SEX ESTIMATION IN SUBADULT SKELETONS:

A TEST OF EIGHT NONMETRIC TRAITS OF THE MANDIBLE AND ILIUM

by

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This thesis was prepared under the direction of the candidate's thesis advisors, Dr. Douglas Broadfield and Dr. Kate Detwiler, Department of Anthropology, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the Dorothy F. Schmidt College of Arts and Letters and was accepted in partial fulfillment of the requirements for the degree of Master of Arts.

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ABSTRACT

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Diagnosing the sex of subadult skeletal material is a difficult task for bioarchaeologists and forensic anthropologists. Metric and nonmetric techniques have been tested utilizing both fetal (Boucher 1957, Weaver 1980) and juvenile (Loth and Henneberg 2001, Weaver 1980) skeletal remains. Some metric techniques show promise in estimating the sex of juvenile skeletons, but most are found to be lacking in adequate accuracies (Holcomb and Konigsberg 1995, Weaver 1980). Nonmetric techniques have been found to be more accurate, performing better than chance (Loth and Henneberg 2001, Mittler and Sheridan 1992, Weaver 1980). This study adds to this conversation, utilizing the Hamann-Todd Osteological Collection at the Cleveland Museum of Natural History, testing the accuracy of eight nonmetric traits of the subadult mandible and ilium for use in forensic investigations and bioarchaeological research.

SEX ESTIMATION IN SUBADULT SKELETONS:
A TEST OF EIGHT NONMETRIC TRAITS OF THE MANDIBLE AND PELVIS

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CHAPTER ONE: INTRODUCTION

When skeletal remains are discovered in a forensic situation, the forensic anthropologist is often called to aid in the identification of the individual. She must determine if the remains are human as well as the sex, age, ancestry, and stature of the individual if the remains are determined to be human. When the remains are of a subadult[1], the matter of estimating sex is complicated. The same problem is faced by the bioarchaeologist; a demographic profile of a society provides researchers with a wealth of information about a potentially unknown population. The demographic profile can provide information on the health of the population as well as aid in the analysis of grave goods found with the body. “Undoubtedly the largest single problem in the analysis of immature skeletal remains is the difficulty of sexing juveniles with any degree of reliability” (Scheuer and Black 2004:19), and a large literature has been amassed attempting to solve this issue.

Despite the determination of sex in the tenth gestational week by the release or withholding of testosterone, assigning sex to skeletal material is problematic until puberty (Lewis 2007). Not only are the sexually dimorphic characteristics of the skull and pelvis difficult to recognize, the chemical differences between male and female skeletal remains

[1] A note on terminology: In the United Kingdom and North America, the terms “immature”, “subadult”, and “nonadult” are used to describe any individual that is not an adult, meaning the bones in the skeleton are still in the stages of fusing (Scheuer and Black 2004). However, the term “juvenile” is growing to replace these terms. In this thesis, the term subadult is used, except in cases where the author of the studies uses alternate terms in their individual studies.

– the differing levels of calcium and citrate, phosphorous and strontium – are also difficult to recognize until puberty. Many techniques employed to sex subadult skeletons use X-rays of living children, and these techniques rarely can apply to dry bone (Bass 2005). Specific methods that have been developed and show some promise in diagnosing sex in subadult skeletal remains are discussed in their relevant sections later in this thesis.

DNA analysis gives researchers the ability to estimate sex, ancestry, disease status, and identity, making it a useful tool in several fields including osteology, forensics, archaeology, and paleontology (White and Folkens 2005). DNA can give information on the sex, pathology, ancestry, individuation, and diet of an individual (White *et al.* 2012). However, the factors involved in DNA analysis – destruction of the sample, cost, and contamination – often outweigh the benefits of using such analyses (White *et al.* 2012). Analyses involving DNA are also discussed in greater detail below.

Cranium and Mandible

As nearly all of the increase in craniofacial growth occurs before puberty, it is expected that there would be differences in growth between girls and boys in the bones of the skull (Scheuer and Black 2004). Many studies (below) do show that there is evidence of sexual dimorphism in the mandible and bones of the face from an early age but the manifestation of the dimorphism is complex and does not allow for useful positive identification until after puberty.

In 1992, Susan R. Loth examined 62 juvenile mandibles of known sex and age from the Dart Collection in South Africa to determine if there were any morphological traits that could distinguish the sexes (Loth and Henneberg 2001). She noticed that adult chin shapes were recognizable by as early as age six and differences could be observed in the inferior body of the symphysis and the outline of the body prior to that age. Loth found that in males, the chin came to a point or squared off at the symphysis, while in females the symphysis was more rounded or the transition from body to symphysis was not abrupt even when the symphysis was pointed. The features were then tested on all nineteen Dart Collection mandibles belonging to individuals under age four by three separate examiners resulting in an average accuracy of 81%. These methods were tested again on a known sex sample of eleven individuals under age seven using CT scans of nine French children and the remains from two South African black forensic cases. In this test, the accuracy was 82% with the only mis-sexed cases being two females over the age of six. In comparing these tests, Loth and Henneberg (2001) determined that it is possible to sex very young individuals using the mandible and preliminary research has shown

Figure 1: HTH2370 1 year old male. Displays the everted gonion region, U-shaped dental arcade, and rough chin indicative of males.

that these features are evident in archaeological contexts, premodern hominids, and chimpanzees.

Scheuer (2002) tested the methods of Loth and Henneberg (2001) using a sample of 36 mandibles of known sex and age from the Spitalfields Collection in two blind tests spaced several days apart. In the first blind test, Scheuer sexed 77.7% of males and 66.6% of females correctly and in the second, 85.1% of males and 44.4% of females were sexed correctly. Overall, Scheuer accurately diagnosed sex in 64% of the mandibles which was lower than the 81% accuracy achieved by Loth and Henneberg (2001). Scheuer notes that a male mandible has a significantly higher chance of being sexed correctly than a female mandible and that consistency in using this method is low.

Molleson *et al.* (1998) sought to identify sexually dimorphic features of the juvenile skull that could be used as sex indicators for archaeological material. They used two skeletal assemblages in their pilot study: the Coffin Plate sample from Christ Church Spitalfields, London and an assemblage from a deserted village in Wharram Percy, North Yorkshire. They focused on the facial bones, specifically the orbits, the mandibular angle, and the mentum, determining that 89% of the adults of their sample from Spitalfields and 78% of juveniles were sexed correctly. They tested their methods on their second skeletal assemblage and determined that 89% of adults were sexed correctly. Molleson *et al.* (1998) compared sex as determined from the facial bones of juveniles to sex as determined from canine dimensions, concluding that their method of sexing juveniles using the facial bones was a valid technique.

Dentition

Other promising techniques for diagnosing sex in subadult skeletal remains involve using the dentition (Byers 2008). One technique was proposed by Hunt and Gleiser (1955) involving the comparison of dental age with skeletal age with the knowledge that boys and girls diverge more rapidly in skeletal than dental maturation.

Figure 2: HTH0437 18 year old female. Displays parabolic dental arcade and smooth chin indicative of females.

They tested their methods on radiographs of living children and determined that their method of sexing is increases in effectiveness with the age of the individual. However, this method is largely unusable in forensic anthropology as it utilizes the bones of the wrist (the carpals) to determine the skeletal age. In forensic situations, the teeth are usually available but the carpals are often difficult to locate (Hunt and Gleiser 1955). Hunt and Gleiser (1955) do note this difficulty and suggest using the skeletal age as estimated from the knee (patella), instead, as the patella is easier to locate in forensic contexts.

