Utility of the sternum to estimate sex and age

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UTILITY OF THE STERNUM TO ESTIMATE SEX AND AGE

by

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ABSTRACT

Of the 206 bones that compose an adult skeleton, only a select few are used in the estimation of sex and age. The best indicator of the sex of an adult skeleton is derived from several morphological features of the pelvis. In addition to the pelvis, characteristics of the sacrum, long bones, and skull have been used to estimate sex in adult remains. The most accurate indicators of age-at-death at the present time are related to features of the pubic bone, the auricular surface of the ilium, and the sternal end of the fourth rib. The current project assesses the utility of the sternum for estimating age and sex using two current methods. The two methods in question are those of Bongiovanni and Spradley (2012) for the estimation of sex and Sun et al., (1995) for the estimation of age. The data gathered at the Robert J. Terry Anatomical Skeletal Collection for this study is used to assess the validity and accuracy of the two different methods utilizing a North American population differing from that of Bongiovanni and Spradley (2012). Results showed a high congruence with the results of Bongiovanni and Spradley (2012) in which an overall classification rate of 81.1% was achieved. The cross-validation classifications for males and females were 79.9% and 83.6% respectively and an overall classification rate of 86.7% was achieved using total sternal length (TL). Results also demonstrate that the mean values of sternal index conform to Hyrtl’s Law, however the range of values largely overlap, and demonstrates the law’s unreliability for sex estimation. Results showed a lack of congruence with the Sun et al.,
(1995) method reaching a classification rate for exact age estimates of 14.4%. Overall, the utility of the human sternum for sex estimation seems promising and practically simple. The utility of the human sternum for age estimation merits further research into methods that might provide higher classification rates, however, at this time no methods seem worthwhile.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title Page</td>
<td>i</td>
</tr>
<tr>
<td>Copyright Page</td>
<td>ii</td>
</tr>
<tr>
<td>Approval Page</td>
<td>iii</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>iv</td>
</tr>
<tr>
<td>Abstract</td>
<td>v-vi</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>vii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>ix</td>
</tr>
<tr>
<td>List of Figures</td>
<td>x</td>
</tr>
<tr>
<td>List of Abbreviations</td>
<td>xi</td>
</tr>
<tr>
<td>Chapter 1: Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 2: Previous Research</td>
<td>4</td>
</tr>
<tr>
<td>Subsection One (Sternal Structure and Development)</td>
<td>6</td>
</tr>
<tr>
<td>Subsection Two (Aging)</td>
<td>15</td>
</tr>
<tr>
<td>Subsection Three (Sexing)</td>
<td>17</td>
</tr>
<tr>
<td>Subsection Four (Stature)</td>
<td>19</td>
</tr>
<tr>
<td>Subsection Five (Population Specificity)</td>
<td>21</td>
</tr>
<tr>
<td>Subsection Six (Ancestry)</td>
<td>22</td>
</tr>
<tr>
<td>Subsection Seven (Discrete Traits)</td>
<td>23</td>
</tr>
<tr>
<td>Subsection Eight (Preservation Bias / Survivability of the Sternum)</td>
<td>24</td>
</tr>
<tr>
<td>Subsection Nine (Common Sternal Pathological Conditions and</td>
<td>27</td>
</tr>
</tbody>
</table>
Developmental/Age-Related Abnormalities)

Subsection Ten (Hyrtl’s Law) 29

Subsection Eleven (Utility of the Sternum: The Two Methods to be used) 30

Subsection Twelve (The Present Study) 31

Chapter 3: Methods 33

Subsection One (Materials) 33

Subsection Two (Method: Bongiovanni and Spradley, 2012) 34

Subsection Three (Data Analysis: Bongiovanni and Spradley, 2012) 37

Subsection Four (Method: Sun et al., 1995) 40

Subsection Five (Data Analysis: Sun et al., 1995) 43

Chapter 4: Results 46

Subsection One (Bongiovanni and Spradley, 2012) 46

Subsection Two (Sun et al., 1995) 54

Chapter 5: Discussion 58

Subsection One (Future Research) 62

Chapter 6: Conclusions 64

Appendix A: Tables and Figures 66

Appendix B: Images 67

References 71

Curriculum Vitae 79
LIST OF TABLES

Table 1. Sternebrae development by age. 12
Table 2. (24) Landmarks Used by FORDISC 3.1. 24
Table 3. Determination and Scoring for (6) Morphological Characteristics of the Female Sternum (Sun et al. 1995) 44
Table 4. Correlations 47
Table 5. Functions at Group Centroids 48
Table 6. Variables in Analysis 49
Table 7. Variables not in Analysis 50
Table 8. Classification Results 50
Table 9. Standardized Canonical Discriminant Function Coefficients 50
Table 10. Classification Function Coefficients for TL 51
Table 11. Descriptive Statistics 51
Table 12. Overall Classification Rates by Variable 52
Table 13. Sternal index mean for females and males with corresponding frequencies and sectioning points. 53
Table 15. Variables in the Analysis 56
Table 16. Variables not in the Analysis 57
Table A.1. Demographic Distribution of the Terry Collection 66
Table A.2 Distribution of the Terry Collection by Age 66
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Timing and Location of Manubrial, Sternebral, and Xiphoidal Ossification Centers.</td>
<td>10</td>
</tr>
<tr>
<td>Figure 2</td>
<td>(4) Ossification Centers of the Sternum at Birth.</td>
<td>11</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Summary of Fusion and Ossification of Sternum</td>
<td>13</td>
</tr>
<tr>
<td>Figure 4</td>
<td>(4) Measurements of the Sternum</td>
<td>35</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Estimated Midline of Sternum</td>
<td>36</td>
</tr>
<tr>
<td>Figure 6</td>
<td>(6) Morphological features of the Sternum</td>
<td>42</td>
</tr>
</tbody>
</table>
LIST OF ABBREVIATIONS

BL  Mesosternal Length
FDB Forensic Data Base
IU/iu Intrauterine
ML Manubrial Length
MNI Minimum number of individuals
PMI Postmortem interval
S1W First Sternebra Width
S3W Third Sternebra Width
SI Sternal Index
SP Sectioning Point
TL Total Length of the Sternum
Chapter 1: Introduction

Creating the biological profile for an individual relies critically on age and sex estimation. With respect to sex, the cranial and pelvic bones provide the most accurate estimates and are the skeletal elements most commonly used by anthropologists (Bongiovanni and Spradley, 2012). However, estimating sex from most postcranial elements can also be effective if the skull or pelvis is not available. When estimating age, researchers assess a variety of developmental factors (Franklin, 2010). For example, the analysis of suture closure for estimating age has been frequently utilized, however can be problematic due to inter-individual variability. Generally, methods utilizing skull measurement for estimating age include large age-range intervals and standard deviations (Cunha et al., 2009). The skeletal elements that provide the most accurate estimate of age are the pubic symphysis of the os coxa and epiphyseal fusion of long bones.

More complex methods are available in forensic laboratories for age and sex estimation, such as aspartic acid racemization. Racemization is a method that evaluates the amount of aspartic acid in tooth enamel to create a biochronological tool to assess the age of skeletal remains (Helfman and Bada, 1975). While useful in forensic cases, problems do arise with respect to the standardization of the conditions and practices used (Wolff et al., 2012).

Despite the existence of current methods to estimate age and sex, several of these methods have limitations and therefore it essential that new methods for age and sex estimation be developed. For example, the sternum has been suggested as a useful element for estimating age and sex of unknown skeletal remains (Bongiovanni and
Spradley, 2012, Chandrakanth *et al.* 2012, Hunnargi *et al.* 2008, and Sun *et al.* 1995). Bongiovanni and Spradley (2012) assert that the sternum can be used as an accurate judge of sex and Sun *et al.* (1995) demonstrated that the sternum can be used as an accurate gauge of age. Even though sternal morphometrics have been considered viable as sex and age estimators, it is seen as controversial. Dwight (1881) asserted that the sternum is not a trustworthy guide for sexing or aging. However, there is enough preliminary data on using the sternum as an indicator of sex and age that further research is warranted.

The current research project tests the suitability of age and sex estimations obtained from the sternum using two methods. In the first method, Bongiovanni and Spradley (2012), estimates of sex are made from (4) morphometric characteristics of the sternum, which are then used in comparing the ratios of manubrium and sternal body measurements (by creating a sternal index) and to test Hyrtl’s Law (later defined). This method will be assessed in the current study for two reasons: (1) newly proposed methods should always be followed with subsequent validation and (2) Bongiovanni and Spradley’s, (2012) sample was from a predominantly white collection with their sample including only 29 Black males and 5 black females thus not fairly representing Black Americans and therefore a more heterogeneous sample should be used.

The second method, Sun *et al.* (1995), observed and scored (6) morphological features of the sternum of Chinese females. This method will also be assessed in the current study. Two reasons for assessing this method are: (1) to test if this method is applicable with sternum from both males and females and (2) to test the method with
respect to a North American population.

In the present study, data was collected from the Robert J. Terry Anatomical Skeletal Collection to test accuracy of the two methods in a population specific environment. Hypothetically, if the methods used by Bongiovanni and Spradley, (2012) and Sun et al., (1995) described above are found to hold true, then a valid estimation of sex and age from sterna examined in the Robert J. Terry Anatomical Skeletal Collection should be possible.
Chapter 2: Previous Research

Many methods have been utilized to generate estimates of age and sex from skeletal remains (Bongiovanni and Spradley, 2012, Chandrakanth et al., 2012, Hunnargi et al., 2008, and Sun et al. 1995). For sex, nonmetric traits such as the nuchal crest of the skull and the greater sciatic notch of the os coxa, along with craniometric analyses, have been used for estimation. Age estimation has utilized nonmetric techniques as well, including suture obliteration and epiphyseal fusion, as well as dental eruption and wear and post-craniometric analyses. However, previous researchers have challenged the usefulness of the sternum for estimating age and sex (Chandrakanth et al., 2012, Dwight, 1881, Dwight, 1890). Some conclude that the sternum alone is inadequate as an indicator of age and sex and that a multivariate approach that uses multiple elements such as the sternum, skull, and pelvis should be used (Chandrakanth et al., 2012). This presumed inadequacy as a standalone indicator is contradicted by approaches that produce high accuracy results using measurements of the sterna alone as a tool for age and sex estimation (Bongiovanni and Spradley, 2012) and Sun et al., 1995). A multivariate approach in this manner has been used successfully when addressing questions of population relationships in human anthropometry (Konigsberg and Ousley, 2009). Some conclude that using multiple skeletal elements is a more suitable method of accurately estimating sex than univariate models, which uses only one (Jit et al. 1980). Brooks (1955) argues for multivariate approaches stating that skeletal remains were treated as a single unit when alive (in vivo), and should still be considered as a whole when analyzed
for sex and age. Others suggest that multivariate approaches can decrease the accuracy of estimations (Bongiovanni and Spradley, 2012).

