliability, giving accuracy ratings as high as 84% using the first and second ribs of a recent forensic North American sample. Modern skeletal collections used in the present study are more appropriate for North American forensic purposes than population groups in previous studies mentioned due to secular change between and within groups.

CHAPTER VI

CONCLUSION

The present research shows that several variables are important for the estimation of sex from the sternal end of the first and second ribs. In this study, these variables include the maximum superior-inferior height and anterior-posterior breadth. Of the rib measurements considered, it was found that using all four measurements in conjunction provide the most significant results, correctly classifying 84% of the individuals. When using the second rib APB and first rib SIH measurements together, significant results were also obtained, classifying 82% of the individuals correctly. This study is a positive first step for estimating sex in forensic settings on recent North American populations based on the sternal ends of the first and second ribs. Results show that sex estimation based on first and second ribs are as reliable as sex estimates from the fourth rib, and the first and second ribs are more easily identified than the fourth rib. Also, the percent classified correctly is comparable to reliable bones such as the femoral head, tibia, and skull.

Metric data are becoming increasingly valuable due to the enforcement of the *Daubert* standard. The *Daubert* standard is becoming extremely important in the forensic community. Consistent and reliable standards are now needed in a court of law to help justify the classification of sex given to a particular individual. Error rates for techniques used are also required when using the *Daubert* standard. The studies mentioned above, as well as the current research and future research are crucial for adhering to the *Daubert* standard, as well as giving additional tools for the estimation of sex.

This research is important within forensic anthropology for many reasons. In the absence of the pelvis, long bones, and skull, which are most commonly used for sex estimation, new methods for estimating sex must continue to be developed and tested. Metric data are crucial when justifying a classification of sexual estimation in court. Further research in this area, looking at estimation of sex in relation to age, stature, and in particular to different populations, will continue to provide valuable information for forensic anthropologists to aid in constructing the biological profile.

APPENDIX A:

SKELETAL INVENTORY OF ALL OBSERVATIONS

Appendix A. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
3	M	16.52	20.24	7.67	11.88	
5	M	9.08	23.47	8.78	16.15	
6*	M	11.83	19.74	9.53	13.98	
7*	M	9.34	21.33	8.57	15.06	
17	M	16.99	20.6	8.93	12.57	EG
21	F	10.2	16.3	6.53	13.47	
28	M	10.58	24.74	8.76	16.51	
29	F	6.73	14.28	6.2	11.49	
31	M	15.39	18.08	8.37	12.48	
42	M	7.9	19.36	7.13	14.23	
44	M	10.17	18.12	9.04	15.64	
45	M	13.72	22.26	3.73	11.84	PM
47	M	14.85	22.6	19.21	15.99	EG
48	F	10.38	19.71	7.22	13.82	
49	F	7.56	21.9	6.55	12.28	EG
52	M	11.82	21.9	5.29	16.98	
56*	M	9.14	18.93	10.81	13.38	
63	M	15.8	25.27	5.23	16.14	EG
65*	M	10.77	19.47	7.83	14.5	
66	M	8.69	18.74	9.13	15.97	
68	M	9.26	16.08	9.24	22.32	
69	M	9.89	20.1	6.81	12.2	
72	M	10.12	22.42	9.39	11.95	
73	M	9.79	17.18	4.37	13.37	
76*	M	19.05	20.91	7.16	13.43	
77	F	8.91	19.18	2.62	14.77	PM
79*	M	15.66	23.16	8.85	16.2	
80	M	16.06	19.52	9.37	15.89	
84	M	12.89	20.09	6.66	14	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
89	M	10.58	14.82	4.51	15.02	
94	M	18.59	18.95	3.86	15.31	PM
99*	M	13.82	18.38	10.49	13.67	
100	M	7.77	21.91	3.35	12.44	PM
111	F	7.34	19.61	5.81	12.57	
113*	M	15.64	17.65	8.48	15.23	
115*	M	11.69	17.39	6.34	13.32	
117	F	5.79	18.81	7.67	12.42	
118	M	11.9	19.01	5.06	11.59	PM
123	M	12.77	20.72	8.12	12.93	
127	F	7.52	21.47	3.7	13.5	
133	M	10.61	24.15	5.91	15.35	
137	M	10.1	29.35	7.15	12.71	
140	F	11.55	16.27	7.11	14.19	
141	M	7.98	13.79	4.13	10.7	PM
142	F	8.1	22.27	5.43	11.01	
143	M	10.04	23.59	4.88	14.08	
145	M	11.58	19.65	4.99	13.53	
156	F	16.88	17.05	5.88	11.74	
157*	M	13.72	19.21	7	14.22	
158	F	8.75	15.07	6.8	11.9	
160	F	10.26	15.06	6.82	13.31	
162	M	10.12	17.9	7.6	13.47	
163	M	12.73	18.79	9.11	15.38	
164	M	15.93	22.04	10.12	14.88	EG
167	M	5.67	18.9	5.56	15.07	
168*	F	12.53	20.74	9.24	13.09	
170	M	9.47	20.78	9.14	23.21	
174*	M	13.64	23.96	8.13	16.43	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
176	M	10.75	16.85	7.33	15.27	
177	M	13.29	31.47	4.87	13.49	PM
179*	M	12.84	21.72	8.96	17.82	
180	M	10.16	20.92	5.07	14.6	PM
182	F	9.07	15.41	6.69	11.89	
183	M	11.22	23.83	9.91	13.86	
186	F	11.1	17.52	6.55	13.43	
187	F	10.02	15.93	6.13	11.47	
188	M	16.16	21.36	11.28	14.81	
189	M	11.07	23.1	7.76	16.18	
190	M	16.83	21.87	9.15	15.1	
192	F	12.77	17.37	8.21	11.18	
193	M	18.1	21.48	8.65	16.18	EG
195	M	15.82	23.08	8.37	14.45	
198	F	8.39	20.48	7.8	14.23	
202*	F	16.11	21.38	9.26	14.82	
208*	F	9.9	23.33	6.97	12.22	
210*	F	13.93	20.47	4.56	14.04	
211	M	12.56	19.55	8.96	13.99	
212	F	10.06	19.41	8.89	15.63	
214	F	11.93	18.59	8.6	14.52	
215	M	14.85	21.64	9.71	16.2	
216	F	11.87	16.85	7.84	12.9	
217*	F	10.3	22.28	3.04	11.78	PM
222	M	12.37	17.55	9	14.87	
223*	M	19.11	21.1	8.79	14.69	
224	M	14.57	25.47	4.39	16.01	EG
225	M	7.65	25.42	4.46	16.64	PM
226	M	15.29	20.88	9.28	15.2	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
227	M	18.81	25.5	4.28	15.82	PM
228	M	12.3	21.37	4.55	15.99	PM
229	M	20.2	23.29	6.21	13.96	
231	F	9.6	19.36	7.73	12.63	
235	F	10.44	23.26	10.6	15.97	
237*	M	17.78	26.91	9.8	15.62	
238	M	8.62	25.3	9.83	14.59	
240	M	8.72	17.35	8.15	13.11	
241	F	10.16	18.62	8.15	12.35	
245	M	17.94	19.54	12.95	14.21	EG
246	M	14.31	19.16	9.82	15.63	
248	F	10.83	15.05	7.56	12.6	
251	F	13.23	18.71	7.81	11.66	
253	F	13.17	16.44	6.82	12.31	
255	F	9.92	20.8	8.22	14.81	
0102D	M	13.51	19.53	9.23	13.56	
0105D	M	12.1	17.42	8.58	11.4	
0188D	F	10.235	19.175	8.71	15.315	
0194D	M	12.33	25.105	8.305	13	EG
0196D	F	7.95	21.065	6.35	11.01	