Bailit and Hunt (1964) tested the methods of Hunt and Gleiser (1955) to determine if both the age and sex of a child could be diagnosed from the dentition and if sex could be more precisely determined if the age of the child was known. They examined the dental radiographs of 25 girls and 25 boys between the ages of seven and twelve years and their results showed that by sexing children using the variation in developmental ages, 58% of the cases were sexed correctly. When they used the canine to determine developmental age and compared it to the known chronological age, 70% of the cases were sexed correctly. They also determined that the skeletal remains of children of unknown age and sex could not be accurately sexed using dental radiographs. However, when the age of a child is known, the accuracy of sex estimation by their methods does increase. Despite this, their methods would not be practical to use in forensic and archaeological contexts as the age of the child is typically unknown.

Alternatively, there is the potential for estimating the sex of subadult skeletal remains using measurements of the deciduous dentition. Two studies have attempted to develop discriminant functions using tooth widths and lengths to determine sex on the assumption that the teeth of boys are generally larger than the teeth of girls. Black (1978) developed functions that correctly estimated sex for about 75% of his sample, whereas De Vito and Saunders (1990) developed functions that were correct 76% to 90% of the time. However, De Vito and Saunders (1990) determined that their sample was biased after they compared it with six other sample groups noting that it showed greater difference in the measurements of male and female deciduous dentition than the other six groups.

Black's (1978) study used the mesiodistal and buccolingual crown dimensions of the deciduous teeth of 133 children to analyze sexual dimorphism and test sex discrimination using discriminant function analysis. He utilized five sets of discriminant functions to determine which combinations were most reliable for sexing the dentition. One set is based on 20 dental measurements and is described in Black (1978); the others include only ten measurements each, including the maxillary and mandibular dentition, and all of the mesiodistal and buccolingual measurements. Those 20 measurements consisted of ten mesiodistal and ten buccolingual measurements for both the right side maxillary and mandibular dentition. Black (1978) determined that there was a relatively small degree of sexual dimorphism in the tooth crown dimensions, causing the discriminant functions to be less effective at estimating sex than similar calculations performed using the permanent dentition. The discriminant function that was able to correctly sex over 75% of his sample required nine measurements on seven deciduous teeth. Black (1978) noted that the sample that he used was a statistical sample and the patterns in dimorphism may be different than in a biological sample, and his results should not be generalized beyond his sample as they may deviate from other samples.

Pelvis

Generally, the pelvis is the skeletal area that shows the highest degree of sexual dimorphism (Scheuer and Black 2004). In 1899, Thomson (1899), reacting to conflicting statements in the midwifery textbooks of his time, examined fetal pelvises to determine if there were any sexual differences that could be recognized during fetal life. His sample came from pelvises that were hardened in formalin that retained their form sufficiently for his research. Thomson (1899) measured the proportions of the pelvis and came to the conclusion that there were identifiable differences in the form of the pelvis between males and females as early as the third month of fetal life. He concluded that the sexual characteristics of the fetal pelvis are as well defined as they are in the adult pelvis, and any differences that occur during growth is due to the muscles that attach to the bone, affecting both of the sexes, and are not accountable for the differences in the features of the male and female pelvis (Thomson 1899).

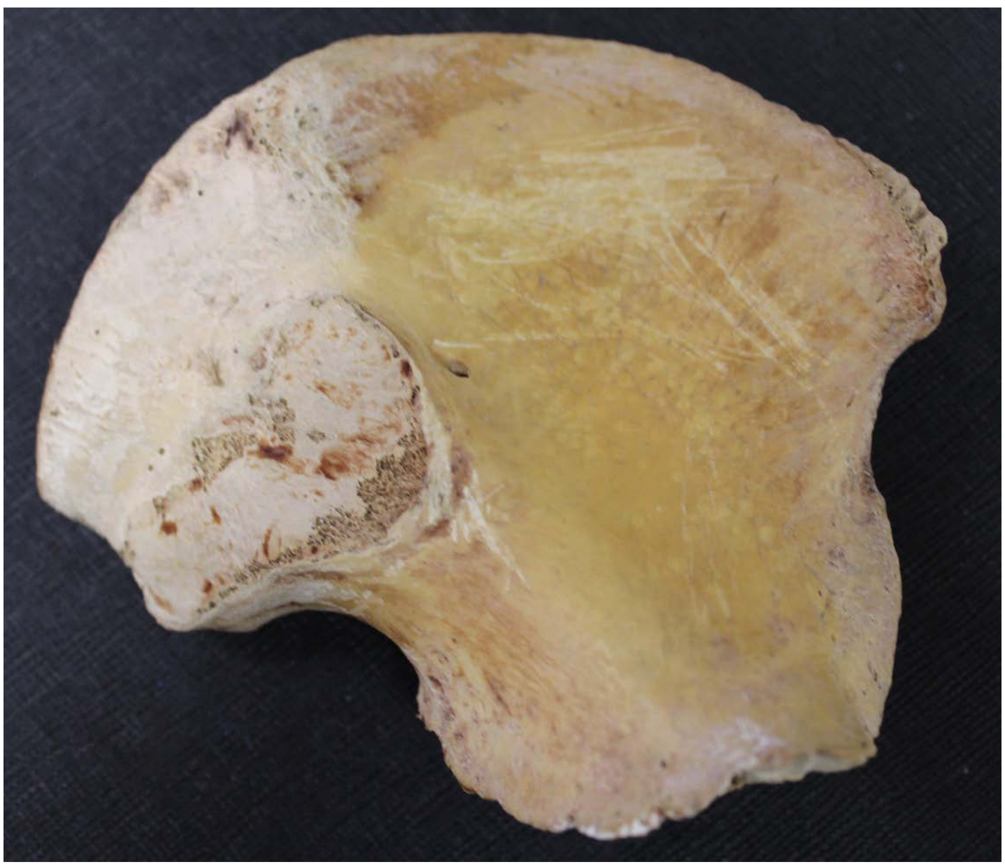

Figure 3: HTH0872 8 year old female. Displays a greater than 90° angle, shallow sciatic notch, an arch criterion that crosses the auricular surface, and a raised auricular surface indicative of females.

Boucher (1957) took metric measurements of the pelvises of 96 black and 33 white stillbirths acquired by the Department of Anatomy at the Washington University School of Medicine to estimate sex differences between the male and female pelvis. She measured the pubic length, the ischial length, and the width and depth of the sciatic notch in order to determine that there are differences between the male and female pelvis. Boucher determined that there is a greater sex difference in the subpubic angles in the fetus than in adults which lead to a conclusion similar to Thomson (1899) that the growth of the pelvis during puberty is not responsible for the sex differences between males and females.

Holcomb and Konigsberg (1995) sought to determine if sex differences in the fetal sciatic notch could be discerned using 133 fetal ilia of known age and sex from the Trotter Collection at Washington University. They digitized photographs of the ventral side of each ilium and plotted them graphically to determine the sciatic notch depth to width ratio for each individual. They determined that, even though there was significant sexual dimorphism in the shape of the fetal sciatic notch, this dimorphism does not reach the level that is found in adults. In addition, they found substantial overlap in the shape characteristics of the fetal sciatic notch which prevents them from recommending the use of notch shape for diagnosing sex in fetal skeletal remains. As they did not have access to a sizable collection of postnatal skeletal material to use in their study, they did not know the effectiveness of their methods in determining the sex of older individuals.

