ASSESSING METHODS FOR ESTIMATING BIOLOGICAL SEX FROM SUBADULT SKELETAL ELEMENTS

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ABSTRACT

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While methods for estimating the sex of adult skeletons are relatively accurate, these methods are often inconclusive when applied to subadults (non-adults), especially when many secondary sexual characteristics have not fully developed. Furthermore, existing methods for subadults are often tested on samples with relatively homogenous ancestries, calling into question their reliability in more diverse populations. This thesis reviewed techniques for estimating sex in subadult skeletal remains, and the most promising methods were retested on individuals of known sex between ages 3 and 17 years (n=39, 14 males, 25 females) from the Hamann-Todd Osteological Collection. Data collection included measurements of the dentition, skull, long bones (i.e., humerus, radius, ulna, femur, tibia, and fibula), ilium, talus, and calcaneus. Non-metric assessment included observations of the eye orbits, mandible, and ilium. For metric methods, the highest level of accuracy was achieved by multivariate analysis of craniometrics (p=0.001, 100.0%), a multivariate analysis of the medial, distal, and mid-shaft breadths (p =0.0004, r =0.94, 95.5% accuracy), a univariate analysis of the distal breadths of the long bones (p =0.0002, r =0.83, 95.8%), and the mesiodistal dimension of the deciduous left lateral incisor (p =0.02, r =0.81, 73.3%). For non-metric methods, the highest level of statistical accuracy was from the protrusion of the chin (64.9%). Factors contributing to

inconclusive results include small sample sizes and overlapping data points between the sexes. Therefore, recommendations are to re-evaluate whether binary dichotomization of sex in the subadult skeleton actually reflects the biological reality, to refine and redefine methods of assessment (e.g., reflecting a scale in variation), and continue testing the methods on larger more diverse sample populations with various methods of analysis.

"With integrity, you have nothing to fear, since you have nothing to hide. With integrity, you will do the right thing, so you will have no guilt."

Zig Ziglar

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INTRODUCTION

One aspect common to biological anthropology work, particularly forensics and bioarchaeology, is the creation of a biological profile based on skeletal remains. This profile typically includes estimation of age, ancestry, stature, and biological sex. The objectives of this thesis were to complete a meta-analysis of techniques for estimating sex from subadult (non-adult) skeletal remains, and then use a skeletal sample of known sex (n=39, 25 females, 14 males, ages 3-17 years) to test the efficacy of the methods that originally produced a minimum of 70% accuracy. The focus was on sex characteristics that can be observed and measured in the field with standard equipment (i.e., sliding/spreading calipers, osteometric board). Emphasis was placed on methods focusing on multiple skeletal elements, so as to better understand the continuum of sex representation in the skeleton and to increase potential statistical accuracy. The elements studied included the skull (with emphasis on the occipital bone, eye orbits, dentition, and mandible), ilium, humerus, radius, ulna, femur, tibia, fibula, talus, and calcaneus. These elements were observed for morphological variation or measured for statistical analysis.

First, this introduction frames the challenges associated with estimating sex from subadult skeletal remains – the history of this endeavor is discussed in more detail in the literature review section. Next, the concept of biological sex is discussed, specifically with respect to the potential issue of dichotomization. Then, osteological growth and development, as applicable to this study, is briefly discussed, followed by a consideration of how environmental factors and disease can affect the skeleton. Finally, issues

associated with osteological collections, such as the one used for this study, are discussed.

Estimating Sex from Subadult Skeletal Remains

When the skeletal remains of an individual are located (e.g., from criminal acts, accidents, disasters, war, or archaeological sites), one of the first steps is constructing a biological profile which includes estimates of age, stature, ancestry, and biological sex – if any of these cannot be reliably estimated, then identification efforts can be impeded. The National Institute for Justice, an organization dedicated to finding the lost and missing, gathers information on missing people and provides information on unidentified individuals. As of November 2020, there were approximately 13,495 unidentified persons in the United States of America and 1,738 of these were of subadult individuals (National Institute for Justice) – these cases could benefit from a variety of improved methods. A better understanding of the efficacy of methodologies available and their accuracy across populations will contribute to this topic. DNA has become a popular method for establishing a decedents' biological profile and it can assist in estimating the sex and ancestry of a decedent (e.g., Mannucci et al., 1994; Tierney & Bird, 2015). However, there are certain limitations to acquiring DNA from a decedent. Gonzalez (2012) noted the difficulty in obtaining a usable DNA sample because it degrades through decomposition, samples are easily contaminated, and it is expensive. In cases where obtaining a DNA sample in not possible, researchers focus on skeletal markers and variations to assist in the identification process.

One of the major challenges in identifying subadult skeletal remains is estimating biological sex. Despite the myriad of relatively reliable methods to estimate the sex of adult skeletal remains, assessing the sex of subadult remains continues to be a challenging task. This is due in part to the absence or minimal expression of sexually dimorphic characteristics normally observed in adult skeletons. Since the late nineteenth century (Fehlings, 1876), researchers have been testing methods for estimating sex from subadult bones. Some early researchers (Boucher 1955, 1957; Fehlings, 1876; Thomas, 1899) concluded that sex differences can be seen in the skeletons of individuals as young as four months of age, whereas others claimed sex estimation is not possible for subadults (Kappers, 1938; Konikow, 1894). More recently, researchers have been able to successfully estimate subabult sex from skeletal remains from a specific collection; however, no method had evinced over 85% accuracy across sample populations, which has been suggested as the minimum standard for adult remains (Klales et al., 2017).

Dichotomization of Biological Sex

For the purpose of this thesis, ‘sex’ is used to refer to that which is biologically determined and represented anatomically (i.e., through soft tissue and skeletal features) and physiologically (e.g., through hormone levels). For anthropological biological profiles, 'females' and 'males' are commonly placed into dichotomized (i.e., binarized) categories based on the physical form and explained through evolutionary mechanisms (e.g., sexual selection, natural selection) (Bettcher, 2011; Dunsworth, 2020). Sex differs from gender, which is self-identified and encompasses cultural perceptions and roles. However, like gender, biological sex is much more complex than a simple binary scheme

suggests (Okin, 1996). For example, with respect to the sex chromosomes, typically females are homozygous (XX) and males are heterozygous (XY). However, variation exists even at this fundamental level, such as one of the pairs being absent (monosomy) or the presence of additional copies (polysomy). An example of a monosomy is Turner Syndrome, which is characterized by the loss of an 'X' chromosome in females (Shi et al., 2016) and results in decreased stature and ovarian insufficiency. An example of polysomy is Klinefelter syndrome in males, which is the presence of, at minimum, one additional 'X' chromosome, although cases have seen an individual with a karyotype of XXXY (Lluch et al., 2012).

Similarly, in the skeleton, sex characteristics are not necessarily binary and often are present on a spectrum, as evidenced by the overlapping data points between sexes obtained within this thesis and data presented in other studies. For example, Garofalo and Garvin (2020) noted that varying features can overlap between sexes, such as a prominent mental protuberance of the mandible (i.e., chin) appearing in females despite being typically associated with males. In fact, some studies represent this overlap and continuum by employing scaling methods (e.g., Klales et al., 2012). However, within the field of forensics, professionals still commonly produce dichotomous sex estimates for matching a decedent’s biological profile to government issued documentation (e.g., driver’s license, birth certificate) (Konigsberg et al., 2009). And within bioarchaeology, dichotomous sex estimations are used to establish biological and demographic profiles, and to evaluate sex, (and therefore presumed) gender roles and their correlates in past cultures. In this thesis, the testing of methods aimed at dichotomous sex estimation

provides an opportunity to not only test the accuracy of the methods, but also to further evaluate the utility of the endeavor itself.

Osteological Growth and Development

Osteological growth and development, as well as soft tissue development, of characteristics that are typically assigned as 'female' or ‘male’, stem from sex steroid hormones. The two common sex steroid hormones are testosterone and estrogen, both of which are important to consider with respect to their effects on the malleable bones of subadult individuals (Lewis, 2018).

Estrogen, which is found in both females and males, works in unison with testosterone (Madimenos, 2015). Estrogen assists in bone and collagen formation, longitudinal bone growth, and epiphyseal closure (Dunsworth, 2020; Madimenos, 2015). Typically, longitudinal bone growth slows or stops for females when menstruation begins because estrogen is reallocated at this time (usually around 13 years) (Dunsworth, 2020).

Testosterone, which is also found in both females and males, is a type of androgen. Androgens not only effect the soft tissue, but also assist in bone metabolism, development, maturation, and homeostasis (Ashida et al., 2010; Madimenos, 2015; Tao & Zhi-Liang, 2005). It is also hypothesized that androgens may, in fact, protect men against osteoporosis as well as maintain cancellous bone mass and cortical bone expansion (Lindberg et al., 2005). Unfortunately, there is minimal published research found on the effects of androgens on bone, with much of the existing research focused on the effects of declining testosterone for males.

A third hormone, the growth hormone (GH), helps regulate both cortical and trabecular thickening (Madimenos, 2015); therefore, a deficiency in a hormone can severely affect normal bone growth and development. Hormone deficiencies can be due to a number of factors such as genetics, environmental effects such as malnutrition, and disease (Madimenos, 2015; Manifold, 2014). These topics will be further discussed in the next section. First, understanding how sex hormones affect primary and secondary sex characteristics and bone development are discussed.

Sex characteristics appear in two phases, as primary and secondary (Norris & Carr, 2013). Primary sex characteristics begin forming during gestation and include the organs that delineate 'female' and 'male' such as ovaries and testes, which are aspects of the soft tissue. Secondary sex characteristics arise during puberty due to increased secretion of sex hormones. This is when aspects like widening of the hips and maintaining the gracile features for the female and relatively more muscle mass and more robust facial features for males begins to appear, resulting in characteristics that can assist in estimating the sex of an individual through their skeleton (Garofalo & Garvin, 2020; Norris & Carr, 2013). However, as aforementioned, Garofalo and Garvin (2020) noted that these varying features can overlap between sexes.

Bones also develop in two main phases, corresponding to primary and secondary ossification centers. Ossification is defined as the formation of bones, usually from a cartilaginous state (Cunningham et al., 2017). Primary ossification centers (POC's) begin transitioning from cartilage to bone during the fifth week of gestation, starting with the clavicle and facial bones (Cunningham et al., 2017). The POC's form the largest portion

of the 22 cranial bones, the mandible, the vertebrae, clavicles, scapulae, ribs, sternum, pelvis, the diaphyses (shafts) of the long bones, phalanges, metacarpals, and metatarsals (Cunningham et al., 2017). Secondary ossification centers (SOC's) develop throughout approximately the first 30 years of life with the formation and fusion of the epiphyses, at the ends of the diaphyses of the long bones, carpals, and tarsals. The SOC's also develop the features for muscle, ligament, tendon, and joint attachments (Cunningham et al., 2017). The development of the skeleton can be altered by external and internal forces.

Skeletal Abnormalities

When conducting studies such as this thesis, it is important to recognize potential skeletal abnormalities to evaluate whether individuals should be excluded from a sample. There are a number of factors that can affect normal skeletal development and bone growth, including traumas, infections, infantile sickness, maternal prenatal care, and activity (Buikstra, 2019; Weis, 2017). Deficiencies in hormones, caused by factors such as genetics, malnutrition and disease, can affect normal bone growth and development and explain some observations made in the collection examined for this thesis (Madimenos, 2015; Manifold, 2014). There are also a number of environmental factors that can affect the normal growth of the skeletal structure, especially due to the flexible nature of developing bone (Lewis, 2018). These factors are referred to as stressors (*singular: stress)*. When the body is under added stress, it can automatically reallocate its energy to protect and preserve aspects important for continued survival, such as the heart and brain, and may postpone or completely stop growth from areas such as the skeleton (Hochberg, 2012).

Environmental effects can be influenced by mechanisms of systematic racism and structural violence to minoritized and marginalized groups, which can result in unhealthy living conditions, limited food resources, deficiencies (e.g.,. nutritional, hormonal), and less access to medical attention, to list a few (Muller et al., 2017). Skeletal collections where there is a prevalence of marginalized individuals such as the Hamann-Todd Osteological (HT) Collection (discussed later in this section) used for this thesis, may show a relatively high degree of effects from environmental factors.

One skeletal abnormality observed in the HT Collection is bowing of the lower limbs (Figure 1). Bowing can potentially be attributed to malnutrition, such as a vitamin D deficiency, also known as rickets (Madimenos, 2015). Vitamin D assists in transporting calcium which is important for keeping bones in a homeostatic state (Holick, 2003). Rickets can cause observable abnormalities, such as bowing of the limbs, especially the lower, weight-bearing extremities (Manifold, 2014). Although rickets is the most common cause of bowed limbs, there are a number of other causes like developmental or congenital conditions, trauma, infection, eccentric pressure, and walking too soon (Bateson, 1968; Espandar et al., 2010).