Different methods for age and sex estimation have been used with various skeletal elements to determine the most effective methods with different bones. Examples include scoring the degree of fusion of the sacral vertebrae (Ríos et al. 2008, McKern and Stewart, 1957), sternal rib end morphometrics (Iscan et al., 1984), postnatal ontogenesis of the tibia (Lopez et al., 2012), and sexual dimorphic traits of the cranial facial region (Kimmerle et al. 2008). This demonstrates a current trend in which alternate skeletal elements are being assessed for their utility in age and sex estimation.

Variation in population specificity increases the complexity of the issue regarding the utility of the sternum for age and sex estimations. It has been suggested that the sternum can be used to develop an accurate estimation of sex and age, however, the majority of the research supporting this idea has used skeletal remains from populations outside of the United States (Bongiovanni and Spradley, 2012). This is an issue because population variability complicates the efforts to apply different methods to other skeletal populations around the globe (Rissech et al., 2011). Whereas techniques for age and sex estimation exist for specific population groups, far fewer exist that are applicable to multiple populations (Iscan, 2005). For example, the Suchy-Brooks system was derived mainly from North American samples, thus making unclear the utility of this system with skeletal remains from other countries (Wärmländer and Sholts, 2011) Many anthropologists seek to expand the current methods for sex and age estimation by using
recent population specific samples in places such as the United States (Bongiovanni and Spradley, 2012).

**Sternal Structure and Development:**

The adult sternum is comprised of three key elements: the superiorly positioned manubrium, the narrow and longitudinally positioned mesosternum found inferior to the manubrium, and lastly the relatively small and most inferiorly positioned cartilaginous xiphoid process (Williams et al., 1989). The manubrium articulates with the superior end of the mesosternum by a synchondrosis also known as the manubrio-mesosternal junction. This articulation forms the sternal angle. The xiphoid similarly unites with the inferior border of the mesosternum by forming the mesosterno-xiphisternal junction (Chandrakanth et al., 2012). The manubrium forms part of the skeletal framework of the neck and the thorax. Its superior surface expands laterally and bears a distinct, palpable notch, known as the jugular notch found on the midline of the body. On either side of the jugular notch a medium-large sized oval fossa is present for articulation with the left and right clavicles. Immediately inferior to the two clavicular fossae on either lateral side are the facets for articulation with the first costal cartilages. Lastly, the most inferior lateral portion on either side of the manubrium holds the demifacets for the second costal cartilages (Williams et al., 1989).

The mesosternum is flat in comparison to the other elements of the sternum. The mesosternum is often marked with transverse lines or ridges that mark the sites of fusion between the three segmental elements referred to as sternebrae. The lateral sides of the
mesosternum have articular facets in support of the costal cartilages of the third through
sixth ribs and demifacets for ribs two (found superiorly) and seven (found inferiorly).
The most inferior portion of the mesosternum is attached to the xiphoid process
(Williams et al., 1989).

The xiphoid process is the petite portion of the sternum. Its shape is variable and
may be broad, emaciated, keen, bifid, curved, or even perforated. It originates as a
cartilaginous element that later may ossify in adults. The superior portion of each lateral
side of the xiphoid has demifacets for the seventh costal cartilages (Williams et al.,
1989).

As mentioned above, the sternum articulates at joints between the seven costal
cartilages and the sternum. These are known as sternocostal joints (Williams et al., 1989).
The joint between the first coastal cartilages and the manubrium are non-synovial and
consist of fibrocartilaginous material. The second through the seventh are synovial and
his have thin capsules structured by the surrounding sternocostal ligaments. The
articulations at the site of second costal cartilages are separated into two compartments
by an intra-articular sinew that attaches the second costal cartilage to the manubriosternal
junction (Williams et al., 1989).

The manubriosternal and xiphisternal joints are symphyses and only slight
movements can occur between the manubrium and mesosternum during respiration. The
xiphoid process generally ossifies completely at the xiphisternal junction with age, thus
not allowing for movement (Williams et al., 1989).

The sternum is composed of vascular cancellous tissue, enclosed by a thin coating
of dense compact bone, which is most substantial in the manubrium linking the articular facets for the clavicles. It develops over an extended period of time, beginning during the prenatal period and enduring all the way through the third and fourth decades of the postnatal phase (Kozielec, 1973, O’Neal et al., 1998, O’Rahilly and Muller, 1992, Rodriguez-Vazquez et al., 2013, and Williams et al., 1989).

The ossification of the human skeleton follows a schedule of appearance as well as definite times of fusion (Chandrakanth et al., 2012). Knowing the fusion schedule of the elements of the sternum above makes age estimation from the sternum possible. To some, a single pattern of development is not essential to successful growth of the human sternum and, thus, postnatal development and maturation of the human sternum is seen as highly variable (O’Neal et al., 1998). However, hyaline cartilage ossification of the xiphoid process and manubrium to the corpus sterni is described as happening only at middle to late adulthood and thus corresponds to age approximation (O’Neal et al., 1998). To obtain an accurate age at death at any age, it is fundamental to comprehend the normal patterns of growth and maturation of every skeletal element, not just the sternum, and to develop their respective growth models (Rissech et al., 2012).

Ossification of axial bones entails both endochondral and intramembranous formation. The sternum, vertebral column, ribs, and basicranial bones develop endochondrally. With the exception of the basicranial bones, the skull forms intramembranously (Williams et al., 1989). Endochondral ossification occurs by the mineralization of a cartilaginous model, or precursor, that appears earlier in embryonic development. These models first undergo rapid alterations as connective tissue cells
expand and in turn obliterate the contiguous matrix. Soon after, the connective tissue cells die. While the cells fragment, a periosteum develops on the exterior of the developing structure (a membrane with numerous blood vessels) after which, blood vessels and undifferentiated cells invade the space under the periosteum. Particular connective tissue cells separate and outline spongy bone in the region of the preceding cartilage template (Williams et al., 1989).

The sternum forms in the embryonic lateral plate mesoderm, beginning around the sixth week of the prenatal period (Bayaroğulları et al., 2013). Ossification centers in the manubrium and the mesosternum develop on cartilage plates located on both sides of the median plane throughout the prenatal phase. The ossification hubs or centers of the manubrium join prior to birth (Bayaroğulları et al., 2013). The primary center of ossification of the manubrium first appears at approximately the fifth fetal month and may develop from more than one ossification center. Initially the manubrium may be difficult to identify and is described as a bony nodule, however, it is clearly recognizable by six months postpartum (Scheuer and Black, 2000).

The term sternebrae is developmental and describes two or supplementary ossification centers that grow on each division of the mesosternum, which are situated on cartilage plates on both sides of the median plane. The timings and degree of appearance differ between each sternebra. The first sternebra appears in the fifth to sixth fetal month. By the seventh to eighth fetal month, the second and third sternebrae appear. Unlike the first three, the fourth sternebra can appear as late as one year postpartum (Scheuer and
Black, 2000). See Figure 1 below for the timing and locations of ossification as described above.

At birth, sterna are represented by four centers of ossification (Figure 2). Sternebrae do not become recognizable in isolation until after approximately 6 months postpartum. Progressing from unrecognizable bony nodules, the sternal segments become flattened in appearance and are roughly oval or rectangular in outline. Fusion of the primary centers of ossification generally occurs in a postero-anterior and caudocranial direction with the lateral surface bearing costal notches last to fuse (Scheuer and Black, 2000).

Figure 1. Timing and Location of Manubrial, Sternebral, and Xiphoidal Ossification Centers. Note that the number of ossification centers varies by element. (Figure created by current author following Williams et al. (1989)).
Figure 2. (4) Ossification Centers of the Sternum at Birth. Observe that the bone is shaped still in cartilage with separated centres - a condition which remains for some years as the centres extend slowly until fusing. Note that in some instances the 1st and 2nd centers can be double centered and perhaps fused in normal specimens. (Figure created by current author following Scheuer and Black, 2000 and Williams et al. 1989).

The use of sternal development as an indicator of age estimation is a promising method. As demonstrated by Scheuer and Black, (2000), a fetus with two ossified sternal segments (including the manubrium) can be defined as at least 30 intrauterine (IU) weeks. Three ossified segments have been found approximately 34 IU weeks and four ossified segments at approximately 37 IU weeks. Previous literature suggests that the ossification centers usually merge into a single ossification center during 6–12 years of age (Bayaroğullari et al., 2013). Others (Scheuer and Black, 2000) show that primary
ossification centers unite at separate times and generally last into the early 20’s as shown in Table 2 below.

Table 1. Sternebrae development by age.

<table>
<thead>
<tr>
<th>Sternebra #</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 &amp; 4</td>
<td>4-10yrs</td>
</tr>
<tr>
<td>2 to 3 &amp; 4</td>
<td>11-16yrs</td>
</tr>
<tr>
<td>1 to 2, 3, &amp; 4</td>
<td>15-20yrs</td>
</tr>
</tbody>
</table>

The fusion and ossification of the sternebrae is usually complete by 25 years of age (Larsen, 1997 and O’Neal, 1998) although, others consider that complete fusion does not occur until 30’s (Scheuer and Black, 2000). The following Figure 3 shows a summary of these appearance and fusion timings as discussed above:
In addition to the primary ossification centers, a variable number of secondary ossification centers may appear. Unlike the bony nodules representative of primary ossification centers, secondary ossification centers present as small, flake-like epiphyses. These ossification centers occur mainly at sites of articulation, the prime examples being
the sternoclavicular and chondrosternal joints. Appearance and fusion times of these secondary centers are extremely variable and poorly documented and are therefore of limited value in age determination at this time (Scheuer and Black, 2000).

The manubriosternal articulation is described as either a primary or more commonly as a secondary cartilaginous joint, the primary peculiarity being the presence or nonappearance of a fibro-cartilage disc between two plates of hyaline-cartilage. The importance here is that unlike hyaline-cartilage, fibro-cartilage does not ossify and thus, secondary cartilaginous joints remain moveable into adult life. For this fibro-cartilage disc develops from a fibrous lamina that will appear early in fetal life and the articulation will then become secondarily cartilaginous. If the lamina fails to develop the joint will become primary cartilaginous allowing union between sternebra 1 and the manubrium (Scheuer and Black, 2000).

Postnatal development, maturation, and ossification center development of the sternum have been shown to differ significantly from person to person; however, three different ossification pattern types have been described according to the ossification of the manubrium and the mesosternum during the postnatal period (Bayaroğulları et al., 2013). Pattern one is characterized by one ossification center in the manubrium and one ossification center in the three sternebrae of the mesosternum. Pattern 2 is defined by one ossification center in the manubrium, one ossification center in the first sternebrae of the mesosternum, and two ossification centers in the other sternebrae. In Pattern 3, only one ossification center in the manubrium and two ossification centers in the sternebrae of the mesosternum occur. Pattern 2 is the most commonly observed in the literature (Ashley,
1956 and Wong and Carter, 1988). In Bayaroğulları et al. 2013, it was shown that measurements of the manubrium, mesosternum, and manubriosternal structures could be used to assess the postnatal development, maturation, and age differences between groups; differences between age groups were found to be statistically significant. This knowledge can aid forensic anthropologists who need developmental correlation to age groups to better assess the age of human remains.