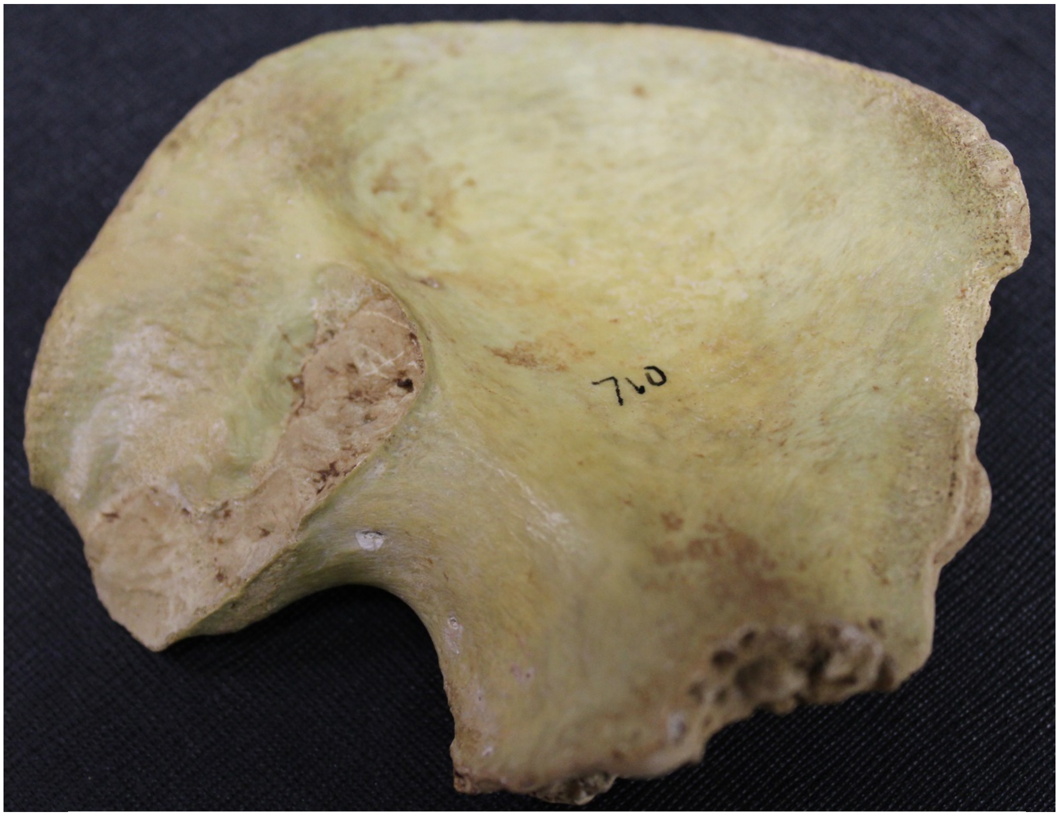

Figure 4: HTH0710 10 year old male. Displays 90° angle, deep sciatic notch, an arch criterion leading to the lateral rim of the auricular surface, and a non-elevated auricular surface indicative of males.

DNA Analysis

When the remains of children are found in a forensic or archeological situation, unless the bodies are preserved and the genitalia are identifiable, forensic anthropologists and archaeologists have a fifty-fifty chance of correctly sexing the skeletal remains through skeletal analysis (Renfrew and Bahn 2012). However, new techniques have been developed to estimate the sex of a skeleton (both subadult and adult) using DNA. DNA can be extracted from bones and teeth, preferably teeth, and amplified using PCR (polymerase chain reaction). Hard tissues, such as bones and teeth, are most often the only possible source of ancient DNA (aDNA) because they undergo the decomposition process at a much slower rate than soft tissues and thus are typically the only part of the body preserved in burial contexts (Bramanti 2013). Bone is an optimal source of aDNA as its composition is two-thirds mineral tissue and one-third organic material. Hydroxyapatite, which is found in the mineral tissue of bones, binds to DNA and slows its degradation over time, but the dissolution of the collagen in bone increases bone porosity which allows hydrolytic and microbial infiltration to damage the DNA content (Bramanti 2013). aDNA from human teeth is typically better for analysis as it is less prone to decay than the aDNA from human bone (Bramanti 2013). This is due to the fact that enamel is the hardest and most highly mineralized substance of the body and therefore protects the dentine and pulp from external factors that would otherwise degrade the sample.

Theoretically two kinds of DNA can be retrieved from a burial: nuclear DNA and mitochondrial DNA (mtDNA) (Bramanti 2013). mtDNA is more likely to be recovered as it is present in multiple copies in a cell whereas nuclear DNA is unique in a cell (Bramanti 2013). As such, samples that fail to yield nuclear DNA that can be amplified will yield well preserved mtDNA. If nuclear DNA is preserved and able to be amplified and analyzed, the biological sex and genotype of the skeleton can be established. Along with mtDNA, nuclear DNA can aid in identifying individual buried in a mass grave and match amputated parts with individual bodies.

Despite the increased accuracy of DNA analysis to determine the sex of a set of remains, the analysis requires sophisticated equipment and may take a long time to get the results back. For bioarchaeology and forensic situations, the time and cost of the test often outweigh the increased accuracy (White *et al.*2012). Additionally, samples may become contaminated by those who examined the remains as well as by other sets of remains (in the case of mass graves), or by other substances (soil, textiles, etc.). There may also be insufficient amounts of the skeletal material available for both DNA analysis and preservation (Bramanti 2013). Due to these disadvantages, morphological methods must be developed and continuously tested to insure the accuracy of determining the sex of juvenile skeletal material.

Stone *et al.* (1996) tested the effectiveness of using DNA to determine the sex of human skeletal material using 20 modern individuals from Indonesia and 20 skeletons from an archaeological site dating to AD 1300 in central Illinois. They estimated the sex of the individuals by analyzing the DNA as well as by standard osteological methods (Stone *et al.* 1996). They accurately sexed 19 of the individuals from the archaeological site and all 20 of the individuals from their modern sample. The one misclassification could have been due to insufficient DNA available to analyze or mutations in the individuals DNA (Stone *et al.* 1996). The samples used for DNA analysis in the archaeological cemetery came from bone that was determined to be sufficiently well-preserved and contain adequate DNA for mitochondrial DNA typing through previous research into the relatedness of the individuals in the community (Stone and Stoneking 1993) and modern blood samples. Stone *et al.* (1996) note that if sufficient DNA can be collected for analysis, and contamination can be prevented, the analysis of DNA can be a valuable resource for researchers to use in sex estimation of subadult or fragmentary skeletal remains.

Faerman *et al.* (1998) found success in using DNA to determine the sex of subadult skeletal material in their analysis of about 100 neonate found in a sewer under a Roman bathhouse, possible brothel, who may have been victims of infanticide. They used

43 left femora in their DNA-based sex identification, 19 of which provided results. They determined that, of the 19 specimens that provided results, 14 were male and 5 were female. They speculate that there was selective preservation of females who may have been the offspring of courtesans that were serving in the bathhouse, which supports the idea that it may also have been a brothel. Mays and Faerman (2001) had similar results in DNA analysis to estimate sex in 31 possible victims of infanticide at two Roman-British burial sites. In this study, of the 13 individuals tested, nine were male and four were female. Their numbers were too small to come to any conclusions on infanticide at the two sites, the main difficulty arising from poor DNA survival in their sample.

In their excavations of the Late Medieval-Modern Convent of Santa Clara-a-Velha in Coimbra, Portugal, Cunha *et al.* (2000) located more than 70 female skeletons, assumed to be the nuns who had lived at the convent. However, they also found the skeletal remains of two children, each about 11 years old, and decided to use DNA analysis to estimate the sex of those individuals given the restrictions on males in the convent. The sex of only one of the children was able to be estimated, and it was determined to be male. With the other child, no genetic amplifications allowing a sex estimation were obtained but these results should eventually give a new insight into the organization of that Monastic Order. Cunha *et al.* (2000) stress the potential for the use of DNA analysis in determining the sex of fragmentary and subadult skeletal remains in archaeological research.