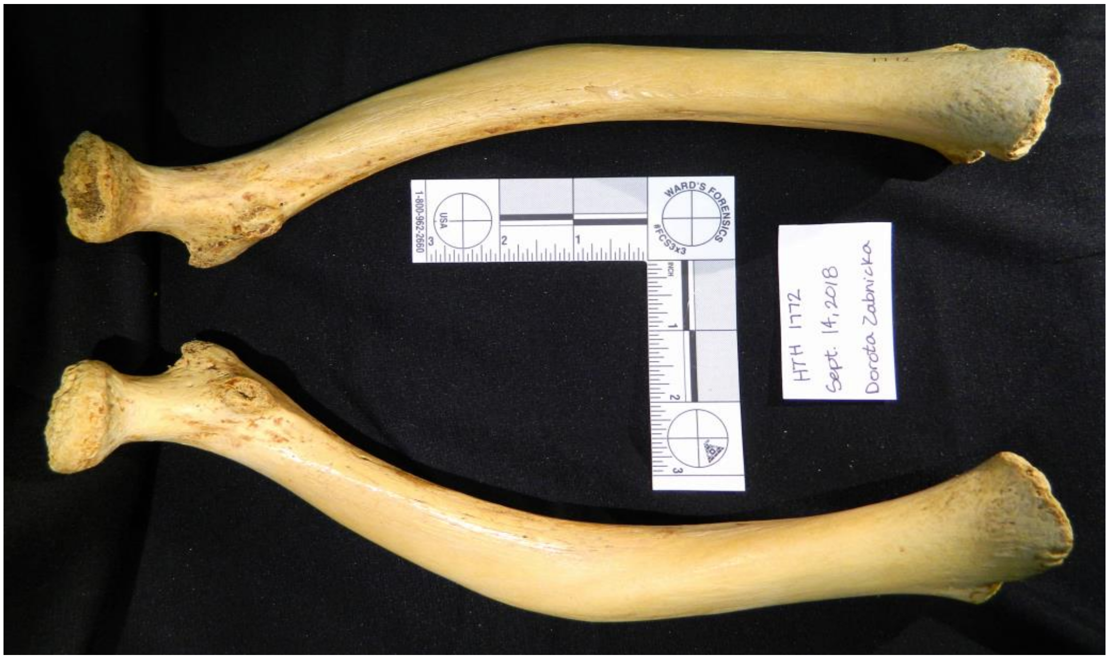


Figure 1. Example of bowed limbs from the Hamann-Todd Collection, descendent 1772. Taken by: Dorota Zabnicka.

Another example of disease present in the HT Collection is tuberculosis. Some of the records from the HT Collections database noted that individuals had tuberculosis (TB) at the time of death. Tuberculosis, also known as consumption or Potts disease, to name two, was an ailment with peaks in the 17th and 19th centuries, coinciding to when the HT Collection was established (Buikstra, 2019; Santos & Roberts, 2011). TB is a bacterium and can affect different aspects of the body with the most common being pulmonary. Some of the reactions to pulmonary TB are loss of weight and appetite, fever, and fatigue, and when left untreated TB can spread to the skeleton and eventually cause death (Buikstra, 2019; Santos & Roberts, 2011). For adults, TB enters the bone through the marrow, affecting the cancellous bone (i.e., diaphyseal ends, metaphysis and epiphysis) and for subadults can also affect the metacarpals, metatarsals, phalanges, and

ossification centers and occasionally result in diaphyseal lesions (Buikstra, 2019). TB can contribute to atypical bone growth and development.

Another atypical example from the Hamman-Todd osteological Collection is decedent HTH 1589, identified as a 17-year-old male who weighed 78 pounds and was 4 foot 11.5 inches tall at time of death. Cause of death was recorded as tuberculosis, although other aspects may have contributed without being known or noted in the records such as pathologies. Observations of the long bones on this individual included lack of fusion of epiphyses to the diaphyses, when at this age most should be nearing completion (Cunningham et al., 2017; Schaefer et al., 2009).

Skeletal abnormalities such as those listed above were observed in the HT Collection and affected whether individuals were excluded from the study sample. It is possible that other, not documented and not readily observed factors affected the skeletal growth and development of the individual included in this thesis. However, it was beyond the scope of this thesis to examine all such possibilities, and therefore they are not discussed here further.

Osteological Collections

Recognition for the importance of studying the human body became increasingly prevalent at the end of the eighteenth century in order to understand concepts such as human origins, biology, and culture (Muller et al., 2017). During the mid-nineteenth century, anatomists began documenting age, sex, stature, ancestry, and medical conditions of medical subjects, which ultimately resulted in the creation of skeletal collections like the Terry Collection, the Huntington Collection, the Hamman-Todd

Collection, and the W. Montague Cobb Skeletal Collection (Quigley, 2001). Quigley (2001) discussed that Robert J. Terry, George S. Huntington, Carl August Hamman, T. Wingate Todd, and William Montague Cobb created these collections to study and understand human anatomy and the variation between females and males and individuals of varying ancestries.

Most major osteological collections, such as those mentioned above, were initiated before modern ethical rules and guidelines were created to protect the individuals being studied. Thus, the majority of historic collections overrepresented the most marginalized individuals from society (Muller et al., 2017). Muller et al. (2017) noted the occurrence of grave robbery of unmarked graves, usually of marginalized people, and unclaimed or unknown bodies were used as cadavers in gross anatomy courses, which was legal up until the mid-1900's. In the mid-1800's anatomical legislation led to populations of marginalized being bulk of cadavers used (Muller et al., 2017).

Unfortunately, it was common for skeletal collections to not contain accurate information on ancestries. Instead, categorization followed the social construct of ‘race’ at the time and most did not account for the variation within and between populations (Latham et al., 2018). Note, ‘race’ is a socially constructed concept which differs from ancestry, the latter of which indicates where an individual and their ancestors originated from geographically. These socially defined ‘racial’ groups, delineated by skin color, such as 'black' and 'white', are not a construct of evolution or discrete biological groups, but instead has been operationalized by western science to support colonialist endeavors

(AAPA Statement of Race, 2019). These collections and others hold value for researchers, however; they are "labeled in terms of preconceived racial categories or broad geographical regions" and researchers must grapple with the ethics of using such collections (Walker, 2000, p.2).

The methods of this thesis were tested on the Hamann-Todd Osteological (HT) collection. The HT Collection, housed at the Cleveland Museum of Natural History in Ohio, is an extensive collection containing over 3,000 human skeletal remains which were initially dissected cadavers (Collections and Database, n.d.). The collection was put together by Carl A. Hamann and T. Wingate Todd from 1893-1938 (Muller et al., 2017; Collections and Database, n.d.). Although Hamann started the collection (Muller et al., 2017), the majority of the human remains were collected by Todd (Quigley, 2001). This collection has extensive documentation of the individuals, which includes medical history, cause and manner of death, age, sex, stature, ‘race’ (based on the historical categorization of the late 1800's to early 1900's), radiographs (x-rays), and images of the decedents postmortem. Through the on-site records provided by the collection, the age and sex of the decedents can be reasonably assumed to be accurate (Dupertuis & Hadden, 1951). The individuals from the HT Collection were born between the years 1823-1934 and died between the years of 1912-1938 (Muller et al., 2017). Todd's interest in studying growth and development contributed to the presence of subadults within the collection (Muller et al., 2017).

The Hamman-Todd Osteological Collection likely included individuals of mixed ancestries, with the majority being placed in racially defined categories of 'black' or

'white'. The majority of the 'black' individuals were reported to be originally from Alabama, and then during the years of World War I, many migrated to Ohio (Dupertuis & Hadden, 1951).Todd assumed the 'black' individuals did not have any ‘white’ ancestors (Dupertuis & Hadden, 1951, p.18). Dupertuis and Hadden (1951) presumed that the individuals identified as ‘black’ are most likely either African or African-American in ancestry. However, it is likely that these individuals were maybe of mixed ancestry (see below). Dupertuis and Hadden (1951) noted that the ‘white’ individuals are of European descent with the majority coming from Germany and Eastern Europe and being immigrants or first-generation US citizens. Dupertuis and Hadden (1951) noted that three quarters of the collection’s population are immigrant or first-generation Americans. The marginalization of migrants and individuals of African or African American ancestry individuals likely contributed to the large percentage of individuals presumed as such in the collection. Dupertuis and Hadden (1951) lacked a deeper discussion of probable mixed ancestries within this collection. Maintaining the dichotomized racially determined categories of 'black' and 'white' not only perpetuates racism, but also limits knowledge of the ancestral composition of the collection, including to what extent that individuals with ancestries from outside of Europe and Africa are included.

The little information discovered on the origins of the individuals within the HT Collection is most likely biased by cultural perceptions of the late 1800’s to early 1900’s. Thus, for the purposes of this thesis, it is assumed that individuals are of primarily African-American and European/European-American ancestry, with unknown levels of admixture therein. Accordingly, this collection provided an opportunity to assess methods

on a population that is not homogeneously European in origin, which has not been the case for many previous studies estimating the sex of subadult decedents. Because the actual ancestries are uncertain and to remain consistent with the collections databases', the terms 'black' and 'white' are used throughout this thesis just for informational purposes, but note these are biased 'racial' categories and not ancestries. This thesis does not study the presumed ancestries of the individual subadult decedents and does not separate 'races' or presumed ancestries during analysis.

LITERATURE REVIEW

The literature review is thematically organized into sections based on the different aspects of the human skeleton and arranged chronologically therein. Each section discusses the general aspects of the growth and development of each skeletal element, followed by a detailed account of what has been studied by previous researchers and the levels of accuracy the researchers obtained. For previous studies, this section identifies the age, number of individuals examined, ancestries, and skeletal collection used to gather data from; if this information is not given, it is because the authors did not provide it. The skeletal elements focused on include the skull, dentition, ilia, appendicular long bones (i.e., humerus, ulna, radius, femur, tibia, and fibula), talus, and calcaneus. These skeletal elements were chosen due to their repetitive testing by a number of researchers, their use when estimating sex of adult skeletal remains, and their reasonably accurate rates for estimating sex of subadult decedents.

Skull

The skull (Figure 2) is comprised of the mandible plus 22 bones of the cranium. At birth, the elements are relatively loosely articulated via open sutures. Some bony elements are separated by cartilaginous masses, called fontanelles. Typically, these fontanelles completely ossify by the fifth year of life (Cunningham et al., 2017).

Secondary sex characteristics of the skull include changes to the morphology of the facial bones and cranial features, like the mastoid processes of the temporal bone and the occipital protuberance of the occipital bone. Generally, females have smaller and

more gracile features, while males tend to be larger and have more robust features. Sex-related changes in features of the skull typically begin to take place during puberty, starting between 11-13 years of age (Hochberg, 2012).

When estimating the sex of an adult skeleton, it can be useful to examine features both qualitatively and quantitatively. Features of particular interest include the size and shape of the mastoid process, the thickness of the brow ridge, and the morphology of the superior margin of the eye orbits (White et al., 2012, originally Acsádi & Nemeskéri, 1970). Some of these features have been assessed on subadult crania.

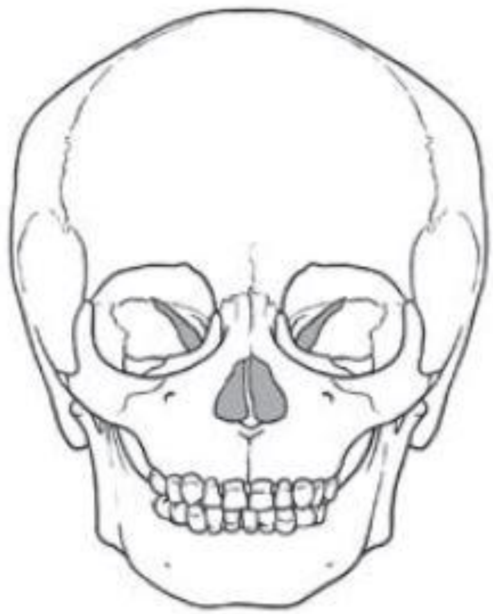


Figure 2. Anterior aspect of subadult skull from *Juvenile Osteology Lab and Field Manual* (p.361), by Schaefer et al., 2009, Burlington, MA, Academic Press, Copyright 2009 by Elsevier Ltd. Reprinted with permission.

In a relatively early study, Giles and Elliot (1963) studied craniometrics of adult skeletons ranging in age from 21-75 years old (187 females, 221 males, n=408) and included individuals identified as ‘black’ and ‘white’ from the Robert J. Terry

Anatomical Skeletal Collection and the Hamann-Todd Osteological Collection. The individuals from theses collections are considered a historical population from the late 1800’s to the early-mid 1900’s. Sex was identified through the written records from the collection (Giles & Elliot, 1963). The authors measured nine points in 21 combinations to evaluate the possibility of sexual dimorphism of the adult skull. By using discriminant analysis, they were able to correctly estimated sex between 82-89% of the individuals; however, they noted that the female-male deviation might need to be adjusted based on populations. Per the authors, if the discriminant functions employed in their paper are reused on other sample populations, results may not be entirely accurate.

Gonzalez (2012) retested the methods of Giles and Elliot (1963) on subadults by measuring lateral cephalometric radiographs housed at the Department of Orthodontics at the University of Michigan-School of Dentistry, an extensive and well-documented collection. The author examined 25 females and 25 males (n=50) randomly selected from a larger sample (47 males, 36 females, n=83) of individuals of European descent and ranging in age from 5-16 years. Gonzalez (2012) selected seven points: basion, bregma, glabella, nasion, opisthocranion, posterior nasal spine, prosthion, and sella (Figure 3). The author then took 20 of the 21 measurements, based off radiographs, on the seven points and employed canonical discriminant analysis, which provided linear combinations of the variables. Three of the 20 combinations were most statistically significant; these included: CAN1 (PNS-prosthion, PNS-nasion, nasion-prosthion, prosthion-sella, basion-nasion) which accounted for 87.3% of the total variation; CAN2 (sella-glabella, PNS-prosthion, bregma-opisthocranion, nasion-prosthion, prosthion-sella)

which accounted for 10.6% of the total variation; and CAN3 (basion-bregma, nasion-bregma, sella-glabella, bregma-opisthocranion, glabella-opisthocranion) which accounted for 4.8% of the total variation. Gonzalez concluded that there are detectable variations between the sexes. Gonzalez also noted that the dimensions for CAN3 are larger for males than for females, resulting in males having longer and taller crania compared to females.

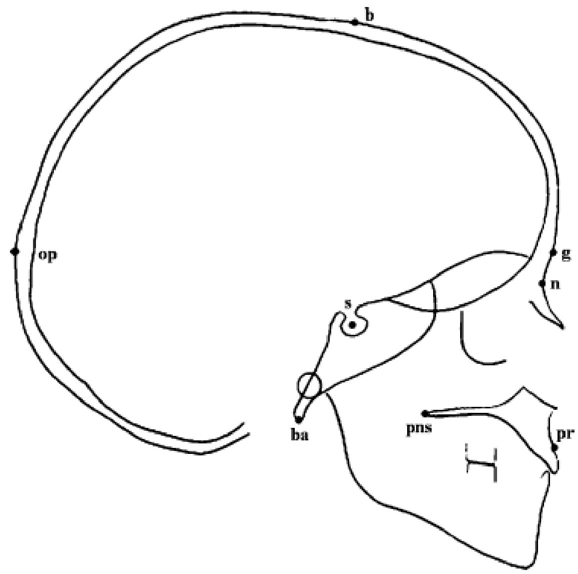


Figure 3. Cephalometric tracing with craniometric points. From 'Determination of sex from juvenile crania by Means of discriminant function analysis' by Gonzalez, 2012. *J Forensic Sci, 57(1).* doi: 10.1111/j.1556-4029.2011.01920.x. Reprinted with permission.