0197D	M	13.74	18.63	7.82	12.775	
0200D	M	18.21	18.985	10.08	14.705	EG
0202D	M	11.53	20.345	8.47	16.15	
0203D*	M	11.29	17.945	6.68	16.76	
0205D	F	8.92	17.19	6.65	11.62	
0292D	F	8.685	18.515	7.885	12.7	
0294D	M	13.915	20.955	8.71	13.27	
0296D	M	17.04	22.69	9.165	14.17	
0299D	M	12.75	22.325	11.135	15.085	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
0300D*	M	12.14	15.745	9.19	16.48	
0303D	M	11.415	18.87	9.295	15.02	
0304D	M	14.71	22.82	10.38	15.72	
0305D	M	15.17	21.53	13.43	17.29	
0388D	M	9.8	19.53	7.63	14.525	
0390D	M	21.675	21.13	10.665	17.61	EG
0397D	M	11.885	21.59	8.43	16.205	
0399D*	F	9.155	18.055	6.335	13.47	
0402D	F	10.73	24.4	8.645	12.67	
0403D*	M	15.515	20.025	5.105	15.275	EG
0405D	M	16.4	22.75	10.57	14.75	EG
0406D	F	13.915	17.97	8.355	11.81	
0489D	M	14.07	19.075	11.54	18.745	
0494D	M	14.575	29.97	8.505	13.245	
0496D	M	10.27	25.675	11.365	17.765	
0497D	M	11.63	16.865	8.14	15.54	
0499D	M	15.24	20.09	8.685	18.77	
0587D	F	18.945	17.525	7.25	10.46	
0598D	M	18.135	21.13	14.005	14.5	
0598D	M	13.56	18.44	14.3	14.5	EG
0599D	M	16.355	17.27	9.08	12.71	EG
0600D	M	15.875	25.88	8.2	15.275	
0602D	M	19.745	21.46	12.57	15.76	EG
0606D	M	14.82	19.085	8.505	17.335	
0687D	M	17.84	22.91	8.19	16.175	EG
0689D	F	13.535	18.745	8.95	10.46	EG
0691D	M	15.39	21.055	11.275	14.855	
0692D	F	10.07	21.92	6.97	12.75	
0693D	F	11.62	17.105	7.135	10.45	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
0698D	M	17.98	21.665	7.44	15.595	
0699D	M	10.74	20.71	6.93	19.15	
0702D	M	14.31	18.515	9.32	14.64	
0705D	M	12.115	17.145	8.66	15.57	
0787D	M	11.58	23.085	10.055	17.195	
0792D	F	15.21	15.95	8.595	11.34	
0793D*	M	11.35	18.795	8.99	13.435	
0801D	M	20.015	28.905	11.455	17.93	
0805D	M	13.8	22.02	8.215	15.25	
0893D	M	10.995	27.44	9.955	17.475	
0895D	M	11.63	21.665	10.185	17.675	
0897D	M	4.165	12.065	9.955	17.27	
0899D	M	7.845	23.595	7.11	14.515	
0900D	F	9.245	18.935	8.365	13.94	
0904D	M	14.8	22.16	12.1	17.04	
0995D	F	10.005	24.56	7.895	14.73	
1001D*	F	15.81	20.115	6.83	12.14	
1095D	M	13.88	21.535	9.51	15.3	
1096D	M	18.005	22.07	8.975	14.655	EG
1099D	M	12.265	18.63	7.555	15.265	
1100D	M	18.145	23.595	8.19	11.885	EG
1101D	F	12.025	19.81	7.34	11.4	EG
1102D*	M	21.08	23.3	9.6	13.305	
1104D	F	11.37	14.42	6.64	12.01	
1190D	F	9.955	16.535	8.645	13.36	
1194D	M	8.39	17.905	8.34	13.295	
1200D	M	17.195	21.89	9.775	12.29	EG
1202D	F	9.025	20.165	9.055	14.655	
1204D	F	11.25	16.23	7.28	11.36	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
1290D	M	16.48	20.535	9.115	18.11	
1291D	M	14.185	19.835	10.87	19.67	
1297D	M	12.775	23.16	11.375	15.265	
1298D	M	11.49	16.57	8.61	14.3	
1300D	M	18.415	22.275	9.33	18.3	EG
1304D	M	17.05	22.86	8.64	12.56	
1305D	F	8.15	18.4	7.845	14.425	
1397D	F	12.01	20.265	7.515	12.01	
1398D	M	15.49	25.855	10.21	17.015	
1402D	M	10.845	21.89	8.28	14.83	
1403D	M	14.17	19.62	5.77	14.55	
1405D	M	10.96	23.96	9.14	12.035	
1493D	M	8.81	18.77	8.775	15.91	
1497D	M	9.75	17.88	9.04	16.175	
1498D	M	12.43	18.97	9.435	14.59	
1505D	M	12.75	23.645	10.22	15.875	
1593D	M	18.615	26.87	10.78	14.005	EG
1598D	F	13.385	19.2	8.15	14.68	
1602D	M	12.835	20.785	6.905	14.705	
1605D	M	11.11	18.92	9.89	15.16	
1698D	M	21.535	27.685	12.175	16.535	EG
1699D	F	6.705	18.995	7.58	15.125	
1701D	M	14.425	24.13	10.74	18.63	
1702D	F	7.795	17.475	6.87	13.74	
1705D	F	10.895	20.015	4.645	14.78	
1706D	F	10.41	16.28	3.07	12.8	
1791D	M	8.33	21.18	8.125	13	
1797D*	F	8.585	18.565	6.985	14.22	
1799D	M	21.145	20.735	9.94	17.625	EG