**Aging:**

The most common methods of the determination of age include analysis of the pattern of tooth eruption, the closure of epiphyseal plates, and the appearance of centers of ossification. However, these methods, though very precise, are mainly useful for skeletons from infants or children (Stewart, 1979). An assessment of the auricular surface and pubic symphysis of the innominate, the medial surface of the clavicle, tooth condition (wear/degradation) and eruption, and cranial suture closure are methods used for age estimation in adolescents and adults (Brooks and Suchey, 1990, Brothwell 1981, Boldsen et al., 2002, Buikstra and Ubelaker, 1994, Meindl and Lovejoy, 1985, and Shirley and Jantz, 2010).

Regardless of the methods, there are increased inconsistencies and error rates in age estimations especially with skeletons of older adult and senescent individuals as there are increased inaccurate or larger age ranges with older individuals. As aging progresses into adulthood, precision in age estimates decreases. Therefore, age ranges must accommodate for error and grow in size (Garvin and Passalacqua, 2011).
When applying methods for estimating age, it is additionally vital to consider the occurrence of secular changes, or changes in skeletal characteristics that differentiate a population from others. This can be done by using the same method on different collections of the same populations collected at different points in time. For example, Meadows and Jantz (1995) in their study on allometric secular change in long bones from the 1800’s to the present used allometric scaling coefficients derived through regression and demonstrated that the tibia, femur and fibula were positively allometric by stature, whereas the humerus, ulna, and radius were isometric. The lower limb bones were more positively allometric and analysis showed that secular increase is accompanied by relatively longer tibiae. Their results showed that secular changes in part possibly will render stature formulae found on nineteenth century examples, such as the Terry collection, unsuitable for contemporary forensic cases. These changes can skew developmental and growth indicators, thus leading to different assessments of age.

Determining age from the sternum has been estimated using multiple methods (Sun et al., (1995), McCormick (1980), and Barres et al., (1989)). Sun et al. (1995) demonstrates that some methods use non-metric trait analysis to age the sternum. McCormick (1980) studied the mineralization of the costal cartilages on an X-ray of a "chest plate" (that is, consisting of the sternum, costal cartilages, rib ends, and attached soft tissue) available during routine autopsy and revealed a significant relationship between morphological changes and the age at death. A positive correlation between cartilage mineralization and age both for males and females was found when examining and quantifying morphological changes in the sternum (Barres et al., 1989).
Sexing:

Methods for estimating sex include examination of gross morphology of the innominate bone (greater sciatic notch, ventral arc, subpubic angle, preauricular surface, ischiopubic ramus, and subpubic concavity), and non-metric landmarks of the skull (primarily nuchal crest, mastoid process, supra-orbital margin, glabella, and mental eminence) (Brooks and Suchey, 1990, Buikstra and Ubelaker, 1994, Klales et al., 2012, and Phenice, 1969). FORDISC 3.1, anthropological software, created by Jantz and Ousley (2005), has also been used for sex estimation employing cranial and postcranial morphometrics. However, this software is limited to skeletons from American White and Black populations.

Sex estimation from sternal remains relies on factors of sexual dimorphism, such as length and proportion differences of the manubrium and corpus sterni between males and females (Hunnargi et al., 2008). Sexual dimorphism has been considered in sex estimation from the sternum, specifically with the application of Hyrtl’s law (Hyrtl, 1860). Hyrtl’s law stipulates that the manubrium length of a female sternum exceeds half the length of the corpus sterni, while the corpus sterni of male sterna are, at least, double the length of the manubrium (Dwight, 1881). In the human sternum, which is considered a highly sexually dimorphic bone, some of its elements may be more useful than others for estimation of sex (Osunwoke et al., 2010). In their study of the sexual dimorphism of the human sternum, Osunwoke et al. (2010) conclude that the mesosternum and combined length of the sternum are exceedingly constructive in distinguishing male from female sterna.
The methods and statistical analyses applied to sex estimation from sterna vary from study to study (Gautam et al., 2003, Ramadan et al., 2012, and Singh et al., 2012). Some find that discriminant function analysis and limiting points are the most apposite methods for determination of sex from the various sternal measurements (Singh et al., 2012). Ramadan et al., (2012) determined sex from sternal dimensions and the fourth rib using multislice computed tomography of the thoracic cavity and concluded that the measurements produced can be made from dry bone or radiographs. In this study they concluded that sternal area, SA, is the most accurate measure for sex determination using the sternum. In contrast, Gautam et al., (2003) uses only manubrial and sternal lengths for sex estimation. Consistent with Hyrtl, Gautum et al., (2003) suggest classification measurements for manubrial length and sternal length as follows:

“If the length of the manubrium is less then 33mm then it is of a female. If it exceeds 63mm it is of a male. If the length of the body of sternum is less than 48mm then it is female, if it is more than 106mm then it is male. If the combined length of a sternum is less than 92mm then it is female where as if it exceeds 161mm, it is male.”

Sex has also been estimated from sternal dimensions. Macaluso and Lucena (2013) uses the same four measurements (ML, BL, S1W, and S3W) used by Bongiovanni and Spradley (2012), on their sample derived from chest plate radiographs in contemporary Spaniards (Macaluso and Lucena, 2013). Osteometric equations involving the sternum have therefore been shown to provide an effective method for assessing sex in numerous population groups, particularly in situations where the innominate or bones of the extremities are not maintained (Bongiovanni and Spradley, 2012 and Macaluso and Lucena, 2013). Other investigators have used statistical analysis to determine which
metrics perform the best when assessing sex using the sternum. For example, Mahajan et al. (2009) determined that total length, mesosternum length, and sternal index in combination produced the most accurate sex estimate.

It is important to also understand how increasing age can lead to ambiguities in sex estimation. Walker (1995) showed that as females’ age, their bones can experience masculinization due to environmental influences/stressors on skeletal development (vitamin D deficiencies, etc.) that appear to provide the most likely explanation for population differences that can ultimately lead to misidentification of sex. Fully understanding the sternum changes as a person ages becomes imperative to sex estimation from the sternum.

**Stature:**

While stature estimation was neither the focus of this paper or conducted in this study, previous research has utilized the human sternum in forming height estimates and some populations have varying statures between the sexes that may be useful in sex estimation studies as well. For instance, the majority of males are taller and more rugged than females of the same population, however an individual female might be taller and/or more rugged than a male (Gustafsson and Lindenfors, 2004). These differences and their extent vary across societies and therefore it is important to understand the previous research involved in stature estimation utilizing the human sternum.

Estimation of stature is an essential component in the discovery of an individual’s identity from mutilated or dismembered or fully skeletonized remains in forensic
casework. Stature estimation, however, has been continually affected by secular trends in stature, migration and bio-distance, and allometric changes in long bones (Menezes et al., 2011). Equations for estimation of stature derived from recent and relevant skeletal samples are generally considered the most accurate and precise (Menezes et al., 2011). It is vital to remember that forensic case work demands equations based on forensic estimates of stature, and equations used are necessarily based on modern samples.

Previous research studies on estimation of stature have shown stature can be estimated effectively using the Fully Method described in Raxter et al. (2006). This method relies on multiple skeletal elements and calculates a skeletal height total and then provides an estimate of living stature. However, this is a multivariate approach, and the likelihood that all of the required elements would survive taphonomic processes will vary from case to case. Thus, methods that can permit estimation of stature from single or lesser groups of variables will be useful. FORDISC 3.1 also follows this multivariate approach in stature estimation using up to 48 postcranial measurements. But again, FORDISC 3.1 is limited by its population groups and may not accurately display the stature statistics for other populations (Jantz and Ousley, 2005).

Research has shown that the sternum may be of use in stature assessment merely when long bones are not obtainable (Singh et al. 2011). For example, sternal lengths display relatively weaker correlation coefficients with stature and superior standard errors of estimate in regression analysis but may still be used if long bones are not available. It must also be stated that any application of formulae utilizing the sternum for stature estimation should be restricted to the population sample for and from which they have
been developed (Singh et al. 2011). Marinho et al. (2012), argues, in concurrence, that results advocate that the sternal length has inadequate forensic value and comparatively low dependability in determining stature from mutilated human skeletal remains, either skeletonized or fresh. In contrast, Menezes et al. (2011) conclude their analysis with the statement that the sternal length is a steadfast predictor of stature in adult South Indian females and can be used as an implement for stature assessment when superior predictors of stature such as long bones of the limbs are not obtainable throughout practical forensic case work involving inspection of skeletal remnants. This again demonstrates the need for validation and further research into other skeletal elements and their use in stature estimation in a North American population.

**Population Specificity:**

Many recent studies have investigated using measurements of the sternum for age and sex estimation of specific populations (Franklin et al., 2012, Macaluso, 2010, Mukhopadhyay, 2010, and Osunmoke et al., 2010). In South Africa, Macaluso, (2010) recently published a study on the efficacy of the sternum for sex estimation. He determined that the sternum is extremely sexually dimorphic and useful for sexing with a high percentage of accuracy. The author reported also that the classification results were analogous to those reported in preceding examinations concerning sex estimation of black South Africans for other postcrania elements. Osunwoke et al., (2010) conducted an examination of sexual dimorphism of the human sternum in a Southern Nigerian population and reported a significant difference between male and female sternum.
Mukhopadhyay, (2010) reported that the sternum exhibits substantial sexual dimorphism and that the variables studied contributed greatly to distinguishing between the two sexes in the studied population and reiterated that discriminant functions are population specific. Another study established that the sternum is a suitable skeletal element for sex estimation in a Western Australian sample (Franklin et al., 2012).

**Ancestry:**

As with stature, ancestry was neither the focus of this paper or examined in this study. However, as previously described, sex differences have been shown in different populations and possible ancestral sternal differences consequently need examination.

In forensic anthropology, a system of both metrics and nonmetrics is used in estimating ancestry. First, the nonmetric method described by Hefner (2009) is employed and scores the landmarks commonly associated with specific ancestries. Some nonmetric traits are seen as being more correlative to one ancestral group than another. For example, the presence of a postbregmatic depression gives more strength to the assessment of a person of African ancestry, while as shoveled incisors indicates Asian ancestry.

Following the metric methodology, craniometric measurements can be made from the 24 most commonly used skeletal landmarks as described in Buikstra and Ubelaker (1994) (See Table 1 for the 24 measurements). These skull measurements can then be evaluated with FORDISC 3.1, which is used by forensic anthropologists to assist in the formation of a decedent's biological profile, even when only parts of the cranium are
available. Postcranial metrics can also be examined in FORDISC 3.1 and can yield an ancestry classification as well, albeit less reliable than craniometric assessments (Jantz and Ousley, 2005). To date, there has been a diminutive amount of research exploring the sternum for indications of ancestry and this may become a future research focus.