Occipital Bone

The occipital bone (Figure 4), located at the posterior-inferior aspect of the cranium, forms in four segments: the pars squama, the largest of the four sections; the pars lateralis, the two elements lateral to the foramen magnum; and the pars basilaris, the element anterior to the foramen magnum (Cunningham et al., 2017). These four elements begin to fuse during the 8^{th}-12^{th} week of gestation and continue to fuse until

approximately 5-7 years of age, with the pars basilaris being the last to fuse (Cunningham et al., 2017).

Sexually variable characteristics include the size of the occipital condyles and the foramen magnum, the degree of projection of the occipital protuberance, and the robusticity of the nuchal ridges. As aforementioned, males' features tend to be larger and more pronounced than females.

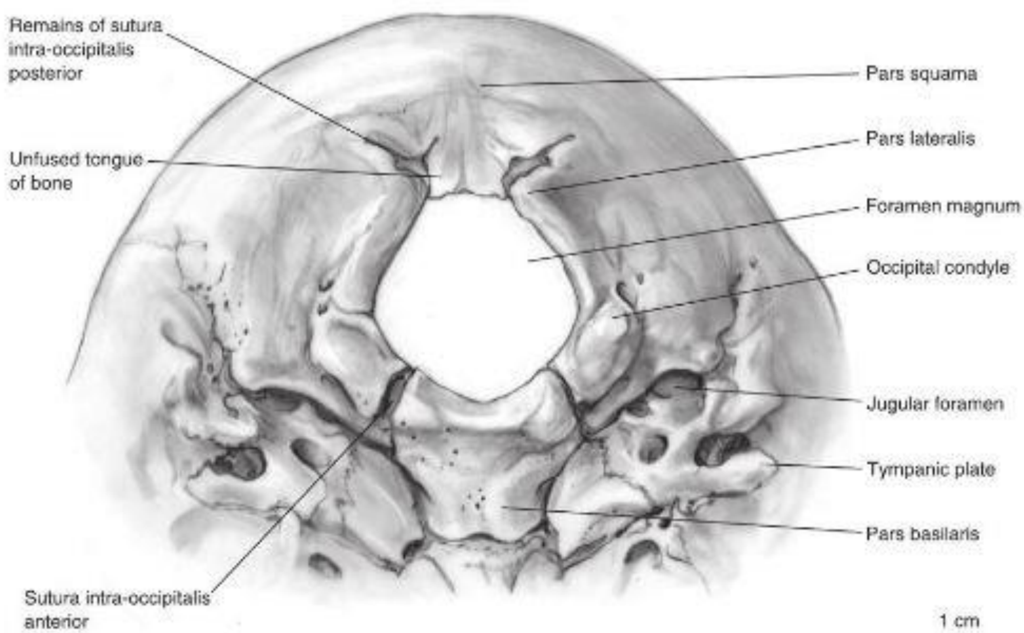


Figure 4. Occipital bone, exocranial. From *Developmental Juvenile Osteology* (p.65), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Reprinted with permission.

An early paper that mentioned the use of the adult occipital bone to assess skeletal sex was that of Holland (1986). The collection the author tested their methods was from the Robert J. Terry Anatomical Skeletal Collection. Holland (1986) included an equal number of adult females and males split into two sample groups (sample 1: n=100, 50 females, 50 males; sample 2: n=20, 10 females, 10 males), from 20 to 50 years old,

divided equally between ‘black’ and ‘white’ individuals. Holland (1986) took nine measurements, which included length and width of the occipital condyles, the minimum distance between the condyles, bicondylar breadth, maximum interior distance between condyles, length and width of foramen magnum, length of basilar process, and distance between the postcondyloid foramina. The author noted that this method works well for fragmented skulls, for which it is challenging to obtain cranial dimensions. Using a multiple linear regression for the analysis where 0 was male and 1 was female, with 0.5 as the sectioning point. Approximately 70-85% of the individuals were sexed accurately (Holland, 1986).

Veroni et al. (2009) tested Holland’s (1986) findings on a subadult skeletal sample of known age and sex at the Bocage Museum in Lisbon, Portugal. The Bocage Museum skeletal collection consisted of individuals born between 1805 and 1972 and derived from cemeteries in Lisbon (Cardoso, 2005). Ancestry is assumed to include individuals of Portuguese (European) descent. Sex was identified from biographic information with age either being given or identified through dental formation and eruption. Veroni et al. (2009) selected 17 females and 19 males (n=36) between 8-18 years of age. The five measurements observed were the foramen magnum length and breadth, occipital condyle length and breadth, and occipital bicondylar breadth. They accurately estimated sex 75.8% of the time (Veroni et al., 2009). Veroni et al. (2009) reported that males exhibited larger dimensions of the foramen magnum length and breadth and the left occipital condyle breadth exhibited the highest dimorphism between males and females.

Eye Orbits

Acsádi and Nemeskéri (1970) studied the morphology of the eye orbits with respect to sexual dimorphism in adults. For their study, individuals were identified as hyper-feminine, feminine, hyper-masculine, masculine, or indeterminate. Hyper-feminine was identified as -2 with a circular orbit and sharp margins. Feminine was identified as -1 and also with a circular orbit and sharp margins. Hypermasculine was identified as +2 with a square orbital shape and rounded edges. Masculine was identified as +1 with slightly square orbits and a round margin. Lastly, 0 was identified as indeterminate when an individual did not fit into any of these categories.

The scaled method as defined by Acsádi and Nemeskéri (1970) was implemented by Molleson and Cruse (1998) on two skeletal collections, the Coffin Plate Sample housed at the Christ Church in Spitalfields, London, England and the Wharram Percy from North Yorkshire, England. For the Coffin Plate Sample, individuals examined were from the 1700's to 1800's with the sex identified on the coffin plates. Molleson and Cruse (1998) examined both adults (34 females, 19 males, n=53) and subadults aged 1-14 years (n=20). The Wharram Percy Collection included individuals from 900 to 1500 CE. From this collection both adults (14 females, 14 males, n=28) were examined with sex being estimated based on the pelvis, and subadults ranging in age from 5 to 17 years old (n=57). Positive sex was not provided within this article for the subadult individuals from both of these collections. The results showed sex was estimated accurately in 90% of the adults and 75% of the subadults when combining observations for the eye orbit and the mandible (Molleson & Cruse, 1998).

Mandible

The mandible is the second bone to fully ossify, and does so during the 6th week of gestation, first forming as two separate pieces and then it fuses completely during the first year of life (Cunningham et al., 2017). Secondary sex characteristics often relate to differences in shape, including the shape of the dental arcade, the eversion of the gonion region, the protrusion of the chin, and the superior and lateral shape of the mandible (Cunningham et al., 2017). During childhood, the mental protuberance of the mandible (i.e., chin) is one of the fastest bones in the skeletal body to change morphologically due to incisal development and eruption (Coquerelle et al., 2011). These variations partly appear because males tend to have larger teeth than females, and males possess more angular and robust features of the gonion region and greater thickness of the anterior-posterior aspect of the mandible compared to females (Schutkowski, 1993; White et al., 2012). The mandible has been a method employed to estimate the sex of adult skeletal remains and select methods listed below have been retested on subadult mandibles.

Schutkowski (1993) tested morphological variation in 24 females and 37 males (n=61) subadults from the Coffin Plate Sample. The features observed were the protrusion of the mental protuberance (chin), the shape of the anterior dental arcade, and the eversion of the gonion region. Schutkowski (1993) concluded that the female chin was smooth with occasional narrowing or tapering of the chin while the male chin was more prominent with elevated rough structures lateral to the mandibular symphysis. The female anterior dental arcade exhibited a smooth U-shape without the canines protruding while males had a protrusion of the canines beyond the U-shape of the dental arcade

(Schutkowski, 1993). The author found that the eversion of the gonion region was smooth for females whereas it protrudes for males. The two features that exhibited the most sexual dimorphism were the gonion region and the chin, particularly for individuals between 0-5 years old. For the Coffin Plate sample, the females were correctly identified 60.0-92.3% of the time while males were identified correctly between 59.3-73.1% of the time (Schutkowski, 1993).

Molleson and Cruse (1998) examined the Coffin Plate Sample and also observed the mandibular angle and the mentum (mental prominence on either side of the mental fossae) and used Acsádi and Nemeskéri's (1970) scaling method. For the mandibular angle, -2 was classified as hyperfeminine with a smooth angle, -1 was feminine with weak eminences, and 0 was moderate eminences; +1 was masculine with marked eminences, and +2 was hypermasculine with strongly visible eminences. For the mentum, -2 was smooth and rounded, -1 was medial and slightly delimited, and 0 was medial and delimited. For the males, +1 had an inverted T-shape, with the eminences protruding, and +2 showed bilateral protuberances. The methods in the study had 78% accuracy for estimating subadult sex when including both the eye orbits and the mandible (Molleson & Cruse, 1998).

Loth and Henneberg (2001) studied the mandibles of 25 males and 27 females (n=62) from 0-19 years of age, of mixed 'race' from the Raymond A. Dart Collection at the University of Witwatersrand in Johannesburg, South Africa. Individuals were identified as 'black' or 'white' in the article (Loth & Henneberg, 2001), and it is noted that the individuals originated from Europe, Africa, and Asia (Dayal et al., 2009). Dayal

et al. (2009) noted that the individuals of this collection are from the mid-1800's to the late-1900's with sex being estimated through medical records and soft tissue inspection. Loth and Henneberg's (2001) observations of the mandible, from the superior aspect, focused on the varying features between females and males. Features consistent as female included the inferior portion appearing round, whereas a protruding chin that was more pointed or square would be considered male. The authors did three blind tests, with the first being taken by the senior author, which resulted in accuracy of 83.8% of the time for females and 100.0% for the males (89.4% combined). The other two tests were performed by two experienced osteologists as blind tests. The first osteologists' results were 66.7% of the time accurate for females and 100.0% of the time accurate for the males (78.9% combined) and the second osteologists' results were 66.7% of the time accurate for females and 85.7% accurate for males (73.7% combined). For all three tests, accuracy was low for ages above six years old (Loth & Henneberg, 2001). As Schutkowski (1993) noted, Loth and Henneberg (2001) also found that it is more difficult to estimate sex of females. Possible factors included the variance of hormones between males and females, environmental factors such as malnutrition and disease, and genetic conditions.

Sutter (2003) tested Schutkowski's (1993) methods for the mental protuberance of the mandible, the mandibular arcade shape, and the gonial eversion. The author tested these methods on a pre-Columbian skeletal sample, ranging from 1300 BCE to 1400 CE (Arriaza et al., 1988) from a northern Chilean population from the Atacama Desert Region. The mummies are currently housed at the Museo San Miguel de Azapa of the

Universidad de Tarapaca in Arica, Chile. The sex was determined through visual inspection of both internal and external organs by a team of pathologists. Subadult individuals ranged from 0-15 years old including 30 females and 55 males ($n=85$). The accuracy of these traits for estimating sex was 35.7% for females and 95.8% for males for mandibular protrusion, 53.6% for females and 91.7% for males for the mandibular arcade, and 64.3% for females and 60.4% for males for gonial eversion (Sutter, 2003). Sutter (2003) concluded that, although the traits did show some sexual dimorphism, the methods are not accurate on individuals less than two years old. Sutter (2003) further mentioned that although the prominence of the chin could potentially be used within bioarchaeology, the accuracy is too low to be used within forensics.

Franklin et al. (2006) studied 96 subadult mandibles from three different documented samples (Hamman-Todd Osteological Collection, Dart Collection, Coffin Plate Sample). The individuals ranged from 1-17 years old. They used a Microscribe G2X portable digitizer and Inscribe-32 software to examine 38 bilateral 3-dimensional landmarks while statistically analyzing the data using principal components analysis (PCA) and discriminant function analysis (DFA) with cross-validation using Genstat 8.10 and SPSS 13.0. The results indicated that, through PCA, 47.4% variance was found with a $p<0.001$. With DFA, males were estimated correctly 55% of the time while females were estimated correctly 65% of the time (59% overall). Looking at sexual dimorphism, only individuals between 15-17 years old showed substantial difference between the sexes ($p=0.061$); however, the result it did not reach the standard threshold of $p\leq0.05$

normally used to estimate statistical significance. Therefore, the final recommendation was that more research is needed, especially for individuals 10-17 years of age.

Coquerelle et al. (2011) examined the mandible of 84 females and 75 males (n=159) ranging in age from 0-25 years of age from Pellegrin Hospital in Bordeaux, the Necker Hospital in Paris, and the Clinique Pasteur in Toulouse, all in France. They studied CT scans from the hospitals with the use of the software Amira. It is unknown how ancestry, age, and sex were estimated, although it can be assumed these were a part of the hospitals' records of the individuals. The authors studied mandibular shape, dental mineralization, and size increase via 14 landmark points with the 3D software Edgewarp 3D. Coquerelle et al. (2011) noted that as individuals increase in age, sexual dimorphism decreases. For individuals between the ages of four to approximately 14 years, the study did not identify variation in shape between males and females. They concluded that the methods employed did not result in highly accurate estimates of biological sex; however, sexual dimorphism exists at birth and slows between ages four to 14 years, and males show more change in shape from the age of 14 to adulthood (Coquerelle et al., 2011).