CHAPTER TWO: PREVIOUS RESEARCH

Weaver (1980) sought to remedy the difficulty in sexing juvenile skeletons by developing a methodology that could adequately sex fetal and infant skeletons. He reasoned that as sex differentiation results from the prenatal testosterone concentration in the male fetus, characteristics that determine sex would become obvious in the fetus after the fifteenth week and would either remain stable or decrease as the infant grows. Weaver determined that, as the ilium is the largest of the infant innominate bones, it would be better preserved in skeletal collections. He developed six metric traits and one nonmetric trait of the ilium that he felt could be used to differentiate sex. These traits are: sciatic notch width, sciatic notch depth, ilium anterior length, ilium posterior length, iliac height, iliac width, and auricular surface elevation.

These measurements have analogous measurements in adults that have been accepted as ways of sexing the adult pelvis (Bass 2005, White *et al.* 2012, White and Folkens 2005). As such, Weaver created three indices that are also analogous to those for adult sex determination. These ratios are: sciatic notch depth over sciatic notch width (Sciatic Apertural Index), ilium posterior length over anterior length (Chilotic Index), and iliac width over height (Index of Iliac Breadth) using 153 fetal and infant skeletons from the Smithsonian Institution Collection. Weaver found that the Sciatic Apertural Index failed to indicate sex in any age group, as did the Chilotic Index. However, Weaver determined that as there was a pattern of Chilotic Index values being smaller for females than for males, this index may be more significant with a larger sample size. The Index of

Iliac Breadth was found to only be significant with the six month age group and, although it shares the same trend with the Chilotic Index, this index might not prove to be significant even with a larger sample size.

Weaver's nonmetric character, auricular surface elevation (shown in Figures 5 and 6), proved to be the most reliable character of this study. However, it proved to be most reliable in diagnosing males as Weaver required the auricular surface to be elevated along the entire length of both the anterior and posterior edges of the ilium for the feature to be classed as elevated. He found the accuracy for this characteristic in the estimation of sex was highest in the fetal and six month age group males. The reliability of this characteristic was also determined to increase with further study on other, perhaps larger, samples.

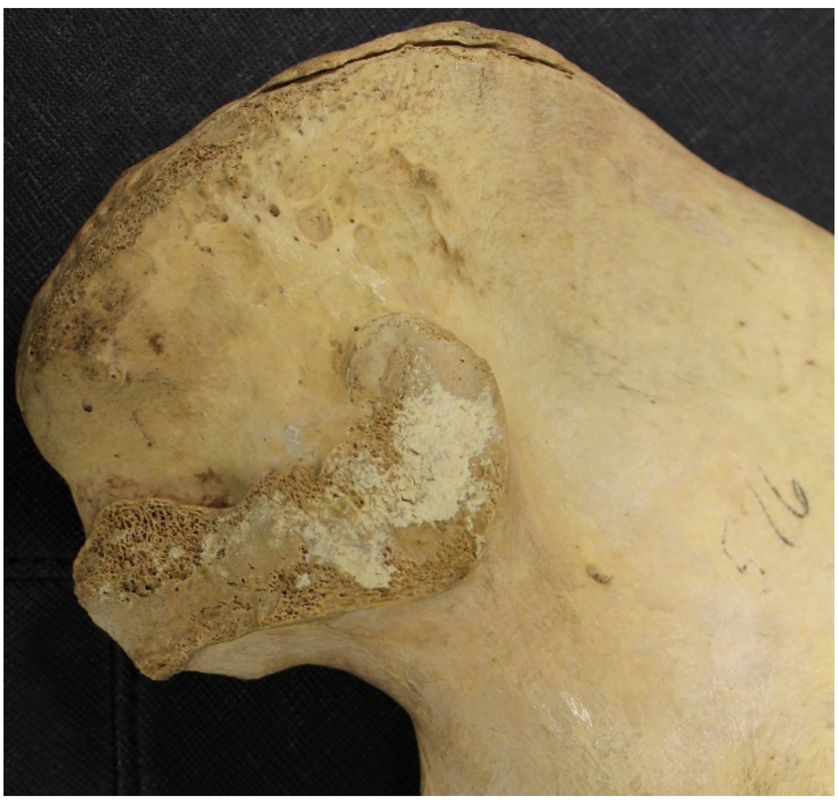

Figure 5: Female ilium (HTH0576) showing an elevated auricular surface.

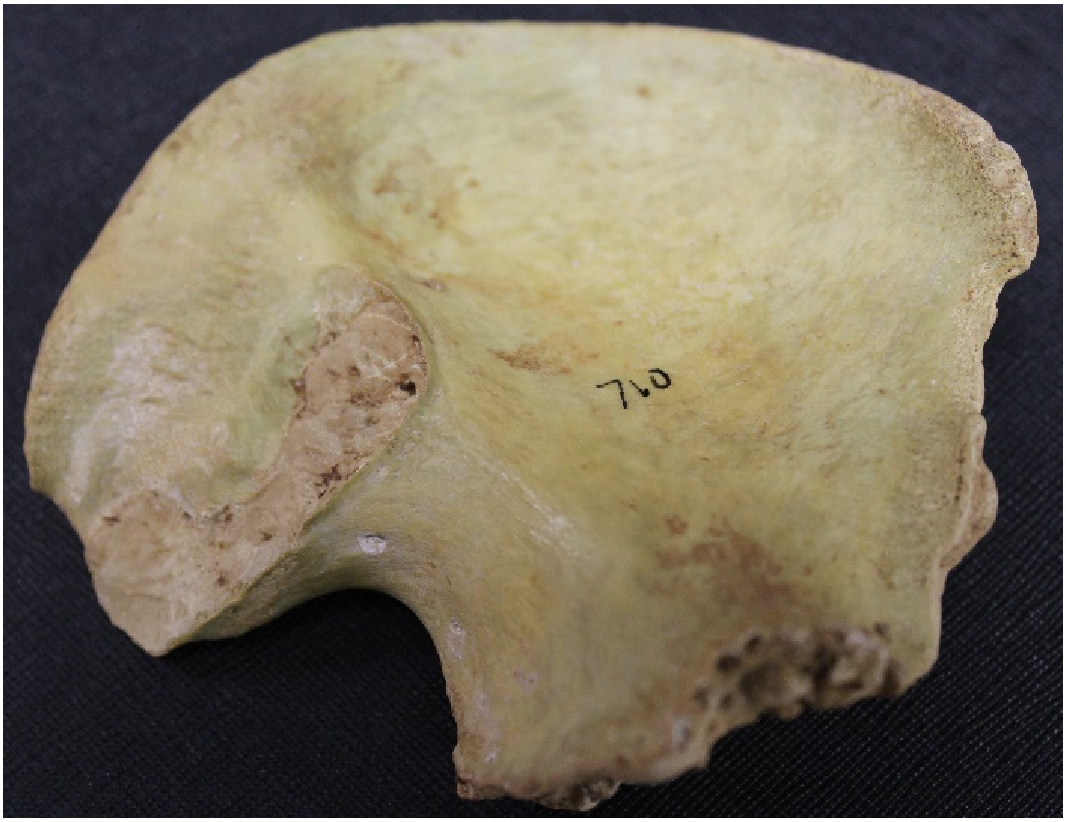

Figure 6: Male ilium (HTH0710) showing a non-elevated auricular surface.

Hunt (1990) tested Weaver's (1980) nonmetric sexing method for his master's thesis in 1983, later publishing his results in the *Journal of Forensic Sciences*. He performed an indirect test on a sample of 275 subadult South Dakota Arikara Indian ilia. He intended to evaluate the level of sex separation identified by Weaver's (1980) method in an unknown archaeological population. As the sex of the skeletons was unknown, a direct test for the accuracy of the method could not be performed. Hunt (1990) determined that auricular surface elevation may have correlations with sex, but only in the fetal age group. However, the auricular surface elevation has a greater correlation with age as any influence that gender has on the formation and modeling of the auricular surface may be deeply hidden by the influence of growth.