Table 2. (24) Cranial Landmarks used for Sex and Ancestry Estimates by FORDISC 3.1

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Measurement</th>
<th>Abbreviation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOL</td>
<td>Maximum Cranial Length</td>
<td>NLH</td>
<td>Nasal Height</td>
</tr>
<tr>
<td>XCB</td>
<td>Maximum Cranial Breadth</td>
<td>NLB</td>
<td>Nasal Breadth</td>
</tr>
<tr>
<td>ZYB</td>
<td>Bizygomatic Breadth</td>
<td>OBB</td>
<td>Orbital Breadth</td>
</tr>
<tr>
<td>BBH</td>
<td>Basion-Bregma Height</td>
<td>OBH</td>
<td>Orbital Height</td>
</tr>
<tr>
<td>BNL</td>
<td>Cranial Base Length</td>
<td>EKB</td>
<td>Bi orbital Breadth</td>
</tr>
<tr>
<td>BPL</td>
<td>Basion-Prosthion Length</td>
<td>DKB</td>
<td>Interorbital Breadth</td>
</tr>
<tr>
<td>MAB</td>
<td>Max. Alveolar Breadth</td>
<td>FRC</td>
<td>Frontal Chord</td>
</tr>
<tr>
<td>MAL</td>
<td>Max. Alveolar Length</td>
<td>PAC</td>
<td>Parietal Chord</td>
</tr>
<tr>
<td>AUB</td>
<td>Bi auricular Breadth</td>
<td>OCC</td>
<td>Occipital Chord</td>
</tr>
<tr>
<td>UFHT</td>
<td>Upper Facial Height</td>
<td>FOL</td>
<td>Foramen Magnum Length</td>
</tr>
<tr>
<td>WFB</td>
<td>Minimum Frontal Breadth</td>
<td>FOB</td>
<td>Foramen Magnum Breadth</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UFBR</td>
<td>Upper Facial Breadth</td>
<td>MDH</td>
<td>Mastoid Height</td>
</tr>
</tbody>
</table>

(This table was created by the current author using the FORDISC 3 help file (Jantz and Ousley, 2005).

**Discrete Traits:**

Verna *et al.*, (2013) contend that methods used in the identification of human skeletal remains are lacking in completeness because profiles may be shared by multiple individuals and are thus ambiguous. Thus, discrete traits, or traits without a range of phenotypes thus indicating something is either one way or another, or asymptomatic variations found on bones, can be scored as either present or absent which can lead to exclusion and narrowing of the profile created. Verna *et al.*, (2013) describe that the
etiology of discrete traits is often unknown; however, it is believed that they are the consequence of an accumulation of traits including genetic, epigenetic, and environmental factors. This again would also promote population specific studies in which certain discrete traits are more prevalent and could also prove to show ancestrally specific discrete traits. Verna et al., (2013) also propose that the sternum holds such discrete traits that can aid a forensic anthropologists creation of the biological profile, either through completion or narrowing. This would mean that forensic anthropologists could rely on antemortem radiographic (x-ray) evidence of the person to identify them in death.

**Preservation Bias / Survivability of the Sternum:**

The bio-mechanics involved in bone preservation of skeletal elements of separate individuals and those elements of a single individual are yet another complication in the utility of the human sternum because they can lead to preservation biases in methodologies. Von Endt and Ortner (1984) stated that the temperature and surface area of an element are directly related to the speed at which destruction of collagen and mineral matrices occur. Therefore, bones such as the sternum that consist of spongy/cancellous bone and have greater surface area, would be expected to deteriorate first (Von Endt and Ortner, 1984). The porous and penetrable vertebra, ribs, sternum, and hand and foot bones generally exhibit marginal preservation (Boddington et al., 1987). Dense areas of bone such as that found on long bone shafts tend to be preserved better (Galloway et al., 1997).
Porosity and penetrability/density can also be used to elucidate the degree of difference in the preservation of elements between individuals. It has been observed that normal bone mineral content increases as we grow in childhood and adolescence, reaches its climax in midlife, and declines with senescence (Riggs and Melton 1986 and Stini et al., 1992). Therefore age specific preservation biases should be expected to occur. Certain pathologies and effects of nutritional/metabolic factors may also affect the preservation of affected skeletal elements in a similar manner where osteoclastic processes (osteoporosis or bone destruction) promote bone deterioration, and osteoblastic processes (osteophyte formation) create new bone.

Nutritional and metabolic bone diseases are umbrella terms referring to abnormalities of bones caused by a broad spectrum of disorders. Most commonly these disorders are caused by the lack or insufficient presence of minerals such as calcium, phosphorus, magnesium or vitamin D causing disorders that are commonly reversible once the nutritional intervention takes place that restores these minerals (Brickley and Ives, 2008). These disorders should not be confused with genetic bone disorders where there is a defect in a gene or cell type that causes the bone disorder (Brickley and Ives, 2008). However, overlap has occurred between metabolic and genetic disorders. For example, hypophosphatemia, a genetic disorder that causes problems in absorption of phosphorous, often results in the metabolic bone disorder osteomalacia. While the problem is genetic, nutritional intervention through, replacement of phosphate often corrects for osteomalacia (Brickley and Ives, 2008).

Arrested or stunted development occurring at any stage of sternal development
can result in anomalies that may be simple and isolated or complex and a part of a multiple malformation syndrome. This can occur as a result or genetic, nutritional, or metabolic factors among others. Premature synostosis may result in short or deformed sterna as seen with many chromosomal conditions such as trisomy 18 and 21 and Turner syndrome (Stevenson, 2005). While rare, congenital nonsegmentation of the sternum may also occur. Multiple ossification centers of the manubrium initially present in development may create asymmetry of the sternoclavicular joints. Infants with Down syndrome, a genetic condition, may produce separate inferior and superior manubrial centers (Stevenson, 2005). Metabolic diseases that affect bone growth include fluorosis, hypophosphatemia, osteopenia, osteoporosis, rickets, Paget’s disease, and scurvy (Brickley and Ives, 2008).

Sex and age can result in differences in body size that may result in comparable effects on the condition of bone (Walker et al., 1988). For example, parts of the male skeleton are more robust than in females due to sexual dimorphism and external factors such as correlated activity patterns (Carlson et al., 2007). Younger adult skeletal elements, when well nourished and disease free in life, are also thought to be stronger as they have reached maturity, but not degradation (Zioupos and Currey, 1998). Thus, younger male adult elements may in fact preserve better simply due to their overall size and age. In preserved assemblages, one would therefore expect to find an underrepresentation of sub-adults, senescent adults, and females due to the decreased resiliency of non-dense bone to taphonomic factors (Walker et al., 1988; Walker, 1995) and geological features such as topsoil composition and reduction, depth, and
water/moisture (Boddington, 1987).

Although preservation of dense elements is much more likely, in cases where the sternum is preserved, it could be used in addition to other surviving skeletal elements to form the biological profile. Thus, validation of those methods that seek to use the sternum, become important.

**Common Sternal Pathological Conditions and Developmental/Age-Related Abnormalities:**

This section will briefly discuss the common pathologies and age-related abnormalities that have been shown to affect the sternum. These disorders are listed in order to demonstrate the most common reasons sterna were excluded from the present study. These listed disorders thus contribute to the overall sample size usable in this study. Corresponding pictures can be found in the Appendix B at the end of this paper.

*Manubrio-mesosternal joint fusion (IMAGE 1):*

This occurs when the fibrous lamina fails to form between the developing manubrium and first sternebra of the mesosternum (Barnes, 2012).

*Misplaced Manubrium-Mesosternal Joint (IMAGE 2):*

This occurs when the fibrous lamina misplaced between the first and second sternebrae, instead of the manubrium and first sternebra (Barnes, 2012).

*Sternal Hyperplasia (IMAGE 3):*

Hyperplasia occurs when extra long sternal bands produce additional sternebrae
or an extra long xiphoid process (Barnes, 2012).

*Sternal Aperture (IMAGE 4):*

Sternal apertures form when there is incomplete fusion of sternal bands, generally between the third and fourth sternebrae (Barnes, 2012).

*Sternal clefts (IMAGE 5):*

Clefts are caused by a delay in fusion at the midline. They are generally thought to correspond with other midline anomalies such as a cleft lip (Barnes, 2012).

*Sclerotic Synostosis (NO IMAGE):*

With age the fibro-cartilage pad can break down leaving two areas of hyaline cartilage opposed. Fusion can then occur across the joint. This degenerative condition predominantly occurs in aging females as they reach older ages (White, 2005).

*Midline Sternal Foramen/Perforation (IMAGE 6):*

This relatively common phenomenon is a sternal perforative anomaly occurring on the third sternebra on the sagittal plane. It is of forensic significance due to its possible confusion with that of perforating injuries or projectile trauma (Byers, 2010).

*Homeostatic Imbalance/Inverted Xiphoid (IMAGE 7):*

In some cases, the xiphoid process can project posteriorly. In such cases, a blow or impact to the chest could potentially thrust the xiphoid into the underlying tissues, primarily the liver or heart. This can cause massive hemorrhage and thus can lead to fatality (Williams et al. 1989).
Hyrtl’s Law:

The discourse on Hyrtl’s Law has a long history. In 1788, J. Wenzel studied the relation among the length of manubrium and mesosternum in males and females (Wenzel, 1788). Wenzel’s work led to the development of Hyrtl’s law (Hyrtl, 1860) which states that the Manubrium-Corpus Index (now known as the Sternal Index (M/B ×100)), a standard derived by dividing the manubrial length by the mesosternal length and multiplying it by 100 in order to test sexual dimorphism in a specific population, exceeded 50 in females while it was less than 50 in males. This Index has been used by many researchers who have conducted studies to determine its reliability (Ashley 1956, Bongiovanni and Spradley 2012, Dwight 1890, Narayan and Verma 1958). Although Dwight found it reliable to use the sternum as an index for sex determination, Ashley and Narayan and Verma found it unreliable for sex determination. Recent works on Hyrtl’s law includes the works of Bongiovanni and Spradley, (2012), Dahipale et al., (2002), Hunnargi et al., (2009), Jit, (1980), and Kaneriya et al., (2013), all of which find that even as the average values of sternal index obey the rules of Hyrtl’s Law, the range of values mostly overlap, and prove anecdotal for sex estimation.

Hyrtl’s law thus, has a specific sectioning point (50) that, when applied to measured sterna, can classify male and female. The numbers of male and female sterna that are correctly classified utilizing this law are then summed and statistically analyzed to address the methods efficacy (Ankit et al. 2013).

Bongiovanni and Spradley (2012) are in agreement with much of the previous research involving Hyrtl’s law (Ashley 1956, Dahipale et al., 2002, Dwight, 1890,
Gautam et al., 2003, Hunnargi et al., 2009, Jit et al., 1980, Kaneriya et al., 2013, and Narayan and Verma, 1958). Accordingly, while the mean values of sternal index fit well with Hyrtl’s Law, the values largely overlap, and prove undependable for sex estimation. The present study will investigate the applicability of Hyrtl’s Law to create a reliable sternal index.