Dentition

Deciduous dentition typically begins to erupt between 6-12 months of age. Deciduous dentition includes two incisors, one canine, and two molars per quadrant. Typically, the roots of the deciduous dentition are reabsorbed by the permanent dentition allowing the deciduous dentition to exfoliate from the mandible and maxillae, which allows the permanent dentition to erupt fully. There are cases where an individual may retain their deciduous dentition or may not have permanent dentition to take their place.

Most permanent teeth, besides the third molars (M3's), emerge by approximately 12-14 years old. The M3's begin to erupt starting at the age of 15 and typically no later than 35 years; however, agenesis and failure of eruption can occur, as can eruption before the age of 15 years (AlQahtani et al., 2010)

Hunt and Gleiser (1955) examined dentition and ossification to estimate the age and sex of subadult individuals. Data was taken on living children; however, the paper does not mention the sample collection definitively. Based on the article it appears the data derives from a previous paper by the authors (Gleiser & Hunt, 1955) which examined 25 males and 25 females (n=50) of ‘white’ individuals from Boston, MA. In order to estimate sex, age based on the bones and dentition was first required. Then, the authors examined the maturation of the first molars and hand bones via radiographs. Hunt and Gleiser (1955) noted that there is sexual variation between males and females which can be seen more clearly as an individual aged. However, estimating sex is still challenging, especially with subadult skeletal remains.

Garn et al. (1964) studied 243 subadult individuals (exact number per each sex was not provided) from the Fels Research Institute in Yellow Spring, Ohio. The study consisted of a middle class ‘white’ subadult population. The authors measured the mesiodistal crown diameters (Figure 5) of all permanent dentition (central and lateral incisors, canines, first and second premolars, first and second molars). They identified sexual dimorphism of 3% for the incisors and 6% for the canines and concluded that male dentition is larger than females (Garn et al.,1964).

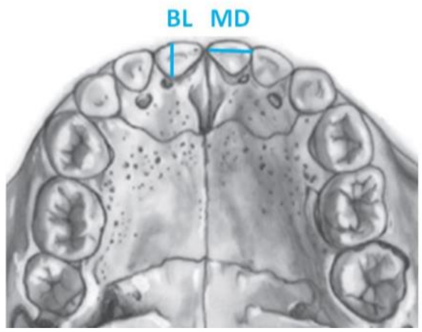


Figure 5. Occlusal view of maxillary dentition showing deciduous dentition with mesiodistal (MD) and buccolingual (BL) dimensions. From *Developmental Juvenile Osteology* (p.153), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Adapted with permission.

The same year, Bailit and Hunt (1964) published a study where they examined subadult radiographs of 25 males and 25 females (n=50) from 7-12 years old from the Forsyth Dental Center and the Children's Hospital Medical Center in Boston. Further information on the sample population is not given; however, it can be hypothesized that age, sex, and ancestry were provided through hospital records. The developmental stages were evaluated for the permanent dentition including the canines, first and second premolars, second molars, and third molars if present. Next, the age corresponding to the developmental stages were matched individually per each sex and the results indicated that sex was estimated accurately 58% of the time (Bailit & Hunt, 1964). However, when using the canine as an indication of age by examining the development, the individual’s sex was estimated accurately 70% of the time (Bailit & Hunt, 1964). When the age was known, the canines were used to identify the developmental age because the canines showed the most sexual dimorphism. The conclusion from this research is that the skeletal remains of those with an unknown age could not be sexed accurately based on the permanent dentition. However, if age was known, estimating the sex of subadult

skeletal remains can be achieved (Bailit & Hunt, 1964). It was mentioned that there had been previous studies that found canine roots to be longer in males; however, the authors were not able to ascertain this based on the radiographs. Both Garn et al. (1964) and Bailit and Hunt (1964) suggested that the Y-chromosome may influence the size of the dentition.

Black III (1978) examined deciduous dentition on a sample of 64 females and 69 males (n=133) from the School of Growth and Study at the University of Michigan. No further information on the sample population and collection were provided. The researcher focused on the right deciduous dentition and measured the mesiodistal and buccolingual dimensions (Figure 5) of all deciduous dentition (central and lateral incisors, canines, first and second molars). Using discriminant function analysis, they concluded that males have larger dentition but that sexual dimorphism in deciduous dentition was less than that observed in permanent dentition (Black III, 1978).

Mesiodistal and buccolingual crown dimensions (Figure 5) of the dentition were also measurement by Rösing (1983) on 28 males and 27 females (n=55) from the 6th and late 26th dynasty from Qubbet-el-Hawa, an ancient Egyptian cemetery near Asswan. Sex was either written or estimated through archaeological evidence or through analysis of the pelvis. Age was not discussed in this paper. The author examined the permanent right dentition (maxillary and mandibular) excluding the second molars and took mesiodistal and buccolingual dimensions, and crown and root height (excluding the crown height of the molars). Rösing (1983) concluded that the methods that produced 97% accuracy were four discriminant functions that included the first incisor and molar of the maxillae and

mandible, the first incisor and canine of the maxillae and mandible, the second incisor and canine of maxillae and mandible, and the first and second incisor and canine of maxillae and mandible. However, this study was on adult individuals with a hypothesis stating that this method could work on deciduous dentition (Rösing, 1983).

De Vito and Saunders (1990) examined deciduous dentition of 80 females and 82 males (n=162) from the Burlington Orthodontic Growth study in Ontario, Canada from a population derived from Burlington identified as ‘white’. Per the authors, the “growth study structure allowed control of such variables as…age and sex” (1990, p.846). The mesiodistal and buccolingual crown diameters were taken from casts of all deciduous dentition and all four permanent first molars, if present. The results indicated that the buccolingual dimensions of the maxillary dentition exhibited the most sexual dimorphism, in particular the first and second left incisors and the right mandibular canine. Through the use of discriminant function analysis, approximately 76-90% of the individuals were sexed correctly, verifying that dental metrics could potentially assist in estimating subadult sex (DeVito & Saunders, 1990). The methods listed From DeVito and Saunders (1990) were retested on a medieval population in Poland (Żadzińska et al., 2008) on 113 subadult skeletal remains with sex being verified by running a DNA sequence. Exact numbers of females and males were not provided in total; however, Table 2 (2008, p.180) identified the number of female and male examined per each tooth. The buccolingual and mesiodistal measurements of all deciduous dentition were obtained, and they concluded that 88% of the females were sexed correctly compared to only 66% of males.

Cardoso (2010) retested the metric methods as discussed by previous researchers (e.g., Black III, 1978; DeVito and Saunders, 1990; Żadzińska et al., 2008). The author examined deciduous dentition of a Portuguese population from the National Museum of Natural History in Lisbon, Portugal, including 26 females and 20 males (n=46) from 0-10 years of age. They measured the mesiodistal and buccolingual dimensions of the central and lateral incisors, canines, and first and second molars of the left maxillary and mandibular deciduous dentition. Using discriminant functions, the author obtained results ranging in accuracy from 33.3-75.0%, which was much lower than the aforementioned other researchers have noted (Cardoso, 2010).

Hassett (2011) examined the canines of 20 adults and five subadults of known sex based off the coffin plate information from the St. Bride's Church and 12 known sex individuals from the Chelsea Old Church, both in London, England with decedents ranging from the time period of the 1100’s to the 1800’s. No other information of the sample population was provided. The author used discriminant function analysis (DFA) to create a means of predicting sex in undocumented cases by using 12 known-sex individuals as the baseline. Hassett (2011) measured the mesiodistal and buccolingual cervical dimensions of the canines. The author concluded that 93.8-95.0% of the known-sex individuals were sexed correctly; however, the success in subadult sex estimation was derived from first estimating the sex of the adults in the sample and using that knowledge to estimate the sex of subadults (Hassett, 2011). Hassett (2011) was unsure if the results would be similar if retested on subadults without referencing adults from the same population.

Ilium

The ilium (Figure 6) forms the superior portion of the os coxae of the pelvis, and it is the largest of the three bones (ilium, ischium and pubis) that form the fully articulated os coxae (Cunningham et al., 2017). At birth, the three bones are held together by cartilage at the acetabulum, where the femur articulates. The cartilage begins to ossify at approximately nine years old and completely ossifies by approximately 15 years old. The ilium grows and develops quickly within the first four years of life, and then slows until puberty (Cunningham et al., 2017). The SOC's, or epiphyses, for the ilium are the anterior inferior iliac spine (AIIS), which forms separately at approximately twelve years of age and fuses to the ilium between 14-20 years old (Coqueugniot & Weaver, 2007). The iliac crest begins to ossify from two opposite centers; the anterior epiphysis, which includes a portion of the anterior superior iliac spine, and the posterior epiphysis, which includes the posterior superior iliac spine and a portion of the posterior portion of the crest. The fusion of the iliac crest begins between 12-17 years old and completely fuses by 23 years of age (Cunningham et al., 2017); once the two epiphyses meet in the center of the ilium, the iliac crest has been formed. The pelvis is one of the most studied bones of the human skeleton in terms of morphologic differences between female and male skeletal remains. These differences are due to the skeletal structural changes during puberty when the female os coxae widens (McKinley et al., 2015).

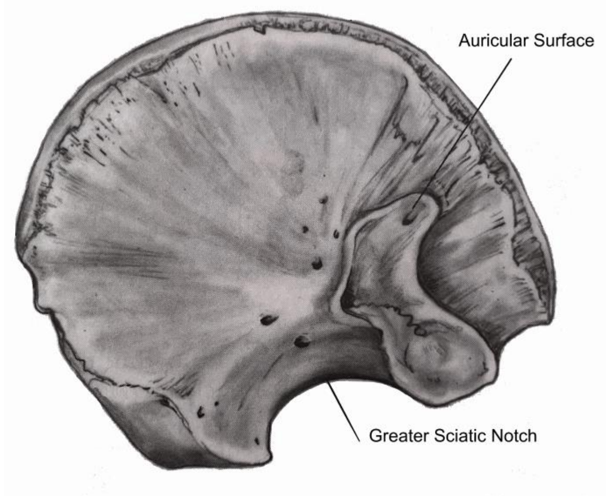


Figure 6. Unfused subadult ilium from the anterior proximal aspect. From *Developmental Juvenile Osteology* (p.363), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Reprinted with permission.

One of the earliest studies on the subadult pelvis was that of Thomson (1899). Thomson observed and described sex differences of the fetal pelvis, hardened in formalin and spirit, from the third month of intrauterine development. Information on the collection was not provided in this paper. The measurements the author took are the breadth and height of each bone and its features (i.e., iliac and ischial spines, ischial tuberosities, obturator foramen, pubic symphysis). It was concluded that differences between females and males were present (Thomson, 1899). The author did note some differences in growth and shape of the pelvis between females and males. For females, the pelvic inlet appeared more oval or elliptical which is distinctly noticeable as early as four months, while the male pelvis width grows faster, with the ilium more laterally flared, curved, and broader than the female (Thomson, 1899). Although the author did show variation between the sexes, it used wet, articulated fetal pelves, which differs from the dry bones normally observed in bioarchaeology and forensic anthropology.

Later research continued studying fetal remains, and accuracy in sex estimation was also achieved. Reynolds (1945, 1947) studied subadult radiographs (x-rays) of the pelvis in individuals aged from birth to 12 months old and noted some sexual dimorphism. The authors first article (1945) examined 46 males and 49 females (n=95) which included 467 sets of radiographs from the first postnatal year. These radiographs derived from SW central Ohio from the study on growth and development conducted by Samuel S. Fels Research Institute. The individuals' radiographs are taken at birth, then at 1, 3, 6, 9, and 12 months of age, resulting in at least 6 radiographs per individual. Due to these radiographs being taken in the hospital, it can be estimated that the sex of the individuals is accurate. The measurements taken included the pelvic height and breadth, inlet breadth, inter-iliac breadth, inter-public breadth, bi-ischial breadth, ilial length and breadth, pubis length, sagittal diameter of the inlet, ischial length, and breadth of the greater sciatic notch (Reynolds, 1945). From these measurements, indices were created. Females had a greater bi-ischial breadth and pubic length, a greater sciatic notch breadth, and a greater inlet breadth as determined by the anterior segment index (sagittal diameter of inlet/pelvis breadth x100) at birth and 1 month of age (Reynolds, 1945). Males had a greater pelvic height, iliac breadth, and ischio-iliac space (Reynolds, 1945). Later, Reynolds (1947) examined 640 posture radiographs taken of 92 males and 91 females (n=183) between 1-9.5 years of age from southwest Ohio. The author identified these individuals as 'white'. The measurements taken included the pelvic breadth and height, inlet breadth, inter-iliac breadth, inter pubic breadth, inter-tuberal breadth, ilial length, pubic length, sagittal diameter of the inlet, ischial length, breadth of iliac notch, inter-

obturator breadth, bi-trochanteric breadth, length of femoral neck pubic and pelvic angle, femoral angle, and femoral-pelvic angle. Reynolds (1947) concludes that the female measurements are larger than males at 34 months, with sexual dimorphism seen at 22 months of age. The author also noted that the measurements for females are more variable than males.

Boucher (1955, 1957) studied the fetal pelvis based on individuals six months of intrauterine age to birth and included the relationship with the femur and the joint attachment at the acetabulum (located at the cartilage that joins the ilium, ischium, and pubis). Preliminary results (1955) on an unidentified collection (possibly from the Anatomy department at the London Hospital Medical College) focused on 20 fetuses who reached 6 months *in utero*. Sex is noted as known but the methods used for this determination are not described (Boucher, 1955). Measurements were taken of the femur width, and the width and depth of the sciatic notch. The results indicated that there is no major difference between the sexes found by studying the ilia and the femur using an index (sciatic notch width/sciatic notch depth). However, the author noted metric differences of the greater sciatic notch between males and females, and indicated that females are quite larger than males, even in the small sample size. Later, Boucher (1957) examined a sample of both 'American black' (49 males, 47 females, n=96), 'American white' (19 males, 14 females, n=33) and British (46 males, 61 females, n=107) stillbirths from the Department of Anatomy at the Washington University School of Medicine. No other information on the individuals was provided in this paper. Boucher (1957) examined the subpubic angle, ischial and pubic lengths, crown rump length, maximum

length of the femur, and the sciatic notch based on their previous paper (Boucher, 1955). They found that for the subpubic angle, American 'black' females were larger than American 'black' males. They also found that that the sciatic notch index (width relative to depth), accurately sexed individuals 85.2% of the time for ‘black’ individuals, 84.5% of the time for British individuals, and 64.6% for American 'white' (Boucher, 1957).