Mittler and Sheridan (1992) tested Weaver's (1980) method of using the auricular surface elevation to estimate the sex of subadult skeletons. They evaluated Weaver's method both to determine what percentage of subadults could be correctly sexed and the probability that an individual will be sexed correctly using Weaver's criteria. They used a sample of mummified remains of known sex from the Kulubnarti, Nubia, numbering 58 individuals from birth to 18 years of age (Mittler and Sheridan 1992). They performed a blind test of Weaver's criteria; they were only able to see the auricular surface and had no prior knowledge of the sex of the individual.

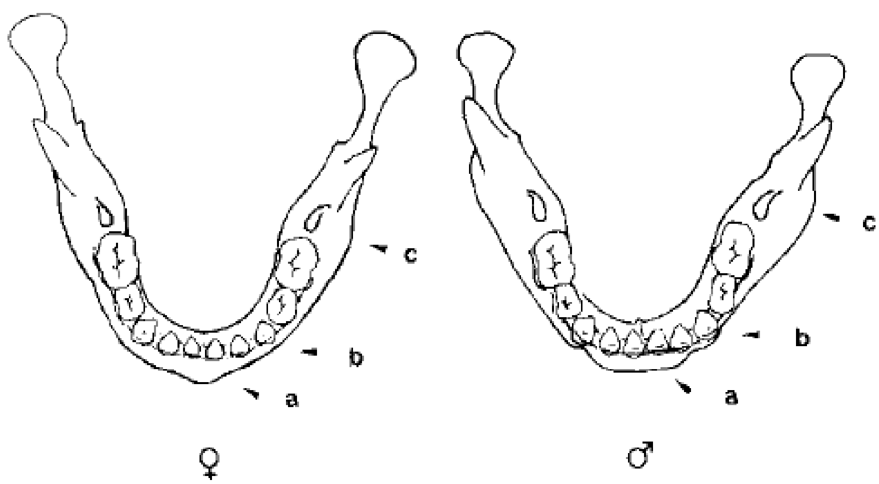

Figure 7: Characteristics of the mandible used to determine sex (Schutkowski 1993). a) Protrusion of the chin region. b) Shape of the anterior dental arcade. c) Eversion of the gonion region.

Mittler and Sheridan found that, with their sample, 74.1% of the subadults were sexed correctly. However, Weaver's technique did not sex males and females equally well. The accuracy in sexing males was 85.3% while the accuracy for sexing females was only 58.3% (Mittler and Sheridan 1992). They also found that the method increased in effectiveness with increased age of the individual. It was determined that for the purposes of forensic science diagnosis, this method is only effective for subadults over age nine with an elevated auricular surface. However, as 25% of the female subadults in the sample did not have an elevated auricular surface, Weaver's technique fails to reliably diagnose males.

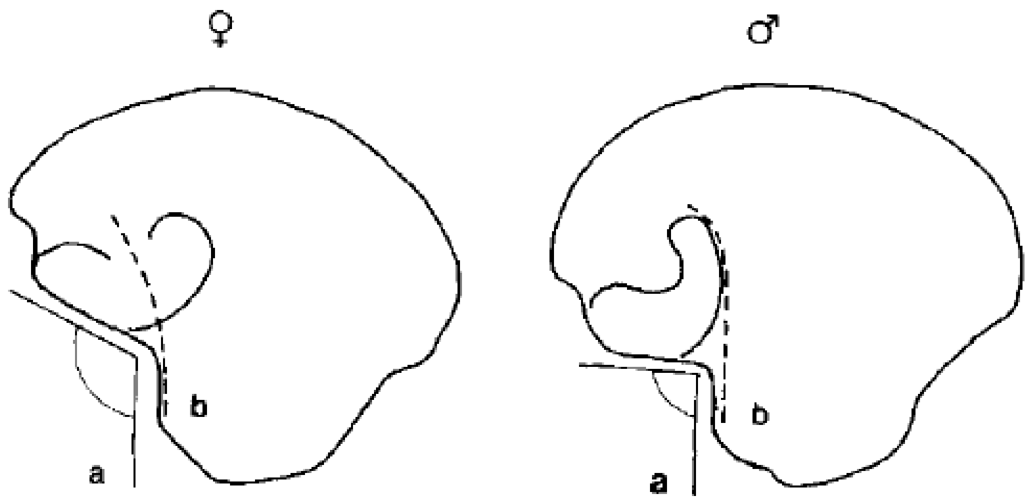

Figure 8: Iliac Characteristics (Schutkowski 1993). a) Angle of the greater sciatic notch. b) Arch criterion.

Schutkowski (1993) identified other morphological characteristics of the subadult ilium and mandible that may be diagnostic of sex in his examinations of the "Coffin Plate Sample" in Spitalfields, London. His study used a sample of 61 subadults of known sex from birth to five years of age and evaluated the accuracies of the characteristics he noted. The features of the mandible that Schutkowski determined were sexually diagnostic were the protrusion of the chin region, shape of the anterior dental arcade, and the eversion of the gonion region (Figure 7). Those features of the ilium that did the same are the angle of the greater sciatic notch, depth of the greater sciatic notch, the arch criterion, and the curvature of the iliac crest (Figures 8, 9 and 10). The arch criterion Schutkowski identified is the arch that can be formed by "drawing a cranial extension from the vertical side of the greater sciatic notch" (Schutkowski 1993:201) to the auricular surface. The arch criterion will be discussed in greater detail later.

Schutkowski determined that the characteristics of the mandible he identified as sexually diagnostic clearly identified males but were not reliable for diagnosing females. For the ilium, the most diagnostic traits were associated with the greater sciatic notch. Again, in diagnosing males, the accuracies were higher than for females. This could be due to the small sample size as well as the differing amounts of males and females in the sample that Schutkowski used for his study.

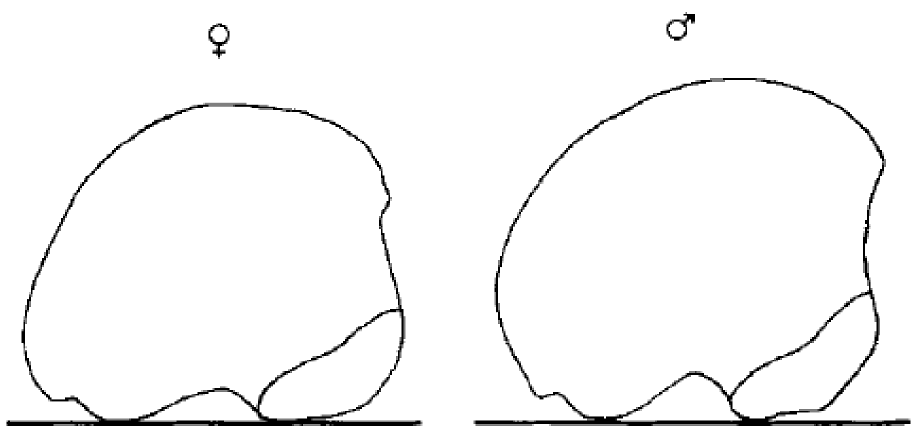

Figure 9: Depth of the greater sciatic notch (Schutkowski 1993).