Utility of the Sternum: The Two Methods to be used:

To test the utility of the human sternum for sex estimation, as reported by Bongiovanni and Spradley, (2012), discriminant function analysis is used to estimate sex from the morphometric measurements of the sternum and supply a population specific classification function for application in the United States (Bongiovanni and Spradley 2012). The authors state that they had insufficient data for females and then assumed that any differences found between American White and Black males will be subsequently representative of females as well (Bongiovanni and Spradley 2012). Their discriminate function analyses produced an altogether cross-validation classification rate of 84.12% for sex assessment. The classification rate for males and females was reported as 80.00% and 88.24% respectively (Bongiovanni and Spradley 2012). They concluded that their methods were accurate and that the sternum could be used in producing estimates of sex. They also noted that their data followed Hyrtl’s Law with respect to the mean of their sample, but asserted that there is too much overlap to be used on the individual level.

To test the utility of the human sternum for age estimation, the Sun et al., (1995) is assessed. The authors of this method claim that they can estimate age of Chinese
females from 18-50 years through the following regression equation:

\[
y = 19.28 + 1.83x_1 + 1.66x_2 + 3.02x_3 + 1.57x_4 + 7.75x_6 + 1.25x_7 + 3.45x_8 + 4.88x_9 + 0.82x_{10} + 2.76x_{11} + 2.48x_{12} + 7.84x_{13} + 1.26x_{14} + 3.80x_{15} \text{ (the correlation coefficient } R = 0.9774, \text{ the standard deviation } S = 2.20, \text{ F } > 0.01) \text{ (Sun et al. 1995).}
\]

More detailed information regarding this method is limited due to the nature of its description in the cited paper. It is complicated by non-standard jargon and statistical language. This comes at the detriment of the methods user’s comprehension and thus increases the likelihood of intra- and inter-observer error.

The Present Study:

The utility of the sternum for sex and age estimation is at times controversial and complicated topic. Several researchers conclude that the sternum is not useful for estimation of age and sex (Chandrakanth et al., 2012, Dwight, 1881, and Dwight, 1890), while others state its usefulness and effectiveness for use in estimating age and sex (Bongiovanni and Spradley, (2012) and Sun et al. (1995)). The purpose of the current study is to investigate the utility of the analysis of the human sternum for age and sex estimation in a North American population using two methods for validation: Bongiovanni and Spradley’s (2012) method for sex estimation and Sun et al., (1995) method for age estimation. This study utilized sterna from 375 human skeletons from the Robert J. Terry Collection at the National Museum of Natural History-Smithsonian in Washington D.C. Hypothetically, if the methods used by Bongiovanni and Spradley, (2012) and Sun et al., (1995) described above are found to hold true, then a valid
estimation of sex and age from sterna examined in the Robert J. Terry Anatomical Skeletal Collection should be possible.
Chapter 3: Materials and Methods

Materials:

Sterna from 375 human skeletons (260 males and 115 females) from the Robert J. Terry Anatomical Skeletal Collection at the National Museum of Natural History-Smithsonian in Washington D.C were used in this study. Of the 260 male sterna, 188 sterna were from American Blacks and 72 sterna were from American Whites. Of the 115 female sterna, 102 sterna were from American Blacks and 13 sterna were from American Whites. Samples were from individuals born between 1822 and 1943 of between 18-50 years. Only intact sterna were used. Sternae were excluded from measurement if they were damaged by injury, disease, or human intervention. These experimental samples were from North American populations alone and were from the most modern samples available in the Robert J. Terry Anatomical Skeletal Collection. This collection contains documented individuals with information regarding morgue records, known sex, age, ancestry, cause of death, date of death, origin, catalogue and permit number, other various dates and a record connected to embalming or remains preservation processes (Hunt 2005).
Method:

Bongiovanni and Spradley (2012)

Morphometric measurements were made with digital calipers (Mitutoyo Inc., Japan). All measurements were recorded to the nearest millimeter. Measurements are illustrated in Figure 4 and consist of the following:

- Manubrium length (ML): the distance between the jugular notch to the sagittal midpoint of the manubriosternal joint.
- Mesosternum length (BL): the distance between sternal angle to the sagittal midpoint of the xiphisternal joint.
- Sternebra 1 width (S1W): the distance between the left and the right first sternebra (depressions between the articulation notches for the second and third costal cartilage).
- Sternebra 3 width (S3W): the distance between the left and right third sternebra (depressions between the articulation notches for the fourth and fifth costal cartilage).
Figure 4. (4) Measurements of the sternum
ML – manubrium length; BL – mesosternum length; S1W – sternebra 1 width;
S3W – sternebra 3 width. (Figure was created by current author
following definitions of Bongiovanni and Spradley, (2012).

Measurements described above were made using an estimated midline of the sternum as
demonstrated in the following Figure 5.
Sternal samples with fused manubrio-mesosternal joints measurements are difficult to analyze since the true location of the joint may be hard to identify. Those sternae lacking obvious fusion lines were not used. Only samples possessing clear fusion lines were retained for measurement.

Sternal width measurements were made transversely in direction at the site of depression between the left and right parasagittal sides of the first and third sternebrae. Measurements were only taken when the left and right parasagittal sides were perpendicular to the sagittal midline. If the right and left lateral sides of the sternebra
were not perpendicular to the sagittal midline they were not measured. Lastly the total
depth of the sternum was taken; no estimations were taken. All measurements were
recorded and entered into Windows Excel for data collection and subsequently
transposed to SPSS 21 for data analysis.

Data Analysis:

Intra-Observer Error:

Test-retest reliability was determined to the presence of differences in the
interpretations of measurements made by an individual making measurements at different
times. Thirty sterna were chosen at random to be re-measured. The 30 sterna were first
arranged into two samples (15 each) and re-measured following the methods outlined
above. The two sets of data were then entered into SPSS to calculate the correlation co-
efficient between variables. A Spearman’s rho correlation analysis was conducted to
discover whether the two data sets were significant at 0.01 and 0.05 (two-tailed) levels.

Analysis of variance (ANOVA):

To assess the utility of sternal measurements in forming accurate estimations of
sex, univariate and multivariate tests were conducted. An analysis of variance (ANOVA)
using SPSS 21 was needed to determine if there were any ancestry specific differences
between American White and Black male and female sterna.
**Sectioning Points:**

Descriptive statistics were calculated to establish sectioning points for each individual variable through use of SPSS 21. Each variable was separated by sex, and the sample size, mean, standard deviation, sectioning point, frequency rate, and overall classification rates were calculated. Results of the univariate analysis that were above the sectioning point were considered male individuals, and results below the sectioning point were considered female individuals, with results that fall at the sectioning point termed indeterminate. The sectioning point (SP) is calculated by taking the group centroids for male and female and averaging the two (See SP formula below). Centroids are the mean discriminant score for each group. Wilk’s lambda is used to test for significant differences between groups. Wilk’s lambda is gauged as a nominal variable between 0 and 1 and tells us the variance of a dependent variable that is not explained by the discriminant function. Wilk’s lambda is also used to test for significant differences between the groups on the individual predictor variables. It tells which variables contribute a significant amount of prediction to help separate the groups.

\[
SP = \text{Group Centroid (Male)}/\text{Group Centroid (Female)}
\]

**Discriminant Function Analysis:**

A stepwise discriminant function was performed to determine which variables provide the best measures for estimation/discrimination of sex including total sternal length. This was followed by a linear discriminant function analysis (DFA). These two analyses were run in SPSS 21. The DFA maximizes between-group differences, and
reduces error rates by excluding the sample being classified from the function and produces cross-validation classification rates (Bongiovanni and Spradley, 2012). The linear discriminant function scores were then utilized to generate a classification function. The classification function is a formula that allows a user to input their sternal measurements and estimate whether the individual is male or female. The cross-validation classification rates indicate how well the classification function performs.

**Sternal Index:**

A sternal index was calculated using Microsoft Excel by creating a formula that divides the length of the manubrium by the length of the mesosternum and multiplied by 100 (Sternal Index (SI) = (ML/BL) \times 100).

The average of the sternal indices for males and females was then compared to see if there was a significant difference between the two sexes and to what degree Hyrtl’s Law applied to a North American population. A sectioning point, described as 50% according to Hyrtl’s law, was calculated since the ratio is considered to be 2:1 in males. A true sectioning point, one calculated by taking the male and female means divided by two, was generated. This true sectioning point allows us to denote male (below sectioning point) and female (above the sectioning point), while values equal to the sectioning point represent indeterminate sterna. These classifications were then compared to the recorded age of the individuals to discern the number of correctly classified sterna and to determine the usefulness of a sternal index in estimating sex.
Sun et al. (1995):

Method:

Samples involved in the validation of the Sun et al. (1995) method were the same 375 human sterna with 260 male and 115 female sterna from the Robert J. Terry Anatomical Skeletal Collection used in testing Bongiovanni and Spradley’s (2012) method. All of the male and female sterna used for testing the first method were also used in testing this method. Likewise, all sterna excluded from the sample for the first method were also excluded in the second. All sterna were scored morphologically following the descriptions of Sun et al. (1995). In their study, Sun et al. (1995) used female sterna alone, from a more homogenous Chinese sample acquired fresh from autopsies. This detail differs from the current study that looks at the utility of sternum for age estimations in both males and females. The samples used in the current study also differ as they come from a prepared anatomical collection and not from fresh autopsies.

When testing the Sun et al. (1995) method, sternae were placed on a laboratory examination table 10-15 at a time to allow for comparison between each sternum. Doing this allowed the current researcher to observe the varying degrees of prominence of each characteristic. Six morphological characteristics of the sterna were then scored. They include: [1] lateral projection of sternal manubrium, [2] superciliary arch-shaped prominence on the ventral side of sternal manubrium, [3] the second coastal notch of sternum and sternal synchondroses, [4] radial stripes on the ventral side of sternal body, [5] the other costal notches of sternum, and [6] the lower part of the dorsal side of sternum, all following the framework of Sun et al. (1995) demonstrated in Figure 6. For
some characteristics it was simply a matter of scoring whether or not the characteristic was present. Other characteristics were scored based on their varying degrees of prominence. Each specimen was scored following the method and criteria demonstrated by Table 3. All scores were recorded for each specimen into a Windows Excel spreadsheet and subsequently transposed to SPSS 21 for data analysis.
Figure 6. (6) Morphological features of the Sternum.