Weaver (1980) examined the Hrdlicka Collections at the Smithsonian Institution observing subadult skeletons of 71 females and 82 males (n=153) ranging from 6-month fetal age to 6-month postnatal age. Although the author mentions that ancestry is known for this collection, the information is not provided for the individuals selected for this study. Weaver (1980) used both metric and nonmetric methods to examine the auricular surface and sciatic notch of fetal and infant ilia. The six measurements taken were of the sciatic notch width and depth, the ilial anterior length and posterior length (with the midpoint being the anterior portion of the auricular surface), and the iliac height and width. The nonmetric method observed the features of the auricular surface, specifically the sacro-iliac surface. If this surface was elevated on both the anterior and posterior aspects, the individual was identified as female, and if it was not elevated, the individual was identified as male (Weaver, 1980). The author’s results indicated that the sciatic notch showed little sexual variation while the ilia showed some variation at the 6-month age group (Weaver, 1980). The morphology of the auricular surface was shown to estimate the sex of fetal and infant skeletal remains with 57.5% of females being sexed accurately 57.5% and 87.5% of males being sexed accurately (73.5% combined) (Weaver, 1980). Weaver (1980) concluded that this study showed that "determination of

sex of infant skeletal remains may eventually be based on criteria which are very similar to those widely used in sexing adult skeletal remains" (Weaver, 1980, p.195).

Weaver's (1980) method of the auricular surface morphology was retested by Hunt (1990) on three age groups (fetal, newborn, and 6-months postnatal age) (n=275) on a sample population of indigenous American individuals from three Arikara sites in South Dakota housed at the Department of Anthropology, University of Tennessee, Knoxville, Tennessee. Descriptions of how sex was posited was not included in this paper. Along with the auricular surface morphology, Hunt (1990) examined the ilia and its association with the femur's diaphyseal length (as an index), following the research done by Boucher (1955, 1957). Based on the auricular surface morphology, the author noted that the distribution between raised and non-raised is "unbalanced" (1980, p.884) and is more due to locomotion than to sex. Hunt (1990) concluded no statistically significant results were found in any of the indices for the ilial and femur measurements and that is the tested methods are more accurate for estimating age than sex.

Mittler and Sheridan (1991) tested Weaver's (1980) method of the morphologic variation of the auricular surface on a mummified sample from a site in Nubia (Southern Egypt to Northern Sudan) from approximately 550 CE to 1450 CE. The individuals age ranged from 0-18 years old (n=58) with biological sex being identified through the preserved external genitalia and with age being previously determined. The males were sexed correctly 85.3% of the time while the females were sexed correctly 58.3% of the time (Mittler & Sheridan, 1991). Mittler and Sheridan (1991) stated that individuals between the ages 0-9 year cannot be sexed accurately based off auricular surface

morphology only; however, for subadults 10 years and older there is a "greater than 99% probability that an individual with an elevated auricular surface is female" (Mittler & Sheridan, 1991, p.1073). This contradicts Hunt (1990) who concluded that the older an individual becomes, the more difficult it is to estimate sex based on the auricular morphology.

Schutkowski’s (1993) study of ilia focused on infants and juveniles ranging from 0-11 years old from the Coffin Plate Sample. The author examined 37 males and 24 females (n=61) and noted that individuals that are over the age of five years are underrepresented. The morphologic features of the ilia studied included the angle and depth of the greater sciatic notch, the arch criterion (located on the posterior aspect where the sacrum articulates with the ilium), and the curvature of the iliac crest. This paper indicated that: sex for the greater sciatic notch angle was estimated correctly 95.2% of the time for females and 71.4% of the time for males; for the greater sciatic notch depth was accurate 86.7% of the time for females and 68.4% for males; for the arch criteria it was accurate 60.0% of the time for females and 81.5% for males; and for the curve of the iliac crest it was accurate 85.7% of the time for females and 54.2% of the time for males (Schutkowski, 1993). The author concluded that the results of this study indicated that it is possible to include sex estimations of subadults in observations of historic populations.

Schutkowski’s (1993) work was quickly retested on subadult populations in France and Portugal including 32 males and 22 females (n=54) from 0 to 16 years of age (Majó et al., 1993). The individuals derived from the collection at Coimbra in Portugal and from the collections at the Museum of Man in Paris. The authors noted the age and

sex is known but did not identify the techniques used. The measurements included were the maximum width and height of the ilium, and the depth and width of the greater sciatic notch. Majó et al. (1993) concluded that 42.1% of individuals were accurately sexed from the Coimbra population and 68.2% from the Museum of Man population. The results were markedly lower than Schutkowski (1993). Majó et al. (1993) concluded that Schutkowski's method was unreliable for estimating subadult sex from skeletal remains.

Sutter (2003) tested both Weaver’s (1980) and Schutkowski’s (1993) methods on a pre-Columbian sample from Chile ranging from 1300 BCE to 1400 CE (Arriaza et al., 1988) from a northern Chilean population from the Atacama Desert Region. The individuals ranged in age from 0-9 years old (30 females, 55 males, n=85). The eight ilial traits they tested were the angle and depth of the sciatic notch, the arch criteria, the ilial curvature, and the auricular elevation (Schutkowski, 1993; Weaver, 1980). Sutter (2003) noted that sex-related differences were found in many of the traits proposed by Weaver (2008) and Schutkowski (1993), except for the auricular surface (accuracy: 60.9% females, 75.7% males). The results indicated that the arch criteria was accurate for 82.4% of females and 81.4% of males, the angle of the sciatic notch was accurate for 68.0% of females and 89.0% of males, the depth of the sciatic notch was accurate for 64.0% of females and 89.5% of males, and the iliac crest was accurate for 37.2% of females and 77.1% of males (Sutter, 2003). When looking at individuals from 0-5 years old, 81.5% of individuals were sexed accurately based on the sciatic notch depth and arch criteria (Sutter, 2003). Sutter (2003) concluded that these methods would work, especially the

sciatic notch, in bioarchaeological contexts; however, the author questioned if the traits were population specific due to the variation in age and sex.

Vlak et al. (2008) also retested Schutkowski's (1993) methods on a Portuguese subadult population from the Bocage Museum in Lisbon on 23 females and 33 males (n=56) born between 1805 and 1972. The methods the authors retested included the greater sciatic notch angle, breadth, and depth, and ilial maximum length and breadth. Vlak et al. (2008) compared their results to those of the original researcher (Schutkowski, 1993) and Sutter (2003) and concluded that there was little to no sexual dimorphism between females and males in the traits studied -- even though some statistical significance was found for some of the traits (e.g. notch breadth p=0.009). The results indicated that 52.5% of females and 54.5% of males were sexed accurately (53.6% combined) for the greater sciatic notch width and 43.5% of females and 69.7% of males sexed accurately for the greater sciatic notch depth (59.8% combined) (Vlak et al., 2008). However, Vlak et al. (2008) recommended more research needs to occur due to the correlation between pelvic features and age.

Holcomb and Konigsberg (1995) examined the fetal sciatic notch from photographs of the ventral aspect of the left ilium of 55 females, 72 males, and five individuals of unknown sex (n=133) ranging from 16-58 weeks *in utero*. The remains derived from the Trotter Collection of Washington University. Estimates of ancestry or explanation of how sex was identified was not discussed in the article. The photographs were digitized and trace coordinates were produced on the greater sciatic notch. The authors reported that 60% of females were sexed correctly via the methods employed

(Holcomb & Konigsberg 1995). The authors also reported that the fetal males were more dimorphic anteriorly, whereas, the females were more dimorphic with the greater sciatic notch posteriorly located. They concluded that, although some sexual dimorphism was found, it did not reach the same level as adults (Holcomb & Konigsberg 1995).

A more recent method adapted Phenice’s (1969) method, which is the basis of a popular current method applied to estimate sex of the adult skeleton, towards subadults skeletal remains (Klales & Burns, 2017). Klales and Burns (2017) used radiographs from the PATRICIA Radiographic Data Bank of an ancestrally diverse modern population of American subadults that were born after 1990. Information on the collection derives from coroners and medical examiners from throughout the United States. The authors examined 185 males and 149 females (n=334) ranging from 1-20.5 years old. The feature tested was the subpubic concavity, which was adapted for use with subadult skeletal remains. In conclusion, 75% of the individuals were sexed accurately, with the highest accuracy found for ages 12.6-20.5 years (Klales & Burns, 2017). The younger an individual was, the less accurate the method became. Klales and Burns (2017) recommend retesting this method on dry bones and not on radiographs due to the potential for inaccuracies when examining radiographs.

Wilson et al. (2008) examined the ilia from the Coffin Plate Sample. Their study focused on subadults ranging in age from birth to 7.88 years old (8 females, 17 males, n=25). Images of the ventral aspect of the ilium were taken and examined with respect to the shape of greater sciatic notch, the curve of the iliac crest, the upper and lower plane of the iliac crest, and the auricular surface morphology. The results indicated a 25-100%

range of accuracy with the highest (100%) found for the male greater sciatic notch shape and the lowest (25%) for the females' upper and lower planes of the curvature of the iliac crest (Wilson et al., 2008). However, it must be noted the ages selected to reach the 100% accuracy were not provided, so it is assumed that all ages were incorporated for each sex to receive this level of accuracy (Wilson et al., 2008). Wilson et al. (2008) noted that more testing of this technique should be done on different, larger, and more diverse samples.

The ilium has been repeatedly studied with varied results depending on the collections observed and methodologies used. When retesting methods, results may have been potentially influenced by observational error, especially those retested by numerous researchers. As many suggested, more studies on larger and more diverse sample populations need to be conducted in order to produce data that can be relatively reliable across populations and time periods.

Long Bones

The long bones discussed in this thesis included the largest of the bones of the appendicular skeleton (i.e., femur, tibia, fibula, humerus, ulna, and radius). The limbs start as primary ossification centers at the nutrient foramen of the diaphysis (Figure 7) and then grow longitudinally and appositionally from this point (Cunningham et al., 2017). At birth, the diaphysis exhibits minimal features. The secondary ossification centers begin to appear after the first year of life and appear/fuse at different times throughout skeletal growth and development. For example, the distal epiphyses of the radius begin to ossify (develop) between 1-2 years of age, while the distal epiphysis of

the ulna develops between 5-7 years of age (Cunningham et al., 2017). Some researchers suggested the length and breadth of the long bones can be used to estimate the sex of subadult remains (Stull et al., 2017).

Figure 7. Diaphysis of right humerus. From *Developmental Juvenile Osteology* (p.291), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Reprinted with permission.

Sawtell (1928) studied radiographs focusing on bone growth of subadults (n=112) from New York City from 0-8 years of age, from 102 females and 133 males (n=235) from Cleveland, Ohio, and from 28 Sicilian infants from the lower east side of New York. The radiographs for the New York samples were provided by the Bureau of Educational Experiments by John C. Gebhardt of the Association for Improving Conditions of the Poor, whereas the Ohio sample derived from the School of Medicine in Western Reserve University with the measurements coming from Prof. T. Wingate Todd's laboratory. Sawtell (1928) noted that these groups are "of varied racial composition, social environment, and nutrition" (1926, p.294). The author stated that, with respect to the radius, the breadth and length of head and diaphyseal length were

greater in males than in females, whereas average lengths of long bones are greater in females than in males (Sawtell, 1928).

Gindhart (1973) studied the growth rate of the tibia and radius in subadults from 0-18 years old in 2,634 females and 3,150 males (n=5,784). The sample derived from the Fels Research Institute for the Study of Human Development with all individuals being of European descent. The author took measurements of the length of the diaphysis based on radiographs. For adolescent individuals (i.e. before 19 years), little variation was noted between male and female tibiae, whereas the radii showed some sexual dimorphism (Gindhart, 1973).

Rogers (2009) examined the distal humerus of 22 females and 20 males (n=42) from 11-20 years of age from the Coffin Plate Sample and the Luis Lopes Skeletal Collection in Portugal. Ancestry was not identified for this collection. The distal epiphyses needed to be fused to the diaphysis in order for this method to be applied. For this method the author examined the features on the posterior surface of the distal humerus focusing on the trochlear constriction (slight for males and very constricted in a 'bow-tie' shape for females), trochlear symmetry (asymmetrical for males, more symmetrical for females), olecranon fossa depth and shape (shallow triangle for males and deep oval for females), and the angle of the medial condyle (parallel to the surface for males and raised posteriorly for females) (Rogers, 2009). The results showed that, overall, the sex of 81% of individuals (82% for females, 80% for males) was accurately estimated based off the non-metric methods for the distal humerus (Rogers, 2009).

Rogers (2009) concluded that more tests on a large sample size need to occur to test this methods' efficacy.

Stull and colleagues (2013, 2017) have reported one of the most recent and accurate methods by examining subadult diaphyses to estimate sex. The first article (Stull et al., 2013) examined the humerus and femur of infants between 0-1 year of age by studying radiographs of 36 females and 49 males (n=85) from the Erie County Medical Examiner's Office in New York with the biological profile being known (age, sex, ancestry, stature, etc.). The authors took two measurements of the femur (maximum length and breadth at the midshaft) and four measurements for the humerus (maximum length, maximum proximal, distal, and midshaft breadth). The results were fairly accurate, estimating the sex accurately 78% of the time using a logistic regression model for the femur for individuals between 20-29 weeks old while accuracy for individuals ranging in age from 0-30+ weeks old ranged from 50%-90% (Stull et al., 2013). The authors noted that when compared to a known sample, and sex of individuals less than 1 year of age can be estimate via metric analysis of the humerus and femur (Stull et al., 2013).