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
1800D	M	12.47	23.1	8.685	13.775	
1803D	F	7.26	17.32	7.18	11.43	
1805D	F	9.32	19.875	3.145	10.805	
1806D	M	15.46	21.89	9.75	14.35	
1888D	M	16.025	20.89	8.39	14.4	
1891D	M	18.935	21.995	11.49	16.28	EG
1899D	M	14.245	18.615	8.175	15.34	EG
1901D	M	15.045	20.94	9.41	15.835	EG
1998D	M	13.725	23.06	7.745	15.62	
1999D*	M	10.525	25.805	9.14	15.935	
2003D	F	7.34	13.7	7.44	10.79	
2092D	M	17.17	21.435	8.075	14.45	EG
2095D	M	17.245	22.045	7.695	16.925	EG
2102D	F	8.15	20.355	9.395	13.255	
2104D	M	10.23	26.89	11.23	17.98	
2190D	M	11.2	20.955	7.59	14.945	
2191D*	M	14.435	16.305	8.165	12.14	
2192D	M	10.385	19.275	7.01	15.39	
2194D	M	13.205	26.21	9.19	15.06	
2199D	M	11.73	23.67	9.575	15.405	
2200D	M	9.675	17.41	8.505	13.345	
2202D	M	10.945	19.175	9.725	14.78	
2205D	M	12.87	16.4	9.49	17.47	
2290D	M	19.58	21.055	9.955	14.245	EG
2291D	M	12.925	18.285	11.375	16.455	
2293D	M	18.31	24.14	12.115	15.11	EG
2300D	F	9.84	18.92	6.985	12.265	
2301D	M	16.735	28.155	13.14	16.735	EG
2302D	F	13.305	18.64	6.65	13.385	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
2303D	M	13.1	20.4	8.89	13.69	
2305D	M	15.34	22.12	8.78	14.02	
2393D	M	17.04	19.3	7.565	12.395	
2402D	M	12	20.24	8.61	14.935	
2405D	M	19.01	20.585	11.87	14.96	
2505D	F	7.21	14.665	8.61	10.575	
2593D	M	11.02	16.175	8.43	12.305	
2601D	M	9.575	21.69	10.005	14.4	
2603D	M	13.62	20.56	8.14	14.05	
2606D	M	14.135	25.755	8.405	16.535	
2693D	F	11.02	19.02	6.095	13.32	
2701D*	F	12.025	17.41	8.255	13.13	
2702D	F	7.53	18.425	6.55	11.885	
2703D	M	9.42	18.6	6.52	11.53	
2703D	M	15.54	18.64	10.84	17.2	
2801D	F	9.355	25.525	8.225	13.525	
2803D	M	13.84	17.76	7.56	14.54	
2804D	M	17.01	20.37	8.8	14.75	
2805D	M	13.955	17.395	9.19	15.085	
2899D	M	12.925	22.095	8.635	15.035	
2904D	M	12.75	22.82	9.32	17.19	
3002D*	M	8.48	16.025	9.47	13.94	PM
3003D	M	17.09	24.35	10.87	15.62	EG
3100D	M	9.98	17.5	8.405	13.28	
3101D	M	18.11	21.93	9.89	16.05	EG
3103D	M	15.79	22.83	7.82	16.77	
3105D*	F	7.87	20.67	7.01	14.3	PM
3204D	F	9.47	18.17	9.81	13.34	
3293D	M	13.245	23.05	9.61	15.77	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
3302D	M	9.395	20.635	8.38	16	
3402D	M	12.965	18.4	8.825	13.89	
3403D	M	12.5	17.56	8.4	16.66	
3404D	F	14.9	18.38	7.01	12.67	
3503D	M	11.89	17.28	8.22	16.14	
3505D	M	9.32	19.605	7.73	15.34	
3603D	M	14.65	20.82	10.84	13.84	
3605D	M	10.665	20.61	8.875	14.68	
3693D	M	17.295	18.275	8.15	14.055	
3701D	M	21.485	19.935	11.87	14.78	EG
3702D	F	9.37	17.535	8.89	13.445	
3703D	M	10.96	18.46	2.56	16.38	
3704D	M	9.34	17.88	8.9	14.94	
3705D	M	12.19	18.12	6.87	13.635	
3804D	M	14.4	19.96	13.91	15.01	
3805D	M	7.975	17.345	8.545	15.365	
3904D	M	9	18.78	7.6	14.4	
3905D	M	15.03	20.37	12.975	13.28	EG
4001D	M	17.345	21.855	8.335	15.695	EG
4003D	M	13.08	20.49	8.64	15.95	
4004D	M	13.89	19.1	10.195	14.145	
4101D	F	9.22	18.135	6.045	13.41	
4104D	M	14.68	20.865	9.905	15.505	
4205D	M	12.92	16.96	10.09	13.01	
4301D	M	15.1	23.11	11.045	13.995	EG
4302D	M	10.615	27.025	9.495	19.25	
4303D	F	7.37	19.76	7.11	14.31	
4401D	M	12.265	18.55	7.87	13.915	
4405D	M	12.115	22.045	9.635	16.05	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
4501D	M	18.275	22.275	9.675	16.125	EG
4504D	M	17.8	22.93	15.7	17.01	PM
4505D	M	13.295	20.75	9.015	15.375	
4593D	M	16.56	19.48	8	15.415	
4705D	M	12.065	26.04	10.26	14.855	
4801D	M	9.905	19.16	9.88	14.245	
4803D	M	8.25	17.17	7.78	14.57	
4805D	M	17.195	20.495	9.79	18.08	
4901D*	F	20.165	18.64	7.695	15.515	
4903D	M	12.47	28.39	3.83	15.62	
4904D	M	13.23	22.475	11.53	20.42	
5003D	M	10.97	20.66	9.72	15.21	
5105D	M	11.605	19.43	10.335	15.365	
5203D	M	17.76	23.66	10.37	17.65	EG
5204D	M	12.39	25.29	9.44	17.7	
5205D	M	13.46	33.195	9.725	16.42	
5303D	F	8.78	20.57	6.93	11.58	
5304D	M	14.37	23.16	12.26	18.18	
5405D	F	7.91	14.26	7.705	11.515	
5704D	F	10.435	19.555	6.335	12.81	
5804D	M	8.89	17.83	7.895	15.185	
5904D	M	10.945	21.65	9.56	16.455	
6004D	M	14.905	20.15	10.97	15.01	
6105D	F	9.27	19.505	9.14	13.23	
6205D	M	19.365	26.565	13.46	15.68	EG
6303D	F	17.27	19.03	6.29	11.55	
6404D	M	14.12	16.48	9.22	12.87	
6405D	M	13.955	27.9	11.25	14.375	
6904D	F	8.505	16.05	3.2	13.535	