Data Analysis

As described above, the scores, representing the changing degree of all morphological characteristics observed were recorded in a Microsoft Excel spreadsheet. The scores were then used to estimate the exact age of each individual following the equation provided by Sun et al., (1995). The resulting age estimates were then compared to the recorded age of the sternae. Discriminant analysis and intra-observer error were also examined from this data.
<table>
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<th>Morphological Characteristics</th>
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<th>Variable</th>
</tr>
</thead>
<tbody>
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<td>No................................................................................................. 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exists......................................................................................... 1</td>
<td>X₁</td>
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</tr>
<tr>
<td>Superciliary arch-shaped prominence on the ventral side of sternal manubrium</td>
<td>No................................................................................................. 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exists......................................................................................... 1</td>
<td>X₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Remarkable................................................................................. 2</td>
<td>X₃</td>
<td></td>
</tr>
<tr>
<td>Second costal notch of sternum and Sternal synchondrosis</td>
<td>Articular surface does not form ........................................ 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Articular surface begins to form............................................... 1</td>
<td>X₄</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conjugation site is slightly projected......................................... 2</td>
<td>X₅</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crested projection forms on the notch, conjugation site is nodularly projected with many holes................................. 3</td>
<td>X₆</td>
<td></td>
</tr>
<tr>
<td>Radial stripes on the ventral side of sternal body</td>
<td>No................................................................................................. 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Appears....................................................................................... 1</td>
<td>X₇</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radial stripes reach near the midline or form small crested projections............ 2</td>
<td>X₈</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radial stripes come together from both sides or crested projection is more prominent.............................................. 3</td>
<td>X₉</td>
<td></td>
</tr>
<tr>
<td>Other costal notches of sternum</td>
<td>Articular surface does not form.............................................. 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glenoid lip forms but is lower than bony surface............................. 1</td>
<td>X₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glenoid lip is fused or higher than bony surface.................................. 2</td>
<td>X₁₁</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glenoid lip is everted and small crested projection and notch appears........... 3</td>
<td>X₁₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glenoid lip is everted prominently, big crested projection forms.............. 4</td>
<td>X₁₃</td>
<td></td>
</tr>
<tr>
<td>Lower part of the dorsal side of sternum</td>
<td>Many small grooves........................................................................ 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface is flat and pitted............................................................ 1</td>
<td>X₁₄</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pit is enlarged, deep, and rough................................................... 2</td>
<td>X₁₅</td>
<td></td>
</tr>
</tbody>
</table>
**Intra-Observer Error:**

Test-retest reliability was also assessed for this method. The same 30 sterna that were chosen at random to be re-measured in the Bongiovanni and Spradley, (2012) method, were again scored following Sun *et al.*, (1995). The 30 sterna were arranged in the same fashion as previously mentioned (2 groups, 15 each) and were re-scored following the methods outlined above. The data were then entered into SPSS to calculate the correlation co-efficient between variables. A Spearman’s rho correlation analysis was conducted to discover whether the two data sets were significant at 0.01 and 0.05 (two-tailed) levels.

**Discriminant Function Analysis:**

A stepwise discriminant function was also performed for the data collected using the Sun *et al.*, (1995) method to determine which variables provide the best measures for estimation and discrimination of age. This was followed by a linear discriminant function analysis (DFA). These two analyses were conducted using SPSS 21. The results of those analyses are considered below.
Chapter 4: Results:

Bongiovanni and Spradley (2012)

Intra-Observer Error:

The Spearman’s rho correlation analysis provided a positive linear relationship between the original and retested data. The two data sets for ML, BL, S1W, and S3W had a correlation coefficient of 1.000, which was significant at the 0.01 confidence level (Table 4.). This indicates the intra-reliability of this method is high when following the same methodology at different times.

Analysis of variance (ANOVA):

To determine if the analysis of the sternum provided accurate sex estimation, univariate and multivariate tests were conducted. An analysis of variance (ANOVA) conducted with SPSS 21 was used to determine whether any ancestry specific differences existed between American White and Black male and female sterna. The ANOVA produced a p-value of 0.29, suggesting no significant difference between the sterna from American White and American Black males and females. Therefore, all groups were combined to create one discriminant function and one sternal index. Sample size was sufficient enough to include all four groups.
Table 4. Correlations

<table>
<thead>
<tr>
<th>Spearman’s Rho</th>
<th>ML</th>
<th>BL</th>
<th>S1W</th>
<th>S3W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-ML</td>
<td>1.000**</td>
<td>-.147</td>
<td>.249</td>
<td>.086</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.</td>
<td>.364</td>
<td>.121</td>
<td>.596</td>
</tr>
<tr>
<td>N</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Intra-BL</td>
<td>-.147</td>
<td>1.000**</td>
<td>-.157</td>
<td>.374*</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.364</td>
<td>.</td>
<td>.333</td>
<td>.017</td>
</tr>
<tr>
<td>N</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Intra-S1W</td>
<td>.248</td>
<td>-.153</td>
<td>1.000**</td>
<td>.462**</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.122</td>
<td>.347</td>
<td>.</td>
<td>.003</td>
</tr>
<tr>
<td>N</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Intra-S3W</td>
<td>.086</td>
<td>.374*</td>
<td>.462**</td>
<td>1.000**</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.596</td>
<td>.017</td>
<td>.003</td>
<td>.</td>
</tr>
<tr>
<td>N</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

Correlation is significant at the 0.01 level (2-tailed);
*Correlation is significant at the 0.05 level (2-tailed).

Sectioning Points (SP):

Descriptive statistics were calculated to establish sectioning points for each individual variable through use of SPSS 21. The sectioning point for the linear regression equation was determined by taking the group centroids for male (0.580) and female (-1.294) classification and averaging them. A sectioning point of (-0.714) was
thus calculated (Table 5). A resulting Wilk’s lambda of 0.000 was calculated inferring that that the given variables were significant.

**Table 5. Functions at Group Centroids**

<table>
<thead>
<tr>
<th>Actual Sex</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>.580</td>
</tr>
<tr>
<td>F</td>
<td>-1.294</td>
</tr>
</tbody>
</table>

Un-standardized canonical discriminant functions evaluated at group means. 
Sectioning point (-0.714).

**Discriminant Function Analysis (DFA):**

Significant differences were found between the sexes according to the DFA for both male and female individuals, at p < .001. According to the stepwise results and as seen in the following Tables 6 and 7, only three of the four variables (ML BL, and S1W) variables provide the classification rate of 81.1%. Therefore, the discriminant function analysis was run using these three variables. The classification rates are found below in Table 8 and are 79.9% for males and 83.6% for females. A linear discriminant function for sex was calculated from the resulting standardized canonical discriminant function coefficients (Table 9) and resulted in the following formula: 

$$y = (ML \times 0.342) + (BL \times 0.762) + (S1W \times 0.352),$$

where (y) equals the discriminant function score. To use this formula, each of the three measurements are multiplied by the corresponding factor provided; take the sum of those values. The sectioning point for this formula is (-0.714), negative values below this point are considered females and positive values above this
point are considered males, with values equaling zero (-0.714) being indeterminate/ambiguous. The overall classification rate using this method was 81.1%.

Significant differences in the total length (TL) of the sternum were found between the sexes. Discriminant analysis produced classification rates of 93.7% for males and 79.7% for females with an overall classification rate higher than that of Bongiovanni and Spradley of 86.7% (Table 10). This classification rate is also higher than the discriminant function classification rate of 81.1% produced in the current study using the Bongiovanni and Spradley, (2012) method. See Table 11 for descriptive statistics and Table 12 for overall classification results by variable.

Table 6. Variables in Analysis

<table>
<thead>
<tr>
<th>Step</th>
<th>Variables</th>
<th>Tolerance</th>
<th>F to Remove</th>
<th>Wilks’ Lambda</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BL</td>
<td>1.000</td>
<td>195.894</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>BL</td>
<td>.995</td>
<td>150.405</td>
<td>.839</td>
</tr>
<tr>
<td></td>
<td>S1W</td>
<td>.995</td>
<td>36.400</td>
<td>.656</td>
</tr>
<tr>
<td>3</td>
<td>S1W</td>
<td>.918</td>
<td>19.080</td>
<td>.599</td>
</tr>
<tr>
<td></td>
<td>ML</td>
<td>.906</td>
<td>17.700</td>
<td>.597</td>
</tr>
</tbody>
</table>
Table 7. Variables not in Analysis

<table>
<thead>
<tr>
<th>Step</th>
<th>Tolerance</th>
<th>Min. Tolerance</th>
<th>F to Enter</th>
<th>Wilks' Lambda</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>ML</td>
<td>1.000</td>
<td>1.000</td>
<td>84.028</td>
</tr>
<tr>
<td></td>
<td>BL</td>
<td>1.000</td>
<td>1.000</td>
<td>195.894</td>
</tr>
<tr>
<td></td>
<td>S1W</td>
<td>1.000</td>
<td>1.000</td>
<td>71.743</td>
</tr>
<tr>
<td></td>
<td>S3W</td>
<td>1.000</td>
<td>1.000</td>
<td>73.003</td>
</tr>
<tr>
<td>1</td>
<td>ML</td>
<td>.981</td>
<td>.981</td>
<td>34.955</td>
</tr>
<tr>
<td></td>
<td>S1W</td>
<td>.995</td>
<td>.995</td>
<td>36.400</td>
</tr>
<tr>
<td></td>
<td>S3W</td>
<td>.917</td>
<td>.917</td>
<td>14.585</td>
</tr>
<tr>
<td>2</td>
<td>ML</td>
<td>.906</td>
<td>.906</td>
<td>17.700</td>
</tr>
<tr>
<td></td>
<td>S3W</td>
<td>.617</td>
<td>.617</td>
<td>.181</td>
</tr>
<tr>
<td>3</td>
<td>S3W</td>
<td>.610</td>
<td>.610</td>
<td>.000</td>
</tr>
</tbody>
</table>

Table 8. Classification Results

<table>
<thead>
<tr>
<th>Known Sex</th>
<th>Predicted Group Membership</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>Original</td>
<td>207</td>
<td>52</td>
</tr>
<tr>
<td>%</td>
<td>79.9</td>
<td>20.1</td>
</tr>
<tr>
<td>Count</td>
<td>259</td>
<td>116</td>
</tr>
</tbody>
</table>

a. 81.1% of original grouped cases correctly classified.

Table 9. Standardized Canonical Discriminant Function Coefficients

<table>
<thead>
<tr>
<th>Function</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td>.342</td>
</tr>
<tr>
<td>BL</td>
<td>.762</td>
</tr>
<tr>
<td>S1W</td>
<td>.352</td>
</tr>
</tbody>
</table>
Table 10. Classification Function Coefficients for TL

<table>
<thead>
<tr>
<th></th>
<th>Actual Sex</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>TL</td>
<td>.937</td>
<td>.797</td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>-70.362</td>
<td>-51.153</td>
<td></td>
</tr>
</tbody>
</table>

Table 11. Descriptive Statistics

**Female**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$n$</th>
<th>Mean</th>
<th>StdDev</th>
<th>% Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td>375</td>
<td>44.83</td>
<td>±4.58</td>
<td>75.9</td>
</tr>
<tr>
<td>BL</td>
<td>375</td>
<td>81.72</td>
<td>±10.90</td>
<td>78.4</td>
</tr>
<tr>
<td>S1W</td>
<td>375</td>
<td>22.44</td>
<td>±3.11</td>
<td>74.1</td>
</tr>
<tr>
<td>S3W</td>
<td>375</td>
<td>26.94</td>
<td>±5.33</td>
<td>75.0</td>
</tr>
<tr>
<td>TL</td>
<td>375</td>
<td>126.55</td>
<td>±11.68</td>
<td>79.7</td>
</tr>
</tbody>
</table>

**Male**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$n$</th>
<th>Mean</th>
<th>StdDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td>375</td>
<td>49.90</td>
<td>±5.10</td>
</tr>
<tr>
<td>BL</td>
<td>375</td>
<td>98.80</td>
<td>±10.94</td>
</tr>
<tr>
<td>S1W</td>
<td>375</td>
<td>25.99</td>
<td>±4.01</td>
</tr>
<tr>
<td>S3W</td>
<td>375</td>
<td>32.19</td>
<td>±5.57</td>
</tr>
<tr>
<td>TL</td>
<td>375</td>
<td>148.70</td>
<td>±12.99</td>
</tr>
</tbody>
</table>
Table 12. Overall Classification Rates by Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall Classification rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td>72.1</td>
</tr>
<tr>
<td>BL</td>
<td>78.95</td>
</tr>
<tr>
<td>S1W</td>
<td>68.3</td>
</tr>
<tr>
<td>S3W</td>
<td>69.55</td>
</tr>
<tr>
<td>TL</td>
<td>86.7</td>
</tr>
</tbody>
</table>

Note that the BL and TL are most reliable.