A subsequent paper (Stull et al., 2017) examined the diaphyseal dimensions through radiographs of the long bones including the humerus, radius, ulna, femur, tibia, and fibula. The radiographs derived from Lodox Statscan from South Africa, originally taken at the Red Cross War Memorial Children's hospital and included 506 females and 804 males (n=1310) between 0-12 years old. It is assumed that age and sex were acquired through records of the hospital, although this information is not noted. Eighteen

measurements of the diaphyseal length and breadth were taken (see methods section for detail), and multiple statically methods were employed when analyzing the data (linear discriminant analysis, flexible discriminant analysis, and logistic regression). The range in accuracy was 49-75% for all single variables (Stull et al., 2017). For the multiple variable subsets, the accuracy rose to 70-93%, with the use of flexible discriminant analysis for all the measurements (distal breadth, proximal breadth, mid-shaft breadth, diaphyseal length) of as the combined variables that resulted in the highest accuracy (93% overall, 90% for females, 95% for males; logistic regression for the same combination resulted in accuracy of 90% overall, 82% for females, and 95% for males) (Stull et al., 2017). The lowest accuracy (70% overall, 74% for males, 68% for females) was obtained by using the statistical model of linear discriminant analysis for the femoral distal breadth, tibial proximal breadth, tibial midshaft breadth, tibial distal breadth, femoral midshaft breadth, and fibular diaphyseal length (Stull et al., 2017). Stull et al. (2017) noted that multiple variable models provided the highest accuracies, with flexible discriminant analysis and logistic regression providing a higher rate of accuracy than linear discriminant analysis which is typically used within biological anthropology when testing statistical accuracy within a sample (Smith, 2018).

Tarsals

The two tarsals observed in this thesis were the talus and calcaneus (Figure 8). The talus links the foot and leg, articulating with the tibia and fibula, and bears the majority of the body’s weight and has no muscular attachments (Cunningham et al., 2017). Ossification of the talus begins during the seventh month of intrauterine

development and the epiphyses develop starting at two years postnatal (Cunningham et al., 2017). By 8-11 years old, the talus is fully ossified and the epiphyses are fully fused. The calcaneus, or heel bone, is the largest tarsal. The calcaneus is the first tarsal to begin ossification, appearing between the fourth to sixth months of fetal life and having two growth centers that fuse before birth (Cunningham et al., 2017). The calcaneus changes substantially during the first few years of life with the posterior epiphysis ossifying during the fifth year and the separate skeletal elements completely fusing between 8-10 years old. Tarsals have shown sexual dimorphism and have been tested to verify if they can accurately estimate sex.

Figure 8. Right calcaneus (left) and talus (right). From *Developmental Juvenile Osteology* (p.454,456), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Reprinted with permission.

Steele (1976) studied tarsals within the Terry Skeletal Collection in Washington D.C. that has records for each individual identifying the age, sex, ‘race’, and stature, and that has photographs of the decedents. The sample consisted of 30 'black' females, 30 'white' females, 30 'black' males, and 30 'white' males (n=120). The measurements were

restricted to the talus and calcaneus. They included the maximum width and length of the calcaneus, calcaneal body height, load arm length and width of talus, talar body height, and maximum length and width of the talar trochlea (Steele, 1976). The author employed discriminant function analysis to examine the data collected and through this statistical method was able to conclude that 79-89% of individuals were sexed correctly. The body height and load arm width of the calcaneus attaining the lowest accuracy (79%), and the maximum length and width of the talus resulted in 89% accuracy (Steele, 1976).

Although sexual dimorphism was observed for multivariate models, there was substantial overlap between the sexes and thus a single dimension does not provide enough statistical significance to accurately estimate sex (Steele, 1976).

Other Elements of Research

In addition to what has been discussed thus far in this thesis, researchers have reported numerous other methods for estimating sex from skeletal remains. Although a detailed discussion is beyond the scope of this thesis, a few have been selected and are discussed here in brief.

Case and Ross (2006) focused their research on the hands and feet. They examined the Terry Anatomical Collection to gather data on 171 females and 171 males (n=342) from 18-72 years old. The measurements taken were the lengths of the metacarpals, metatarsals, all hand phalanges, and the proximal pedal phalanges. Through discriminant function analysis on all 19 bones, sex was correctly classified 80% of the time (Case & Ross, 2006). The authors noted that more research needs to be done

because the epiphyses are notably impacted by activity throughout life (Case & Ross, 2006).

Osipov et al. (2013) examined the bony labyrinth of the inner ear to understand if this area could provide any accuracy in estimating sex of adult decedents. They studied individuals exhumed from St. Konstantinos and Pateles cemeteries in Heraklion, Crete This was done through a study population, allowed by the local district attorney, of individuals from 1867-1998 (Kranioti et al., 2008). Kranioti et al. (2008) noted that the age and cause of death were acquired from the Heraklion City Hall records and sex was “obvious from the names written on the boxes" (2008, p.110.e2) There were 45 females and 49 males (n=94) examined from these two sites, ranging from 19-97 years old. CT-scans of 53 of the skulls and 62 skulls were obtained with a Siemens SOMATOM Sensation 16. From there, measurements were taken of the height and width of the semicircular canals and basal turn of the cochlea (Osipov et al., 2013). The measurements and indices were analyzed with results indicating 76-84% accuracy for sex estimation, with the highest accuracy stemming from the posterior semicircular canal (Osipov et al., 2013).

In conclusion, the study of estimating sex of subadult skeletal remains has been extensive in both adapting methods originally used to estimate sex in adults (e.g., Acsádi & Nemeskéri, 1970) and in identifying new methods specific for subadult decedents (e.g., Stull et al., 2017). Although the range in accuracies reported for the reviewed studies varied from 42.1-100% (Majó et al., 1993; Wilson et al., 2008) the average was around 70%, which provided a rough benchmark for future research with the specific elements

and methods resulting an accuracy of 70% or higher. Many methods have been discussed in this literature review, however only a few were selected to be retested for this thesis based on the results of previous studies, as discussed in the methods section that follows.

METHODS

Sexually dimorphic features, even in adults, are challenging to estimate as female or male when targeting a singular criterion (Keen, 1950). Many methods rely on dichotomized traits, but because sexual expression in the skeleton occurs on a spectrum, such methods are not easily employed. Furthermore, traits associated with one sex can be present in another. Therefore, for this thesis it was decided to test multiple methods and features to evaluate their accuracy in estimating the sex of subadult decedents and to discover which skeletal element(s) are most useful for this task. The elements studied included the skull (with emphasis on the mandible, occipital bone, parietal bone, and eye orbits), dentition, ilium, humerus, radius, ulna, femur, tibia, fibula, talus, and calcaneus. These elements were observed for morphological variation and measured for statistical analysis. All the data (i.e., measured and observed) were taken according to the directions given in the articles in which the methods were described. This section of the thesis details the methods employed; however, for further clarification of the methods and measurement, please refer to the original authors' papers and methods.

Materials

The skeletal collection selected for this thesis was the Hamann-Todd Osteological Collection (HT) because the sample population differs from the original papers defining or testing the methods used for this thesis. The individuals included in the study ranged from 3-17 years old and included 14 males and 25 females (n=39) (Table 1). The individuals were identified in the collection as 'black' and 'white' and will be referred to

as such in this thesis to stay transparent against the HT Collection's database. These terms are marked with ‘direct quotes’ in recognition that these are socially-derived ‘race’ categories labeled by the collection. Overall, there are more ‘black’ individuals than ‘white’ (33 ‘black’, 6 ‘white’), likely a reflection of the marginalization of individuals based on skin color that is associated with disproportionate targeting for collections (please refer to the introduction). As discussed in the introduction to this thesis, ancestry is uncertain but likely included individuals of at least partial African-American and European/European-American descent (Dupertuis & Hadden, 1951). Because ancestry is uncertain and ‘race’ is an inappropriate substitute, and because this thesis focused on sex, ‘race’ and potential ancestry were not factored into the data collection and statistical analysis and data on ‘race’ is only provided for informational purposes.

Table 1. List of individuals examined for this study from the Hamann-Todd Osteological Collection; organized by age, male or female, and ‘black’ or ‘white’.

Age (years)	**‘White’ Female**	**‘Black’ Female**	**‘White’ Male**	**‘Black’ Male**	**TOTAL**
3	0	1	0	1	2
4	0	2	0	1	3
5	0	2	0	0	2
6	0	1	0	2	3
7	1	0	0	0	1
8	0	3	0	1	4
9	0	0	0	0	0
10	0	1	0	3	4
11	0	1	0	1	2
12	3	0	0	0	3
13	0	1	0	0	1
14	0	1	0	0	1
15	0	0	0	1	1
16	1	3	0	0	4
17	1	3	0	4	8
TOTAL	6	19	0	14	**39**

As discussed in the introduction, some individuals had growth abnormalities, such as bowed limbs, or other variances which are discussed below; therefore, some individuals and measurements were excluded. In addition to removing individuals from the HT Collection, an individual examined, from the Hamann-Todd Decimal Collection (HTD 0.207), was also removed from the sample due to possible skeletal pathology and because little to no research has been found pertaining to the Decimal Collection on if the origins of the individuals within this collection are the same as the HT Collection. Therefore, no individuals from the Decimal Collection were included.

Another aspect in need of minor discussion is the state of the crania of the collection. The vast majority of the skulls were bisected either in a midsagittal plane (Figure 9) or in a midtransverse plane from mid-frontal to above the occipital protuberance (Figure 10) in order for Hamann and Todd to remove the brain for study. This made it difficult to obtain all the cranial measurements as proposed by Gonzalez (2012). Therefore, not all measurements were obtained for each decedent, which reduced the sample size per each measurement.

Figure 9. Anterior aspect of cranium, decedent 0548. Taken by: Dorota Zabnicka.

Figure 10. Lateral aspect of cranium, decedent 0404. Image taken by Dorota Zabnicka.

Age Estimation

Age, as indicated by the HT Collection, was crosschecked by observing dental eruption using Ubelaker et al.'s (1979) method to ensure there were no major errors in the ages recorded within the collection. It was decided that this was sufficient enough to verify age because there was extensive documentation of each individual within the collection. The method outlined by Ubelaker et al (1979) is based on the development and eruption of dentition, both deciduous and permanent. From this scale, eruption begins at three-to-seven month’s intrauterine age when the deciduous dentition form prior to eruption and ends when all permanent dentition have fully erupted. This method also indicated the approximate age of each tooth starts to erupt, plus or minus a few months to a couple years. Although there is variation in dental eruption timeline based on ancestry,

population, and nutrition, this method allowed verification of whether the individuals were consistent with the age indicated in the records.

For only one individual, HTH 2135, the crosschecked age based on the dentition did not match the collections' database. The records stated that this individual was 14 years old at the time of death. However, all observed epiphyses were fused and all permanent teeth were fully erupted (Figure 11), including all the third molars (M3’s). According to AlQahtani and colleagues (2010), an individual’s M3’s may begin to erupt by the age of 15 years and usually fully erupt at the age of 23 years, although they can erupt earlier, later, or not at all. If an individual's M3's have fully erupted, the age can be estimated to be 17 years or older (source). The recorded age of 14 could have been reduced from the actual age by this individual to receive medical care (Yarrow, 2009), or it could have been a records error. It is unknown at this time. For this thesis, it was decided to not include the individual in this research.

Figure 11. Decedent 2135, superior mandible. Taken by: Dorota Zabnicka.

For all other individuals, the age indicated in the collection records was in line with the age estimate obtained via the method outlined by Ubelaker et al. (1979). It was therefore determined that no other method, such as estimating age based on epiphyseal union, to estimate age was required.

Methods of Sex Estimation

The methods to estimate sex that were tested within this thesis included those that provided high percentages of accuracy in their original studies and those who have been retested with useful levels of accuracy. These methods are discussed in more detail in this section. For each method, a description followed by figures and tables outlines how the information was gathered and what tools were used.

Dentition

Black III (1978) noted in their research that males have larger dentition than females. Based on their research and recommendations, it was decided to examine left and right maxillary and mandibular first and second incisors and canines of deciduous and permanent dentition of all four quadrants (maximum 12 teeth, 24 measurements per individual) (Figure 12). The measurements were of the buccolingual (BL) (from the most lateral to most medial aspect) and mesiodistal (MD) (from the most anterior to most posterior aspect) dimensions and were taken with sliding calipers (Black III, 1978; DeVito & Saunders, 1990). Each measurement was taken at the widest part of the crown per the recommendations. Measurements were taken of both loose teeth and of teeth that were still articulated in the mandible and maxillae. Although some teeth still in the crypt

were challenging to measure, the majority of individuals were missing dentition on either side of the tooth of interest or there was enough room to obtain the full measurements. Teeth that could not be reliably measured due to inaccessibility, damage (e.g. chipping, tooth decay), or were missing were excluded. Each tooth was measured three times, and the averages of each measurement were analyzed.