Sutter (2003) tested eight nonmetric traits for subadult sex estimation; auricular surface morphology from Weaver (1980) and the seven identified by Schutkowski (1993). He performed a blind test of the accuracy of these characteristics on 85 autopsied mummified subadult remains of known sex from northern Chile, ranging in age from birth to 15. Sutter sought to answer two questions in the course of his study: Are each of the eight traits related to known sex at each age? Which of the eight traits have a high enough accuracy to be used in forensic cases? Through his investigation, Sutter demonstrated that each of the traits was indeed related to known sex. However, only four of the traits had accuracies that were acceptable for forensic investigations[2] – the arch criteria (82.3%), angle of the greater sciatic notch (80.7%), depth of the greater sciatic notch (79.0%), and mandibular arcade shape (77.6%) – for all subadults. For subadults ranging in age from birth to five years, only the depth of the greater sciatic notch (81.5%) and the arch criterion (81.5%) were of acceptable accuracy for forensic investigations (Sutter 2003).

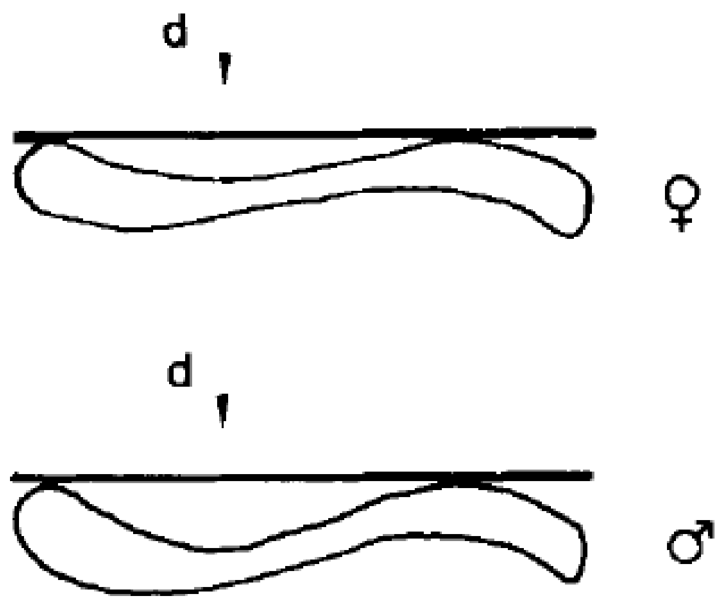

Figure 10: Curvature of the iliac crest (Schutkowski 1993).

[2] Acceptable accuracy was determined to be 75% by De Vito and Saunders (1990).

CHAPTER THREE: METHODS AND MATERIALS

I continued this investigation of the nonmetric methods developed by Weaver (1980) and Schutkowski (1993) using the subadult section of the Hamann-Todd Osteological Collection housed at the Cleveland Museum of Natural History in a blind test of the methods listed below. Photographs were taken of each sample as they were examined.

Table 1 – Demographics of the subadult section of the Hamann-Todd Osteological Collection included in this study

Age	Male	Female	Total
0	0	1	1
1	6	1	7
3	1	0	1
4	0	2	2
5	0	1	1
6	2	1	3
7	0	1	1
8	1	3	4
10	2	1	3
11	1	1	2
12	0	3	3
13	0	1	1
14	0	2	2
15	1	0	1
16	0	2	2
17	2	1	3
18	6	3	9
Total	22	24	46

Mandibular Traits

Protrusion of the chin region (Figure 3a). In females, the chin is not prominent and the surface of the bone is smooth (Schutkowski 1993). The mental protuberance appears narrow and faint and sometimes tapers, when viewed from above. In males, the chin is more prominent, showing slightly elevated rough structures on either side of the midsagittal plane. The mental protuberance is wide and angular against the mandibular body when viewed from above.

Shape of the anterior dental arcade (Figure 3b). The shape is roughly parabolic in females as the alveoli of the front teeth conform to a rounded contour and the canines do not protrude in the dental arch (Schutkowski 1993). In males, it is more U-shaped as the dental arcade is wider anteriorly and the canines protrude slightly.

Eversion of the gonion region (Figure 3c). In females, the gonion region is in line with the outer surfaces of the horizontal rami (Schutkowski 1993). The gonion region protrudes slightly beyond the outer surfaces of the horizontal rami in males.

Iliac Traits

Angle of the greater sciatic notch (Figure 4a). When the ilium is viewed from the ventral aspect and positioned so the anterior side of the greater sciatic notch is aligned vertically, the angle is greater than 90° in females and about 90° in males (Schutkowski 1993).

Depth of the greater sciatic notch (Figure 5). When the ilium is viewed from the dorsal aspect, the notch is shallow in females and deep in males (Schutkowski 1993).

Arch criterion (Figure 4b). When the ilium is positioned as for the analysis of the angle of the greater sciatic notch, drawing a cranial extension from the vertical side of the greater sciatic notch crosses the auricular surface forms an arch in females (Schutkowski 1993). In males, this line leads into the lateral rim of the auricular surface.

Curvature of the iliac crest (Figure 6). When the ilium is viewed from above and the dorsal surface is aligned horizontally, the crest shows a faint S-shape in females and a marked S-shape in males (Schutkowski 1993).

Auricular surface elevation (Figures 1 and 2). If the auricular surface is elevated along the entire length of both the anterior and posterior edges (Figure 1), the ilium is classed as female (Weaver 1980). If there is no elevation (Figure 2), the ilium is classed as male.

The Hamann –Todd Osteological Collection

The Hamann-Todd Osteological Collection began in 1893 at the Case Western Reserve University in Cleveland, Ohio with Carl August Hamann, who was hired as an anatomy professor, as an educational and research tool (Jones-Kern and Latimer 1996). By 1912, when Hamann was named dean of the medical school, the collection numbered 100 human skeletons and the collection known as the H.K. Cushing Collection of Rocky

Figure 11: Mandible illustrating the preservation of the skeletal material (HTH1861).

Mountain Mammals. At this point, the young anatomist from England, T. Wingate Todd, took over the collection and built it to the resource it is today.

The collection today contains more than 3,100 sets of human remains, with known demographics (age, sex, ancestry, stature, cause of death). Most of the collection came from the unclaimed bodies at the Cuyahoga County Morgue and the city hospitals. This was made possible because the city hospitals were required to notify Todd of any unclaimed bodes in their possession, part of the Anatomical Laws of the State of Ohio that were formulated by Hamann. The bodies were sent to the medical school where they were dissected and then labeled and stored in pine boxes.

The collection was moved in 1924, with the medical school, to a new building and was stored on the first floor in the Hamann Museum of Comparative Anthropology and Anatomy. However, with the death of Hamann in 1930 and Todd in 1938, the Hamann Museum was closed and the skeletons were returned to their pine boxes and stored wherever space was available until the medical school decided to look for an alternate

Figure 12: Ilium illustrating the preservation of the skeletal material (HTH1861).

location to maintain the collection. It was moved to its current location, the Cleveland Museum of Natural History, in 1951.

In the Cleveland Museum of Natural History, the skeletons were placed in padded plastic drawers that were labeled with the demographics of each individual. They are organized in an automated compact storage system that makes locating and retrieving individual skeletons easy and quick, and also provides environmentally controlled conditions in which to store the remains. In the 1990s, all of the original files on each individual in the collection were digitized, allowing for easier access and reducing the degradation of the original paper files. The bones themselves were also finally cleaned of dirt and grime that had accumulated through the many years of non-ideal storage conditions of the previous decades.

As mentioned previously, the collection is dominated by unclaimed bodies from morgues around Cleveland which limits the relevancy of the individuals in the collection. The individuals in the collection are indicative of the “poor working class” of America in the late 1800s and early 1900s (Arney 2011). These individuals are classed as Black or White and died around Cleveland, Ohio, but they were not necessarily born in the region. Many are first generation Americans, with the individuals classed as White originating from the Northern States and those classed as Black originating from the Southern States who were likely emancipated slaves who migrated north (Arney 2011). In addition, the fact that the collection is composed of all age groups, is as much a negative aspect of the collection as it is a positive one. Researchers are able to examine skeletal traits as they relate to all age groups, but this suggests that the age of death for the time period was evenly distributed when it was not so. Remains were also selected purely because they displayed pathological lesions and are considered to be the most robust or healthiest individuals of the population because they survived the diseases long enough to develop the skeletal lesions.