Sternal Index:

In the present study a sternal index was created using Microsoft Excel. A formula was then created that divides the length of the manubrium by the length of the mesosternum and multiplied it by 100. The average of the sternal index for males and females was compared to see if there was a significant difference between the two sexes and to what degree Hyrtl’s Law could be applied to a North American population. Results showed that male sternal index ranged from 35.57% to 80.56%, with a mean of 51.03%. The sternal index for females ranged from 39.39% to 85.52%, with a mean of 55.96%. This indicates that minor differences do occur between the sexes with respect to the ratio between manubrium length and mesosternum length. However, it also shows that, as Bongiovanni and Spradley, (2012) found, there is considerable overlap among males and females. Following Hyrtl’s law, a sectioning point of 50% yields a frequency rate of 47.7% in males and 69.6% in females. This indicates that out of the 260 males
and 115 females included in this sample, 47.7% of males and 69.6% of females were correctly identified using the sternal index. Therefore 124 males and 80 females were correctly classified; leaving 171 individuals incorrectly identified utilizing this law.

Alternatively, the sectioning point gained by averaging the means of the male and female sternal index is 53.5%. This produces a frequency rate for females of 54.78%, indicating that out of the 115 females included in this sample, 54.78% or 63 were correctly identified as females using the sternal index with the true sectioning point. The frequency rate for males is 67.31%, which shows that out of the 260 males included in this sample, 67.31% or 175 were correctly identified as males using the sternal index with the true sectioning point. This means that 137 individuals, or 36.53%, of this sample were incorrectly identified. Results are shown in Table 13.

Table 131. Sternal index mean for females and males with corresponding frequencies and sectioning points.

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>115</td>
<td>260</td>
</tr>
<tr>
<td>Mean</td>
<td>55.96%</td>
<td>51.03%</td>
</tr>
<tr>
<td>Frequency: sectioning point 50%</td>
<td>69.6%</td>
<td>47.7%</td>
</tr>
<tr>
<td>Frequency: sectioning point 53.5%</td>
<td>54.78%</td>
<td>67.31%</td>
</tr>
</tbody>
</table>

(Table was created by the current author using SPSS 21 output).
**Sun et al. (1995)**

**Intra-Observer Error:**

The Spearman’s rho correlation analysis provided a presumed perfect positive linear relationship. The two data sets for the (6) morphological characteristics had a correlation coefficient of between 0.819 and 1.000, which was significant at the 0.01 confidence level (See Table 14). This indicates either that the intra-reliability of this method is very high when following the same methodology at different times or, that the current author was consistent in their analyses.

**Discriminant Function Analysis (DFA):**

Only 14.4% of sterna were correctly classified to the exact age through the discriminant function in SPSS 21 using the method of Sun et al., (1995). This means only 54 of the 375 sterna examined were aged correctly showing a low success rate for exact classification. The majority of these correctly classified sterna were female. On average, age classifications were off by $7.93 \pm 6.11$ years for a maximum of 14.04 years and a minimum of 1.82 years. Younger age ranges matched closer to estimates while older age ranges had larger estimate errors in age assessment. There was a trend of over estimating for younger individuals and under estimating for older individuals. The DFA analysis also denoted that the first, second, and sixth variable were poor contributors to age estimation using the human sternum, but that variables three through five were more significant. Moreover, variables three and four (the second costal notch and the presence of radial stripes) were denoted the strongest variables for estimating age. This is
demonstrated in the following stepwise Tables 15 and 16 that show the variables in and not in analysis.

**Table 2 Intra-observer Error Sun et al., (1995)**

<table>
<thead>
<tr>
<th>Spearman’s Rho</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-1</td>
<td>1.00</td>
<td>.096</td>
<td>.341</td>
<td>.377</td>
<td>.10</td>
<td>.252</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>**</td>
<td>.557</td>
<td>*</td>
<td>*</td>
<td>0</td>
<td>.117</td>
</tr>
<tr>
<td>Intra-2</td>
<td>.096</td>
<td>1.00</td>
<td>.34</td>
<td>.385</td>
<td>.22</td>
<td>.193</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>.557</td>
<td>**</td>
<td>1*</td>
<td>*</td>
<td>1</td>
<td>.234</td>
</tr>
<tr>
<td>Intra-3</td>
<td>-.039</td>
<td>.226</td>
<td>.819</td>
<td>.096</td>
<td>.391</td>
<td>.398*</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>.512</td>
<td>.161</td>
<td>**</td>
<td>.557</td>
<td>*</td>
<td>.011</td>
</tr>
<tr>
<td>Intra-4</td>
<td>.392*</td>
<td>.387*</td>
<td>.246</td>
<td>.987</td>
<td>.411</td>
<td>.187</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>.012</td>
<td>.017</td>
<td>.125</td>
<td>**</td>
<td>**</td>
<td>.247</td>
</tr>
<tr>
<td>Intra-5</td>
<td>.099</td>
<td>.247</td>
<td>.556</td>
<td>.373</td>
<td>.963</td>
<td>.341*</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>.542</td>
<td>.125</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>.032</td>
</tr>
<tr>
<td>Intra-6</td>
<td>.301</td>
<td>.214</td>
<td>.33</td>
<td>.80</td>
<td>.34</td>
<td>.942</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>.059</td>
<td>.186</td>
<td>3*</td>
<td>3*</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed);**

*Correlation is significant at the 0.05 level (2-tailed).

(Table created by current author using SPSS 21 output).
### Table 15 Variables in the Analysis

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Due to the low accuracy of this method in an American population, no classification function was created after initial stepwise analyses and subsequent analysis stopped.
Chapter 5: Discussion:

Overall, this study found general agreement with that of Bongiovanni and Spradley, (2012) and other previous studies with respect to the utility of the sternum for sex assessment. The present study found similar results with which measurements prove most and least reliable for sex estimation. The sternebra widths, sternal index, and manubrium length, while fair indicators of sex, were found to not differ enough between the mean values and/or hold too much overlap between the sexes (Demonstrated in Table 11). For example, the sternal index means for males and females differed only by 4.93% (Table 10). In contrast, the total sternum length and mesosternum length were found to prove most useful in differentiating between the sexes, thus providing a reliable indicator for sex (Table 12).

The current studies results are notable and significant in that they provide a reliable method for estimating sex from the human sternum in the United States. As intra-observer analysis shows, this method has well defined measurements that yield reliable results. With an overall cross-validated classification rate of 81.1% and a TL classification rate of 86.7% using a nearly equal sample size, this study falls in suit with the results of Bongiovanni and Spradley, (2012). This demonstrates that the sternum can be used for sex estimation when the primary elements (pelvis and skull) are absent or too damaged to be used. The analyses conducted in the present study also offer the reader an accurate assessment of the method’s performance and as Bongiovanni and Spradley, (2012) state, addresses the Daubert Ruling. As this was a validation study, it only further satisfies the Daubert Ruling and through its utilization by practitioners and scientists will
undoubtedly reach legal admissibility in the near future.

The results of the present study reaffirm that the sternum is highly sexually dimorphic, with little secular change in the United States. The sterna in the American population are congruent with that of Western Australia (Franklin et al., 2012), India (Mukhopadhyay, 2010), South Africa (Macaluso, 2010), and Southern Nigeria (Osunwoke et al., 2010). With nearly identical classification rates as Bongiovanni and Spradley, (2012), no obvious secular changes were found between populations. This is not to say that it has not occurred at all, just that the degree to which it has occurred is minimal. In their study, Bongiovanni and Spradley, (2012) state that there is a general trend that indicates that sterna from East African and Indian populations are, on average, smaller than in the United States and the other populations mentioned previously. They address many of the inter-study comparisons and observations that they made between different studies that utilize the sternum for sex estimation; however, this is something future research can address and was not one of the points of analysis or discussion for the current study.

Many shortcomings in previous methods are addressed by Bongiovanni and Spradley, (2012) including sample size, secular trends, and forensic applicability. The authors believe that these shortcomings were not a part of their method and denote the use of the method by forensic anthropologists. The current author agrees with Bongiovanni and Spradley’s, (2012) statement, but has shown, using a near equal sample size from a less modern collection, that secular change may not be affecting the sternum in the United States as greatly as they previously thought. In fact, classification rates for
the method were nearly identical, showing very minimal change if any at all.

Overall, the findings in the present study contrast the results from Sun et al., (1995) with respect to the utility of the sternum for age estimation. Only 14.4% of sterna were correctly classified to the exact age through the discriminant function. As previously stated, this means only 54 of the 375 sterna examined were aged correctly showing a significantly poor success rate for exact classification. Of the 14.4% correctly classified females were the majority, possibly suggesting higher accuracy of sternal age estimations of females using this method. The current author found many shortcomings with this proposed method. First, the method seeks to estimate an exact age. Exact aging has been used in the past when assessing age from teeth, i.e. analyzing cementum annuli (Garvin and Passalacqua, 2011), a highly researched field and one that has shown promise in many other species besides humans. However, the sternum as an age indicator has not been so widely researched and exact estimates are deemed premature by the current author.

Second, Sun et al., (1995) conducted their research on female skeletons alone from a presumed nearly homogenous population with respect to overall size. China’s biological homogeneity has been a topic of discussion in the scientific and anthropological discourses. Oota et al., (2002) reported extreme mtDNA homogeneity in Asian populations, especially China, and attributed it to the onset of rice agriculture and other cultural factors such as marriage customs and ethnocentrism. Conducting this type of research on a biological homogenous population is thus the more likely the reason for the resulting classification rate of 97.74%.
Third, the methods and descriptions outlined in Sun et al., (1995) published work are weak and unclear. Non-metric measurements already hold some subjectivity and that can cause errors in assessment. The inclusion of inaccurate or unclear descriptors only furthers the chance that these errors can take place. The overall classification rate of 14% may be unrepresentative of the actual methods used due to the uncertainty of the method. For example, when describing the changing degrees of the costal notches, the authors describe what they call the glenoid lip of the incisure. As understanding this feature was critical to scoring between a 1, 2, or 3, for two of the traits in this method, the current author looked for clarification elsewhere. Unfortunately, the term glenoid lip refers to the cartilaginous margin of the glenoid fossa of the scapula. No sources were found using this term with respect to the sternum in any way. Furthermore the term costal incisure is an arcane term and refers to sternal notches for articulations with the ribs.