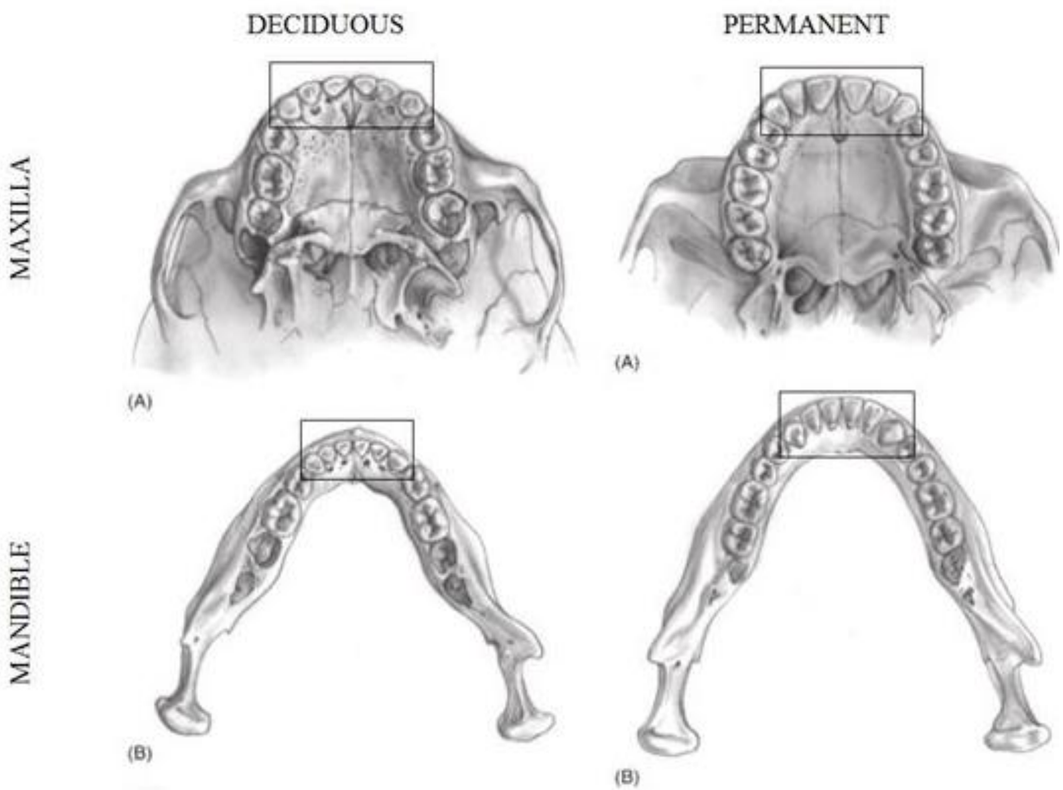


Figure 12. Deciduous (left) and permanent (right) dentition; maxillary (A) and mandibular (B). From *Developmental Juvenile Osteology* (p.155), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Adapted with permission.

Mandible

The first examination of the mandible followed Schutkowski's (1993) method, which observed three features viewed from the superior aspect of the mandible. These

included the protrusion of the chin (Figure 13A), the shape of the anterior aspect of the dental arcade (Figure 13B), and the eversion of the gonial region (Figure 13C).

For the protrusion of the chin (Figure 13A), females were defined as not having a prominent chin (e.g. the chin is flatter looking at the chin laterally), having no noticeable elevation lateral to the mandibular symphysis, having a smooth surface, and the superior aspect of the mandible appeared faint, narrow, and with slight tapering anterior to the coronoid process of the mandible on the interior surface of the body (Schutkowski, 1993). Males were defined as having a more prominent protrusion of the chin (a more defined chin while looking at the mandible laterally) with slight elevations and rough structures laterally, and shallow indentations lateral to the mandibular symphysis; from the superior view, the chin appeared wide and angular (Schutkowski, 1993).

Observations of the dental arcade focused on the degree to which the canines protruded the shape of the mandibular dentition (Figure 13B) and the overall shape of the dentition as viewed from the superior aspect. Females had canines that were in line with the mandible in a parabolic shape, Males had canines that protruded beyond the shape of the mandible with the mandible appearing to have a U-shape.

For the eversion of the gonial region (Figure 13C) as viewed from the superior aspect of the mandible, females were seen as having the lateral aspect of the mandible, anterior to the condyles on the exterior surface of the mandible, with a moderate eversion or flaring and the ramus not undulated where the body and ramus articulate on the exterior lateral surface of the mandible. For males, they were identified as having a mandible that was flared or everted on the lateral aspect of the mandible, at the point

where the body and ramus meet, on the exterior lateral aspect of the mandible (almost a direct line inferior to the coronoid process) and the area undulated (Table 2).

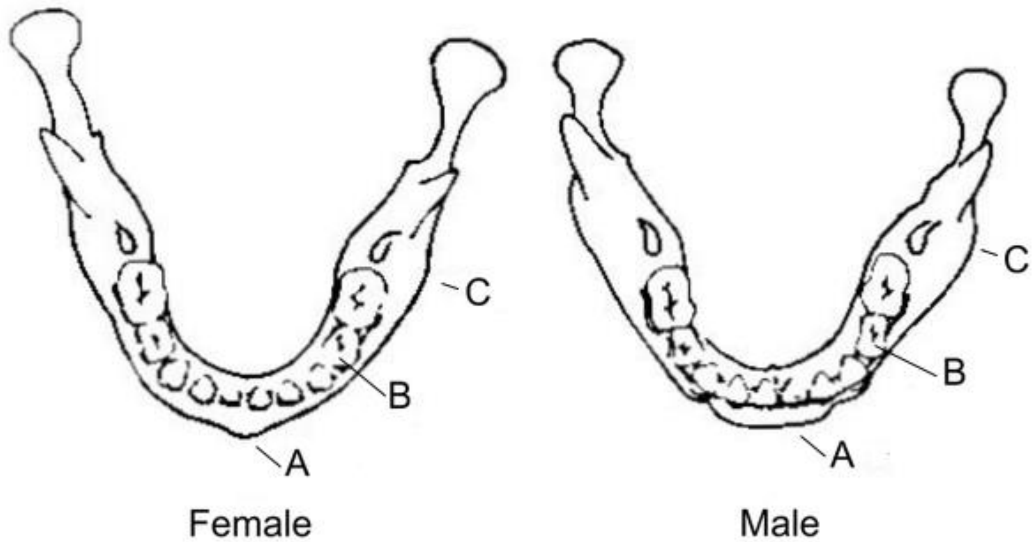


Figure 13. Superior mandible; female (left) and male (right) mandible from the superior view, exhibiting the three features; A) protrusion of chin; B) shape of anterior dental arcade; C) eversion of gonion region. From 'Sex determination of infant and juvenile skeletons: I. morphognostic features' (p.200). by Schutkowski, 1993. *Am J Phys Anthropol 90.* Reprinted with permission.

Table 2. Information taken from Schutkowski (1993, 200) showing the variation of the three features between male and female mandibles.

Feature	Female	Male
Protrusion of Chin	Not prominent; no distinct elevation lateral to mandibular symphysis; smooth surface; from superior view appears faint, narrow, tapers sometimes.	More prominent; slight elevation lateral to mandibular symphysis; rough structures lateral to mandibular symphysis; shallow indentations distal to rough structures; wide & angular chin from superior view.
Shape of Anterior Dental Arcade	Dentition conform to round shape with all teeth in line; parabolic shape.	Canines protrude dental line, U-shape.
Eversion of Gonion Region	Ramus and corpus of mandible are smooth & aligned.	Gonion areas everted; slightly protruding laterally (not turned but jutting out compared to the surface surround it).

The second method, as described by Loth and Henneberg (2001), observed the mandible from the superior (Figure 14) and anterior (Figure 15) aspects focusing on the angle and shape of the mandibular corpus (or body). Females were defined as having a more rounded mandibular shape with an inferior round outline and a gradual transition from the mandibular symphysis to the ramus. In contrast, males were more pointed with a sharp, angular transition from the mandibular symphysis to the ramus. Table 3 describes the specific differences.

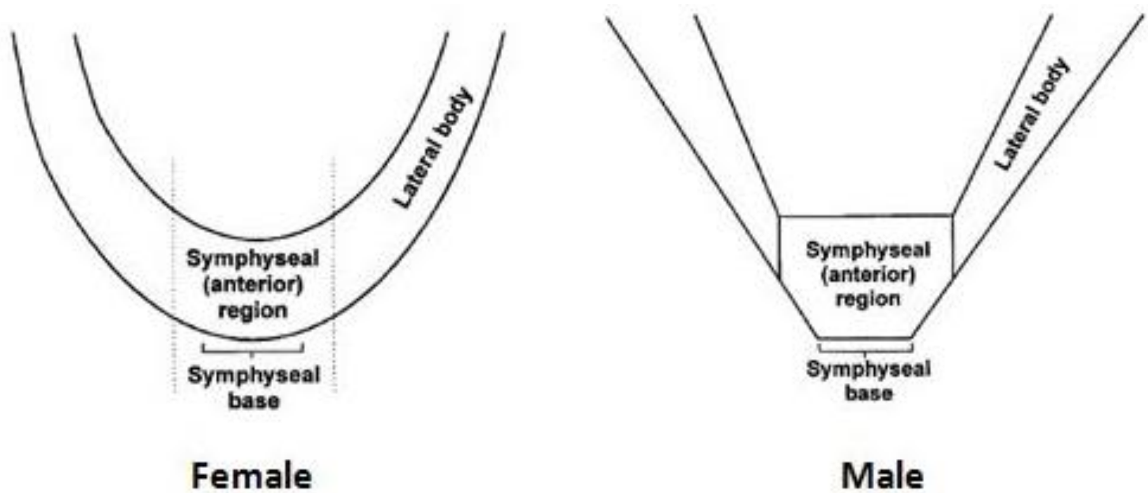


Figure 14. Superior mandible, exhibiting mandibular shape between females (left) and males (right). From 'Sexually dimorphic mandibular shape in the first few years of life' (p.181), by Loth & Henneberg, 2001, *Am J Phys Anthropol, 115.* Reprinted with permission.

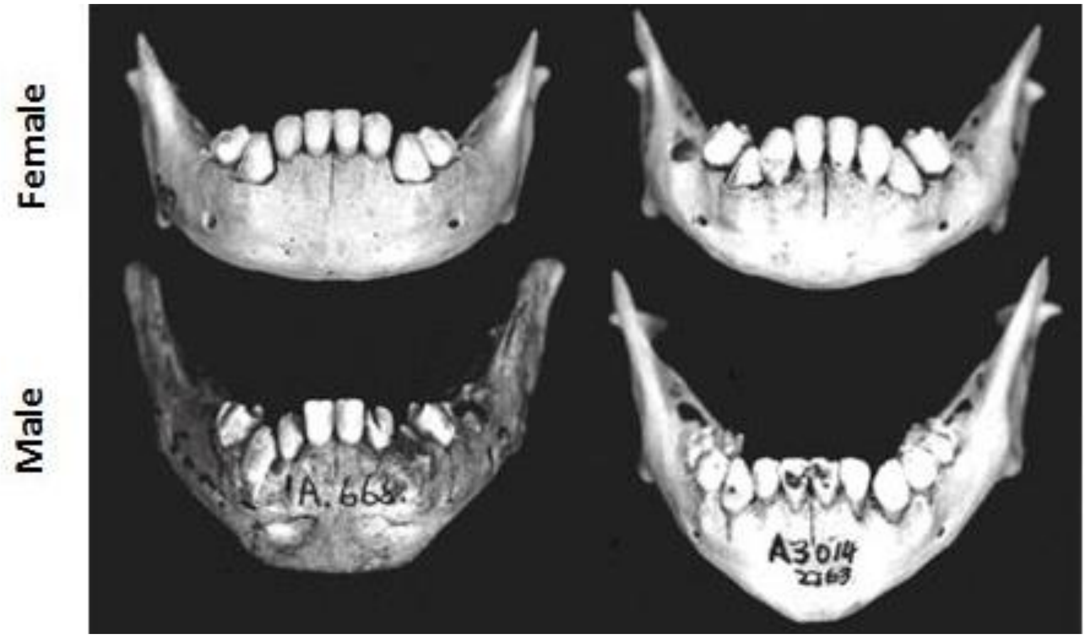


Figure 15. Anterior mandible; exhibits mandibular shape. From 'Sexually dimorphic mandibular morphology in the first few years of life' (p.182), by Loth & Henneberg, 2001, *Am J Phys Anthropol, 115.* Reprinted with permission.

Table 3. Variation between mandibular shape taken from Loth & Henneberg (2001, 182).

Sex	Symphyseal Base	Body shape
Female (more varied results)	Rounded	Curved, round inferior outline; gradual transition from mandibular symphysis to ramus.
Male (less varied results)	Pointed	Sharp; angular transition from mandibular symphysis to ramus.

The final method tested for the mandible observed the lateral aspect of the mandible, including the variation in shape which could be altered based on the gonial angle, ramus, and mentum (Molleson & Cruse, 1998). The authors employed a scaling system were -1 and -2 are feminine and hyperfeminine, respectively, and +1 and +2 were masculine and hypermasculine, respectively, and 0 indicates that the sex was indeterminate. For feminine mandibles, the authors identified that the gonial angle had an even curve, a straight posterior border, a smooth outline, and a moderate angle. The

feminine mentum exhibited a smooth curved outline and weakly developed tubercles that were wide apart, and the mental triangle was narrow and close to the symphysis, which did not protrude in lateral view. Hyperfeminine mandibles exhibited an underdeveloped angle with weakly developed tubercles that were wide apart on the mentum (Molleson & Cruse, 1998). For a masculine mandible, the ascending ramus appeared to have a wider (open, hinged) angle; it may have appeared to have a rugosity or thickening of the bone at the gonial angle. Molleson and Cruse (1998) identified that the masculine mentum had a squared outline with distinct tubercles and a mental triangle that was delimited and appeared to be broad, prominent, and protruding from the lateral view. For hypermasculine mandibles, the lower border of the angle extended the outline abruptly downward with the mentum not being fully developed (Molleson & Cruse, 1998). Figures 16 and 17 provide images of the variation in morphology between males and females and Table 4 describes the variation.

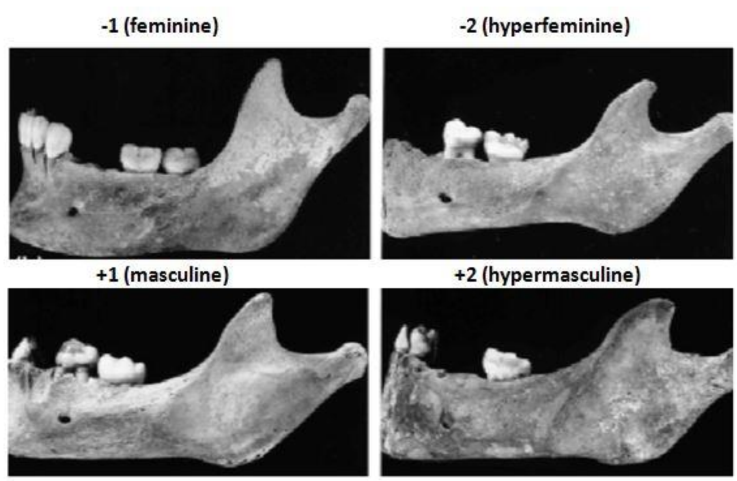


Figure 16. Lateral mandible, variation in mandibular angle. From 'Some sexually dimorphic features of the human juvenile skull and their value in sex determination in immature skeletal remains' (p.721), by Molleson & Cruse, 1998, *J Archaeological Sci 25.* Adapted with permission.