Considering the way this collection was assembled, the Hamann-Todd Osteological Collection is not the ideal collection to use for research purposes. Most of the skeletons in the collection were unclaimed bodies from hospitals and morgues in the state of Ohio. The individuals in the collection were of low socio-economic status, likely dying in almshouses, public healthcare institutions, and municipal hospitals. The high amount of trauma and pathologies in the collection is due to the fact that these individuals likely worked as laborers and lived in urban settings in the early 20th century. In addition, when putting the collection together, Todd was particularly concerned with skeletal aging, so while individuals of all ages are represented, they are not all of the same ethnicity or sex. While this collection is not an ideal sample for research involving the general population, or current populations, it is an idea sample for the low-income individuals of the early 20th century.

Despite the biases in this collection illustrated above, this collection was chosen for use in this study because it was the most accessible and contained individuals of a large range of ages. Other collections that were considered for use in this study were either located at too great a distance (the Coffin Plate Sample in Spitalfields, London) or did not contain individuals belonging to a wide age range (the Smithsonian Fetal Collection). As there are few collections that contain subadult individuals with known demographics, this collection was selected because it was one such collection.

CHAPTER FOUR: RESULTS

Of the 68 sets of remains that were available for examination, only 46 were acceptable for use in this study (Table 1). Most of those eliminated were missing one or both elements that were examined in the course of this study; the rest were eliminated because the method of preservation prevented an examination of the sexually dimorphic features of the ilium. This latter case primarily affected the remains of the youngest individuals in this study whose innominate bones were articulated together with the sacrum, likely for preservation and educational purposes.

TABLE 2 – Percent distribution of sex-related skeletal traits for known sex skeletal remains from Hamann-Todd Collection at CMNH: newborn to 18 years of age

Trait	Sex	Classification		Overall % Correct
Angle of Sciatic Notch		>90	~90	
	Female (24)			37.0%
	Male (22)			32.6%
Depth of Sciatic Notch		Shallow	Deep	
	Female (24)			41.3%
	Male (22)			30.4%
Arch Criterion		Bordering	Crosses	
	Female (24)			39.1%
	Male (22)			21.7%
Iliac Crest Curvature		Slight-S	Marked-S	
	Female (24)			41.3%
	Male (22)			28.3%
Auricular Surface Elevation		Elevated	Flat	
	Female (24)			17.4%
	Male (22)			45.7%
Mandibular Protrusion		Smooth	Prominent	
	Female (24)			41.3%
	Male (22)			41.3%
Mandibular Arcade Shape		U-Shaped	Parabolic	
	Female (24)			39.1%
	Male (22)			37.0%
Gonial Eversion		In-Line	Everted	
	Female (24)			43.5%
	Male (22)			21.7%

Of the eight traits that were examined, only two met the minimum acceptable accuracy established by De Vito and Saunders (1990) – mandibular protrusion (82.6%) and mandibular arcade shape (76.1%). Of the other six traits, the depth of the greater sciatic notch (71.7%), the angle of the greater sciatic notch (69.6%), and the iliac crest curvature (69.6%) approached the minimum acceptable accuracy but did not meet it. However, further examination using additional collections may improve the accuracy of these traits. The remaining three traits – the arch criterion (60.9%), auricular surface elevation (63.0%), and gonial eversion (65.2%) – did perform better than chance. However, as this performance was only slightly better than chance, further study is needed on these traits for their use in estimating the sex of subadult skeletal remains.

Overall, the traits were better at diagnosing female than male, with the exception of auricular surface elevation. Diagnosing sex according to auricular surface elevation was more accurate in diagnosing male and female in the individuals aged 16 to 18. In the younger individuals, the auricular surface was, more often than not, not elevated, resulting in the estimation that the individual was male. Three of the traits diagnosed male and female almost equally – angle of the sciatic notch (female – 37.0%, male – 32.6%), mandibular protrusion (female – 41.3%, male – 41.3%), and mandibular arcade shape (female – 39.1%, male – 37.0%).

TABLE 3 – Comparison of reported accuracies for subadult sex determination using auricular surface elevation

Study	Male	Female	Combined
Weaver (1980)	85.4% (n = 80)	57.7% (n = 71)	73.5% (n = 151)
Mittler and Sheridan (1992)	85.3% (n = 34)	58.3% (n = 24)	74.1% (n = 58)
Sutter (2003)	77.8% (n = 37)	60.9% (n = 23)	71.7% (n = 60)
This Study	45.7% (n = 22)	17.4% (n = 24)	63.0% (n = 46)

In comparison with the previous research, the accuracies achieved in this study were lower or about the same, depending on the trait. Regarding the auricular surface elevation, the accuracy achieved in this study was much lower than the accuracies reported by previous researchers, as seen in Table 3. This trait was better at diagnosing male than female as most of the ilia examined in this study did not have the raised auricular surface indicative of females. In Table 4, (on the next page) the reported accuracies of the other seven nonmetric traits are summarized for individuals under the age of five. Comparing these accuracies shows that the accuracies in this study were largely lower than those reported by previous researchers. These differences could be due to the number of individuals under the age of five that were available for use in this study, there were at least half as many in this study as in the previous studies.

TABLE 4 – Comparison of reported accuracies for subadult sexing techniques of the ilium and mandible: newborn to 5 years of age

Trait and Study	Male	Female	Combined
Angle of Greater Sciatic Notch			
Schutkowski (1993)	71.4% (n = 28)	95.2% (n = 21)	81.6% (n = 49)
Sutter (2003)	69.2% (n = 13)	78.6% (n = 14)	74.1% (n = 27)
This Study	42.9% (n = 7)	100% (n = 5)	66.7% (n = 12)
Depth of Greater Sciatic Notch			
Schutkowski (1993)	86.7% (n = 30)	68.4% (n = 19)	79.6% (n = 49)
Sutter (2003)	69.2% (n = 13)	92.9% (n = 14)	81.5% (n = 27)
This Study	28.6% (n = 7)	100% (n = 5)	58.3% (n = 12)
Arch Criterion			
Schutkowski (1993)	81.5% (n = 27)	60.0% (n = 20)	72.3% (n = 47)
Sutter (2003)	76.9% (n = 13)	85.7% (n = 14)	81.5% (n = 27)
This Study	14.3% (n = 7)	100% (n = 5)	50.0% (n = 12)
Iliac Crest Curvature			
Schutkowski (1993)	54.2% (n = 24)	85.7% (n = 21)	68.9% (n = 45)
Sutter (2003)	38.5% (n = 13)	92.9% (n = 14)	66.6% (n = 27)
This Study	14.3% (n = 7)	100% (n = 5)	50.0% (n = 12)
Mandibular Protrusion			
Schutkowski (1993)	59.3% (n = 27)	92.3% (n = 13)	80.0% (n = 40)
Sutter (2003)	100% (n = 28)	25.0% (n = 16)	72.7% (n = 44)
This Study	71.4% (n = 7)	100% (n = 5)	83.3% (n = 12)
Mandibular Arcade Shape			
Schutkowski (1993)	73.1% (n = 26)	69.2% (n = 13)	71.8% (n = 39)
Sutter (2003)	96.4% (n = 28)	31.3% (n = 16)	72.7% (n = 44)
This Study	85.7% (n = 7)	100% (n = 5)	91.7% (n = 12)
Gonial Eversion			
Schutkowski (1993)	68.0% (n = 25)	62.5% (n = 16)	65.9% (n = 41)
Sutter (2003)	60.7% (n = 28)	56.3% (n = 16)	59.1% (n = 44)
This Study	57.1% (n = 7)	100% (n = 5)	75.0% (n = 12)

CHAPTER FIVE: CONCLUSIONS

"Before puberty, there's no reliable way to distinguish between the bones of males and those of females. All you can do is tell whether the bones you have are the right size for a boy or girl of a given age." Carved in Bone by Jefferson Bass

The identification of human skeletal remains is important not only to forensic anthropologists, but also to bioarchaeologists. The human skeleton can give researchers a wealth of information about the individual as well as the society in question. For adult skeletons, putting together a demographic profile is fairly straightforward. When the remains are those of a child, the demographic profile becomes complicated, as is illustrated in the quote above. Sex forms a key part of the demographic profile as methods to determine the other aspects of the demographic profile, especially age at death, are more accurate when sex is known. Unfortunately, as the sexually dimorphic characteristics of the skull and pelvis are difficult to recognize until puberty, morphological methods are less reliable for younger individuals (Rosing *et al*. 2007).