Finally, the statistical analysis of the data from Sun et al., (1995) was conducted using stepwise regression and what the authors called quantification theory I, more commonly referred to as multinomial logistic regression. The issue with this approach is that no subsequent analyses were presented regarding reliability of intra-observer or inter-observer observations but the authors give a standard deviation of 2.2 years and 4.4 years that corresponds to classification rates of 73% and 95% respectively.

On average, age classifications from the current study were off by 7.93 ± 6.11 years for a maximum of 14.04 years and a minimum of 1.82 years, as reported above. Younger age ranges matched closer to estimates whilst older age ranges had larger error in estimates, as would be expected in any age assessment method. This suggests that
with clarification of methods and an age interval structure, age estimation may be possible from the sternum. However, validation of this study as is suggests the contrary. Moreover, as previously stated, variables three and four (the second costal notch and the presence of radial stripes) were denoted the strongest variables for estimating age. This was previously demonstrated in the stepwise Tables 11 and 12 that showed the variables in and not in analysis. If age estimation from the sternum is to be achieved using anything from this method, perhaps these two traits are a suitable starting point.

Future Research:

With the significant diversity of the population of the United States, future research should exemplify methods that consider expanding sternal sex estimation using the methods described by Bongiovanni and Spradley, (2012) as well as the current author on other American populations not included in these two studies. Obtaining information with respect to other population groups from other collections would increase the utility of the human sternum as an indicator for sex (Bongiovanni and Spradley, 2012).

Future research regarding age estimation using the sternum should be conducted as some of the traits examined in this study suggest age related changes and thus may prove useful through further analysis. Although the classification rate produced in this research project was low, future projects may be able to discern more useful traits of the human sternum for age estimation or continue research on the second costal notch and radial striping, as they have shown promise in this study. In addition, the majority of the 14.4% specimens that were classified correctly were female. This could be another
starting point for future research in age estimations from female sterna or population specific studies of the human sternum.
Chapter 6: Conclusions:

The results of the present study show that the sternum is useful in generating an accurate estimate of sex but a poor indicator of age. Discriminant function analysis achieved the highest classification rate for sex, 81.1%. Only a 14.4% classification rate for age was achieved. No difference between American Blacks or Whites was found in the sample used and therefore analysis included both population groups together to assess sex. Additionally, female sterna were on average shorter than male sterna, again suggesting a sexually dimorphic population.

The mean values of the sternal index data observed in the present study confirm Hyrtl’s Law. However, there was overlap that decreased the reliability of a sternal index for sex estimation. In congruence with Bongiovanni and Spradley’s, (2012) findings, the manubrium and sternebrae widths showed statistically insignificant differences between the sexes. The most reliable indices of the human sternum are the total sternal length (TL) and discriminant function analysis of the manubrium length, mesosternum length, and first sternebrae width, with accuracy rates of 86.7% and 81.1% respectively. Thus the generated classification function, now validated, is considered reliable for use in forensic anthropological studies.

The use of morphometric measurements rather than visual assessments, like that of the method of Sun et al., (1995), makes the method more objective and makes the estimates more reliable and less subject to error (Bongiovanni and Spradley, 2012). Morphometric measurements are also easier to take than more subjective visual assessments of non-metric traits.
Sun et al., (1995), in summary, provides an unreliable method for age estimation from the female sternum, and especially the male sternum in an American population of Whites and Blacks. The method is difficult to follow, complicated, unclear, and at this time of little importance to creating the biological profile in the United States.

Bongiovanni and Spradley, (2012) on the other hand is a uncomplicated, precise method that shows high promise for sex estimation using the human sternum. The utility of the human sternum for sex is advisable. However, age estimation using the human sternum merits further research into methods that might provide higher classification rates, however, at this time no methods seem worthwhile.
APPENDIX A: Tables and Figures

Table A.1 Demographic Distribution of the Terry Collection

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<tr>
<td>White Females</td>
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<tr>
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<td>546*</td>
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<tr>
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*The current sample was drawn from these populations.

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Populations sampled from 18-50 years. Adapted from Hunt, (2005)).
APPENDIX B: Images

IMAGE 1. Manubrio-mesosternal joint fusion

IMAGE 2. Misplaced Manubrium-Mesosternal Joint:
IMAGE 3. *Sternal Hyperplasia:*

![Image 3: Sternal Hyperplasia](image3)

IMAGE 4. *Sternal Aperture:*

![Image 4: Sternal Aperture](image4)
IMAGE 5. *Sternal cleft:*

![Sternal cleft image](image)

IMAGE 6. *Midline Sternal Foramen/Perforation:*

![Midline Sternal Foramen/Perforation image](image)
IMAGE 7. *Homeostatic Imbalance/Inverted Xiphoid:*

Note the dorsal inversion of the xiphoid process.
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Byers, Steven  

Carlson, K. J., F.E. Grine, and O. M. Pearson  

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Franklin, Daniel

Galloway A, Willey P, Snyder L.

Garvin, Heather M. and Nicholas V. Passalacqua

Gautam, R. S., Shah, G. V., Jadav, H.R., Gohil, B.J

Helfman, P. M. and Jeffrey L. Bada


Hunt, D.R. and J. Albanese
Hyrtl, Joseph

Iscan, Mehmet Yasar

Jantz, R. and S. Ousley

Jit, Indar, V. Jhinganet, et al.

Kaneriya, D., K. Suthar, V. Patel, B. Umarvanshi, C. Mehta, and C. Tailor

Kimmerle, E.H., Ann Ross, Dennis Slice

Konigsberg, Lyle W. and Stephen D. Ousley

Kozielec, T.

Larsen, W.J.

López-Costas, Olalla, Carmie Rissech, Gonzalo Trancho, and Daniel Turbón

Macaluso, J. P.
Macaluso, J. P. and Joaquín Lucena  

Mahajan, Anupama, Batra Arvinder Pal Singh, Khurana Baljiit Singh, and Sharma Sita Rani  

Marinho, L., D. Almeida, A. Santos, and H.F. Cardoso  

McCormick, W. F.  

McKern, T. W. and T. D. Stewart  

Meindl, Richard S. and C. Owen Lovejoy  


Mukhopadhyay, P. P.  

Narayan, D., and H.C. Varma  
O’Neal M.L., JJ Dwornik, T.M. Ganey, and J.A. Ogden

O’Rahilly, R., and F. Muller

Oota, Hiroki, Kitano, Takashi, Jin, Feng, Yuasa, Isao, Wang, Li, Ueda, Shintaroh, Saitou, Naruya, Stoneking, Mark


Raxter, Michelle H., Benjamin M. Auerbach, and Christopher B. Ruff

Ramadan, Selma Uysal, Nursel Turkmen, N. Anıl Dolgun, Dilek Gokharman, Ritesh G. Menezes, Mahmut Kacar, Ugur Kosar

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Ríos L, and Weisensee K, and Rissech C.

Rissech, Carmie et al.

Rissech, Carmie et al.
Rodriguez-Vazquez, J. F., Samuel Verdugo-Lopez, Jose Manuel Garrido, Gen Murakami, and Ji Hyun Kim

Shirley, Natalie and Richard L. Jantz


Singh, Jagmahender, R.K. Pathak, and Dalbir Singh

Singh, Jagmahender and R.K. Pathak

Spradley, Katherine and Richard L. Jantz

Stevenson, Roger E.

Stewart, T. D.

Stini WA, P. Stein, Z. Chen

Sun, Yv-Xian, et al.


CURRICULUM VITAE

JOHNATHAN BRUCE
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EDUCATION

Boston University, Graduate Medical Sciences, Boston, MA Current – Sept. 2014
• Masters in Forensic Anthropology

Hartwick College, Oneonta, NY 2007 - 2011
• Bachelors in Anthropology
• Areas of Interest and Concentration: forensic anthropology, human anatomy and osteology
• Minor Biology
• Completed Optional Honor’s Thesis: Skeletal Trauma and Interpersonal Violence in South Africa

AWARDS

Magna cum Laude, Hartwick College
College Honors, Hartwick College
Distinguishment in Anthropology, Hartwick College, 2011
Dean’s List Recipient, Hartwick College, 2007 – 2011
The Duffy Ambassadorial Scholarship, Hartwick College, 2010 – 2011
Samuel Nelson Scholarship, 2007

Research

July 2013 (BUSM)
I spent 4 weeks in Washington, D.C at the Smithsonian and the Terry Collection where I conducted forensic and osteological research. I gathered morphometric and non-metric data to analyze the utility of the human sternum for sex and age estimation.

Spring 2011
Capstone research: I spent a month ethnographically analyzing daily cell phone usage on the school campus and wrote a paper on cell phone paranoia and dependency.

January 2011 – February 2011
Spent 5 weeks in Johannesburg, South Africa at the University of Witwatersrand Medical School where I conducted forensic and osteological research. I studied interpersonal violence evident as trauma in skeletal remains of about 355 cadaver skeletons that were a part of the Raymond A. Dart Collection at the Medical School.
Related Courses

Spring 2013 (Current)
Bioarchaeology, Forensic Anthropology Field Methods, Applied Forensic Anthropology, and Expert Witness testimony

Fall 2013 (BUSM)
Advanced Osteology, Mortuary Archaeology, and Taphonomy

Summer 2013 (BUSM)
Homicide Investigation

Spring 2013 (BUSM)
Forensic Anthropology Techniques, Outdoor Crime Scene Investigation, Forensic Pathology, Zoo-Archaeology, Biostatistics, Homicide Investigation, and Biostatistics

Fall 2012 (BUSM)
Professional Skills, History, Method, and Theory in Biological Anthropology, Human Anatomy and Osteology

2007-2011 (Hartwick College)
Biology 202, Biology 203, Human Anatomy and Physiology (1 & 2), Bioanthropology, Introduction to Anthropology, Cultural Anthropology, Archaeology, Forensic Anthropology, Biological Anthropology, Statistics, and Medical Physiology

PUBLICATIONS AND PAPERS

Graduate Thesis - BUSM (Current) 2012-Present
Topic: Utility of the Human Sternum to Estimate both Sex and Age

- My research focuses on the human sternum as an indicator for sex and age.

Data were collected at the Robert J. Terry Anatomical Skeletal Collection in Washington, DC. My research is a validation study of two methods, Bongiovanni and Spradley, (2012) for sex estimation using the sternum, and Sun et al., (1995) for age estimation using the sternum. At this time, my results suggest that the sternum is useful in sex estimation, but not in age estimation.

Undergraduate Thesis - Hartwick College (Complete and seeking to publish) 2011-Present
The paper discussed the accuracy and degree to which a forensic anthropologist can distinguish interpersonal violence evident in bones as trauma, from accidental trauma.
LANGUAGES
English-native language
Spanish- Speak, read, and writes with competency
Zulu (S. Africa) - Working knowledge/basic conversational
Xhosa (S. Africa) - Working knowledge/basic conversational

MEMBERSHIPS
American Academy of Forensic Sciences (AAFS)
American Anthropological Association (AAA)
Phi Mu Alpha Sinfonia
Lambda Alpha (Anthropology Honor Society)
Tri-Beta (Biology Honor Society)
NSHSS (National Society of High School Scholars)