Appendix A-Continued. Skeletal inventory of all observations.

ID Number	Sex	First Right SIH	First Right APB	Second Right SIH	Second Right APB	Notes
6905D	M	17.525	19.58	9.355	14.36	
7905D	F	12.065	19.515	7.795	13.14	
8005D*	F	11.095	16.09	8.225	12.48	
9005D	M	15.325	20.89	9.105	14.63	

*Left side used
EG=Extra Growth
PM=Postmortem Damage

REFERENCES CITED

ABFA. 1996. ABFA Home Page. In: Murad TA, editor.

Christensen AM. 2004. The impact of Daubert: implications for testimony and research in forensic anthropology (and the use of frontal sinuses in personal identification). J Forensic Sci 49(3):427-430.

Cologlu AS, Iscan MY, Yavuz MF, and Sari H. 1998. Sex determination from the ribs of contemporary Turks. J Forensic Sci 43(2):273-276.

Dirkmaat DC, Cabo LL, Ousley ST, and Symes SA. 2008. New Perspectives in Forensic Anthropology. Am J Phys Anthropol 137(S47):33-52.

Giles E, and Elliot O. 1963. Sex Determination by Discriminant Function Analysis of Crania. . Am J Phys Anthropol 21(1):53-68.

Högler W, Blimkie CJ, Cowell CT, Inglis D, Rauch F, Kemp AF, Wiebe P, Duncan CS, Farpour-Lambert N, and Woodhead HJ. 2008. Sex-specific developmental changes in muscle size and bone geometry at the femoral shaft. Bone 42(5):982-989.

Iscan MY. 1985. Osteometric analysis of sexual dimorphism in the sternal end of the rib. J Forensic Sci 30(4):1090-1099.