Forensic Anthropology

Methods for sexing human skeletal remains using morphological characteristics remain the most used methods despite advances in DNA research. Morphological methods allow for a quicker estimation of sex, which aids in investigations when time is of the essence in identifying the unknown deceased individual. DNA, when it is used in filling out a demographic profile, would most often be used to support what was determined by the morphological methods, or when the morphological methods cannot be used (as in the case of fragmentary remains).

The best available feature to use to diagnose sex in subadult skeletons is tooth size as the dentition develops early in life (Rosing *et al.* 2007). With children under age three, the deciduous dentition is used, resulting in accuracies around 60%. With older children, the permanent dentition can be utilized, increasing the accuracies to about 80%. Other methods use traits of the cranium and pelvis to estimate sex, as described above, but many do not meet the minimum acceptable accuracy of 75% (De Vito and Saunders 1990), for use in forensic cases. In those tests that do meet the minimum acceptable accuracy, further testing shows that the methods may not be of use in all populations, as research utilizing different skeletal collections may not meet the minimum acceptable accuracy (see method descriptions in chapters one and two).

Due to the plethora of crime shows on television, people (potential jurors) expect the identification process to be easy and unquestionable. However, in many cases, an investigator can only answer a few demographic questions about a set of skeletal remains. These potential jurors expect that it would be just as easy to identify a child as it is for an adult because it looks so simple on television. While these studies may stay in the academic world, studies like this need to be conducted to both improve accuracies in identification methods and modify or create new methods of identification.

Bioarchaeology

As the cost of DNA analysis can be high and the destruction of the sample that comes with extracting and isolating DNA in a sample, many bioarchaeologists choose to use morphological methods determine the demographic profile of individuals recovered from archaeological sites (White *et al.*2012). Morphological methods are quicker than DNA analysis, and the cost of examining a set of remains is typically free if you are already examining them in the course of your research.

Sexing adult skeletons is relatively easy to do compared with subadult skeletal material as the sexually dimorphic traits are easy to identify in adult skeletal remains. The challenge with subadults is identifying methods that can be used to distinguish between the sexes before those sexually dimorphic traits become easily identifiable after puberty. This study, and others like it, continuously test methods that have previously been developed to determine if the accuracies are acceptable for use in bioarchaeological research and forensic investigations. With the ability to sex subadult skeletal remains they come across accurately, bioarchaeologists are able to come to better understandings about the archaeological populations they are studying. They are better able to comment on the burial methods and the health of the population, as well as the gender roles that can be inferred from the grave goods buried with child skeletons.

This Study and the Potential for Future Research

This study sought to test the accuracies of eight nonmetric sex estimation methods using the subadult mandible and pelvis at a collection that had not been utilized by other researchers. Of the eight methods, only two were found to meet the minimum acceptable accuracy requirements, the other six came close to meeting the minimum acceptable accuracy, but may not be acceptable for use in forensic investigations in isolation. Sex determination based on those six traits must be supported by another method, whether another nonmetric method or by DNA analysis. None of these eight traits should be used in isolation to diagnose sex in asubadult skeleton, they must be used in combination with another method, either another morphological method or DNA analysis. More studies must be conducted on these methods used in this study and the others mentioned in this thesis to improve the accuracies of using any of the methods on skeletal populations where sex is unknown.

APPENDIX

Hamann-Todd Osteological Collection Data

Hamann Todd Osteological Collection Data

Specimen Number	Cadaver Age	Known Sex	Chin Region	Dental Arcade	Gonion Region	Sciatic Notch Angle	Sciatic Notch Depth	Iliac Curvature	Arch Criterion	Auricular Surface
HTH 0404	11	M	M	F	F	M	M	F	M	F
HTH 0437	18	F	F	F	F	M	F	F	F	F
HTH 0485	16	F	F	M	M	M	F	F	M	M
HTH 0526	11	F	F	F	F	F	F	F	M	F
HTH 0576	16	F	F	M	F	F	F	F	F	F
HTH 0624	6	F	F	M	F	F	F	F	F	M
HTH 0632	10	F	F	M	F	F	M	M	F	M
HTH 0633	14	F	F	F	M	M	M	F	M	M
HTH 0645	12	F	M	M	M	M	M	F	M	M
HTH 0695	18	M	M	M	M	M	M	M	M	M
HTH 0710	10	M	M	F	F	M	M	F	F	M
HTH 0721	18	M	M	M	F	M	M	M	M	M
HTH 0872	8	F	F	M	F	F	F	F	F	M
HTH 1012	18	F	M	F	F	M	M	M	M	F
HTH 1041	17	F	F	F	F	F	F	M	F	F
HTH 1074	4	F	F	F	F	F	F	F	F	M
HTH 1097	18	M	M	M	F	M	M	M	M	M
HTH 1115	5	F	F	F	F	F	F	F	F	M
HTH 1140	18	M	M	M	M	M	M	M	M	M
HTH 1156	8	F	F	F	M	M	F	M	F	M
HTH 1240	12	F	F	F	F	F	F	F	M	F
HTH 1385	1	M	M	M	M	M	M	F	F	M
HTH 1441	10	M	M	F	F	M	M	F	F	M
HTH 1557	3	M	F	M	F	M	M	M	F	M

Hamann-Todd Osteological Collection Data Continued

HTH 1583	1	M	M	M	F	M	F	F	M	M
HTH 1589	17	M	M	M	M	M	M	M	M	M
HTH 1590	18	F	M	F	F	F	F	F	F	F
HTH 1768	1	M	F	M	M	F	F	F	F	M
HTH 1772	12	F	M	F	F	M	M	M	F	M
HTH 1784	6	M	M	M	M	F	F	M	F	M
HTH 1834	8	M	M	M	M	F	F	M	F	M
HTH 1861	0	F	F	F	F	F	F	F	F	F
HTH 1894	1	M	M	M	M	F	F	F	F	M
HTH 1974	18	M	M	M	M	M	M	M	F	M
HTH 2036	7	F	F	F	F	F	F	F	F	M
HTH 2074	8	F	M	F	F	F	F	F	F	M
HTH 2075	1	M	M	F	F	F	F	F	F	M
HTH 2118	13	F	F	F	F	F	F	F	F	M
HTH 2135	14	F	F	F	F	F	F	F	F	M
HTH 2141	4	F	F	F	F	F	F	F	F	M
HTH 2144	6	M	M	M	F	F	F	M	F	M
HTH 2370	1	M	M	M	M	F	F	F	F	M
HTH 2714	1	F	F	F	F	F	F	F	F	M
HTH 3112	15	M	F	M	F	M	M	M	M	M
HTH 3455	18	M	M	F	F	M	M	M	M	M
HTH 3470	17	M	M	M	F	M	M	M	M	M

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