Iscan MY, and Loth SR. 1986. Determination of age from the sternal rib in white females: a test of the phase method. J Forensic Sci 31(3):990-999.

Iscan MY, and Miller-Shaivitz P. 1984. Discriminant function sexing of the tibia. J Forensic Sci 29(4):1087-1093.

Kocak A, Ozgur Aktas E, Erturk S, Aktas S, and Yemiscigil A. 2003. Sex determination from the sternal end of the rib by osteometric analysis. Leg Med (Tokyo) 5(2):100-104.

Krogman W. 1962. The Human Skeleton in Forensic Medicine. Springfield: Charles C. Thomas.

McCormick WF, and Stewart JH. 1983. Ossification patterns of costal cartilages as an indicator of sex. Arch Pathol Lab Med 107(4):206-210.

McCormick WF, Stewart JH, and Langford LA. 1985. Sex determination from chest plate roentgenograms. Am J Phys Anthropol 68(2):173-195.

Meindl RS, Lovejoy CO, Mensforth RP, and Don Carlos L. 1985. Accuracy and direction of error in the sexing of the skeleton: implications for paleodemography. Am J Phys Anthropol 68(1):79-85.

Navani S, Shah JR, and Levy PS. 1970. Determination of sex by costal cartilage calcification. Am J Roentgenol Radium Ther Nucl Med 108(4):771-774.

Oettlé AC, and Steyn M. 2000. Age Estimation from Sternal Ends of Ribs by Phase Analysis in South African Blacks. J Forensic Sci 45(5):1071-1079.

Patil KR, and Mody RN. 2005. Determination of sex by discriminant function analysis and stature by regression analysis: a lateral cephalometric study. Forensic Sci Int 147(2-3):175-180.

Phenice TW. 1969. A newly developed visual method of sexing the os pubis. Am J Phys Anthropol 30(2):297-301.

Purkait R. 2003. Sex determination from femoral head measurements: a new approach. Leg Med (Tokyo) 5 Suppl 1:S347-350.

Purkait R, and Chandra H. 2004. A study of sexual variation in Indian femur. Forensic Sci Int 146(1):25-33.

Rissech C, Schaefer M, and Malgosa A. 2008. Development of the femur--implications for age and sex determination. Forensic Sci Int 180(1):1-9.

Semine AA, and Damon A. 1975. Costochondral ossification and aging in five populations. Hum Biol 47(1):101-116.

Steel FLD. 1972. The sexing of the long bones, with reference to the St. Bride Series of identified skeletons. JR Anthropol Inst GB and Ire 92:212-222.

Stewart TD. 1963. New developments in evaluating evidence from the skeleton. J Dent Res 42(1)Pt 2:264-273.

Stewart JH, and McCormick WF. 1984. A sex- and age-limited ossification pattern in human costal cartilages. Am J Clin Pathol 81(6):765-769.

Torwalt CR, and Hoppa RD. 2005. A test of sex determination from measurements of chest radiographs. J Forensic Sci 50(4):785-790.

Ubelaker DH. 1997. Taphonomic Applications in Forensic Anthropology. In *Forensic Taphonomy: The Postmortem Fate of Human Remains*, edited by Haglund WD and MH Sorg, pp. 77-90. CRC Press, Boca Raton, FL.

United States Supreme Court in Daubert v. Merrell Dow Pharmaceuticals, Inc. 2003. 509 U.S. 579.

White TD, and Folkens PA. 2005. The Human Bone Manual: Elsevier Academic Press.

Wiredu EK, Kumoji R, Seshadri R, and Biritwum RB. 1999. Osteometric analysis of sexual dimorphism in the sternal end of the rib in a west African population. J Forensic Sci 44(5):921-925.

VITA

Kristina Rhea Gavit was born in Austin, Texas, on May 3, 1979, the daughter of Keri and Ray Gavit. After completing her work at Hutto High School, Hutto, Texas, in 1997, she entered The University of Texas at Austin. In 2001 she transferred to Texas State University-San Marcos. She received the degree of Bachelor of Business Administration in Accounting from Texas State University-San Marcos in August 2003. During the following years she was employed as an accountant. In August 2007, she entered the Graduate College of Texas State University-San Marcos.

Permanent Address: 80 Mager Lane

Hutto, Texas 78634

This thesis was typed by Kristina Rhea Gavit.