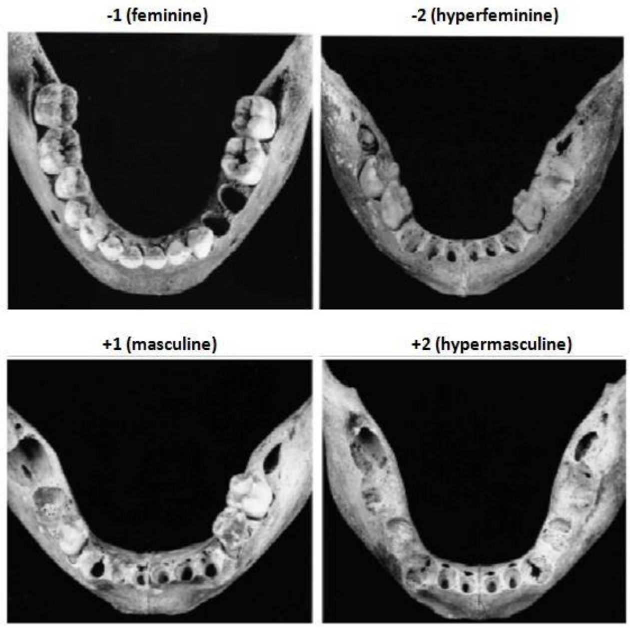


Figure 17. Superior mandible, Variation in mentum. From 'Some sexually dimorphic features of the human juvenile skull and their value in sex determination in immature skeletal remains' (p.721), by Molleson & Cruse, 1998, *J Archaeological Sci 25.* Adapted with permission.

Table 4. Specific differences between mandibles of males and females based on the scores provided by Molleson & Cruse (1998, 720, 723).

Score	Angle	Mentum
-2	Angle under-developed.	Smooth curve; tubercles are weakly developed and wide apart.
-1	Even curve of gonial angle; smooth outline; moderate angle even; straight posterior border.	Smooth curved outline; tubercles weakly developed & wide apart; mental triangle narrow & close to symphysis; does not protrude in lateral view.
0	Indeterminate.	Indeterminate.
+1	Ascending ramus hinged; open angle; potential rugosity/thickening of bone at gonial angle.	Squared outline; distinct tubercles; mental triangle delimited; broad & prominent; protruding in lateral view.
+2	Lower border extends outline abruptly downward.	Tubercles are pronounced and wide apart.

Cranium

The methods reevaluated in regards to the cranium derived from Gonzalez (2012) and Giles and Elliot (1963) which employed both sliding and spreading calipers to obtain

the measurements. For Gonzalez (2012) only six of the seven points were used, with the point labeled “sella” being excluded because it was difficult to measure with consistency on skeletal remains due to the endocranial location of this point (Gonzalez, 2012, p.25). Therefore, only 14 of the 20 dimensions were taken, including: the glabella-opisthocranion (GOL), nasion-opisthocranion (NOL), nasion-bregma (NBL), bregma-opisthocranion (BOL), opisthocranion-basion (OBL), basion-bregma (BBL), basion-prosthion (BPL), basion-nasion (BNL), nasion-prosthion (NPL), posterior nasal spine (PNS)-basion (PBL), PNS-prosthion (PPL), PNS-nasion (PNL), opisthocranion-prosthion (OPL), and prosthion-bregma (PBL). The exact placement for these points matches those described by Langley et al. (2016) and are explained in Table 5 and shown in Figure 3 (see Literature Review section).

Table 5. Cranial landmarks taken from Langley et al. (2016) on the location of six points, with the posterior nasal spine (PNS) taken from Gonzalez (2012).

Measurement	Location
Opisthocranion (Op)	The furthest point on the posterior aspect of cranium.
Glabella (G)	Anterior aspect of the cranium, on the frontal bone between the brow ridges and slightly above.
Nasion (N)	Anterior aspect of the cranium at the superior aspect of the nasal suture, where the nasal bone meets the frontal bone.
Bregma (B)	At the superior aspect of the cranium at the posterior.
Basion (Ba)	The inferior posterior aspect of the cranium located at the center of the foramen magnum of the occipital bone of the pars basilaris.
Prosthion (Pr)	Located at the anterior aspect of the cranium at the inferior point where the maxillae meet.
Posterior Nasal Spine (PNS)	The most posterior point of the palatine bone where the palatine bones meet.

Giles and Elliot (1963) also measured the maximum width, nasal breadth, maximum bi-zygomatic diameter, and opisthion to forehead length. Please refer to Table

5 for details about the specific points listed above (i.e., glabella, prosthion, and nasion) and Langley et al. (2016). The remaining cranial measurements are listed in Table 6 along with how to obtain the measurements as described by Giles and Elliot (1963).

Table 6. Measurements for methods as defined by Giles and Elliot (1963).

Measurement	Location
Maximum Width	Maximum width of most lateral aspect of cranium.
Nasal Breadth	Maximum distance from most lateral aspects of nasal aperture.
Maximum bi-zygomatic diameter	Maximum distance of the zygomatic bones from the superior view.
Opisthion to forehead length	Maximum distance from opisthion point to the most anterior point of the forehead (frontal bone).

<u>Occipital</u>

The foramen magnum and occipital condyles, as per Veroni et al. (2009) and Holland (1986), were measured using sliding calipers. The five measurements included: the foramen magnum length (FML) and breadth (FMB) which are the maximum distances of the foramen magnum; the occipital condyle length (OCL) and breadth (OCB) which include the maximum dimensions of both the left and right occipital condyles; and the occipital bicondylar breadth (BCB) which is the maximum distance from the most lateral aspect of each occipital condyle (Figure 18).

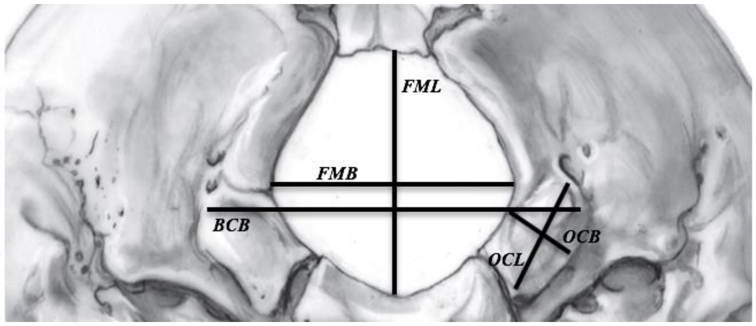


Figure 18. Measurements of the occipital bone at the foramen magnum and occipital condyles From *Developmental Juvenile Osteology* (p.65), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Adapted with permission.

<u>Temporal</u>

Measurements of the mastoid length were also taken as proposed by Giles and Elliot (1963). Each measurement was taken using sliding calipers from the superior aspect of the external acoustic meatus to the inferior aspect of the mastoid process (Figure 19) with the cranium in Frankfurt Horizontal position and calipers perpendicular to the cranium.

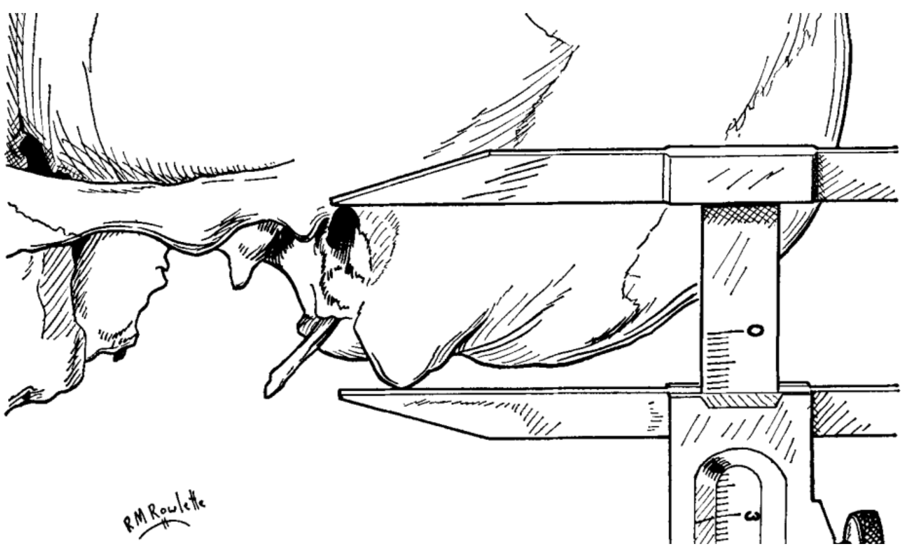


Figure 19. Lateral left cranium, exhibiting how to take mastoid process measurement. From 'Sex determination by discriminant function analysis of crania', (p.58), by Giles & Elliot, 1963, *Am J Phys Anthropol, 21.* Reprinted with permission.

Eye Orbits

Table 7 identifies the parameters used to estimate the sex of a decedent based on the morphology of the eye orbits (Molleson & Cruse, 1998). The cranium was viewed from the anterior aspect with the face in a vertical position (Figure 20). This method employed a scoring system where -1 was feminine, -2 was hyperfeminine, +1 was masculine, +2 was hypermasculine, and 0 was intermediate.

For a feminine individual, the eye orbits had sharp margins with a thin rim and a deep-set roof. The lateral and vertical planes were symmetrical, and the supraorbital margin did not interrupt the face when looking at the skull with the anterior side facing the observers' shoulder, rotated slightly to the side. For a hyper-feminine individual, the individual exhibited very sharp margins/rims with a circular, symmetrical orbit and the lateral portions of the roof appeared deep-set (Figure 20).

For a masculine individual, the eye orbits had an asymmetrical outline with slight round margins and a slight square appearance. The rim appeared thickened with the lateral portions bulging slightly and the side view did not interrupt the face (Figure 20). Observations consistent with a hyper-masculine individual included the eye orbits exhibiting a square shape with rounded edges. If an individual did not fit the parameters for masculine, feminine, or hyper-masculine/feminine, then the individual was identified as indeterminate.

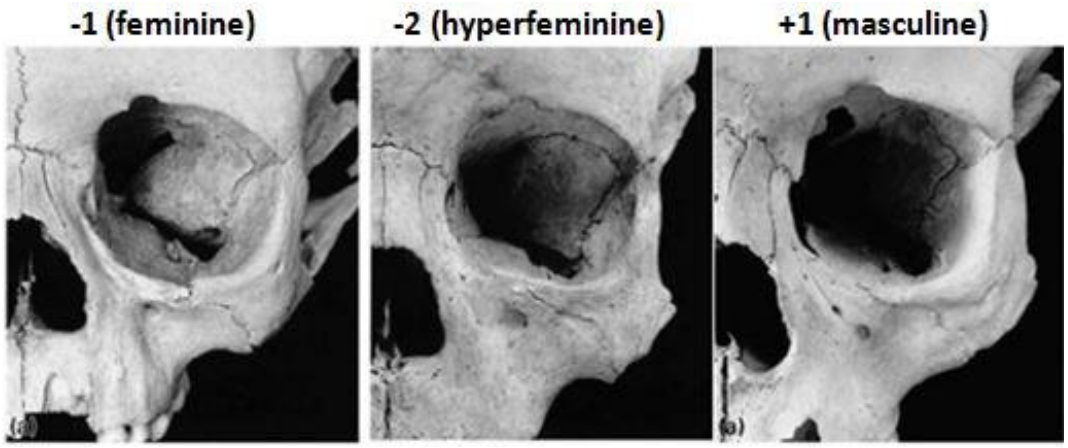


Figure 20. Anterior skull; variation of eye orbit morphology from feminine (left) to masculine (right). From 'Some sexually dimorphic features of the human juvenile skull and their value in sex determination in immature skeletal remains' (p.721, 722), by Molleson & Cruse, 1998, *J Archaeological Sci 25.* Adapted with permission.

Table 7. Represents variations in eye orbit morphology in males and females per score as noted in Molleson & Cruse (1998, p.720).

Score	Feature
-2	Very sharp margins/rims, circular, symmetrical, lateral portion of roof deep-set.
-1	Sharp margins, thin rim, deep-set roof, lateral and vertical planes symmetrical, orbit does not interrupt face when looking at the side.
0	Indeterminate.
+1	Asymmetrical outline, slightly rounded margins, slightly square, thickened rim, lateral portion of margin may bulge slightly, side view does interrupt face.
+2	Rounded edge, square.

Ilium

The methods for the ilium were only applied when the body of the ilium was not fused to other elements in the pelvis (i.e., iliac crest, pubis, ischium) and consisted of nonmetric and metric methods, using sliding calipers to gather the metric data. The nonmetric methods tested for the ilium were those established by Schutkowski (1993). The three observations were the arch criteria, the angle of the greater sciatic notch, and

the curve of the iliac crest (Figure 21). It was decided not to include the nonmetric assessment of the depth of the grater sciatic notch since the depth was measured.

The arch criterion (Figure 21Ab) was observed as a curved line that begins at the inferior point of the greater sciatic notch, inferior to the auricular surface, and extends to the auricular surface. If this curved line passed through the auricular surface then the individual was considered likely female. If the line ran alongside the auricular surface, eventually merging with the spina limitans, the individual was identified as male (Schutkowski, 1993). The greater sciatic notch (Figure 21Aa) was examined by placing the corner of a piece of paper within the greater sciatic notch to estimate the angle. If the angle appeared to be 90° or less, the individual was identified as male, whereas if it was over 90°, the individual was classified as female. The curve of the iliac crest (Figure 21B) was evaluated by placing the ilium on a flat surface with the gluteal surface inferior and pelvic surface superior. Looking at the pelvis, at eye level, with the iliac crest facing the observer, a curve was seen (Figure 21B). If the curve was a faint S-shape, the individual was identified as likely female, and if there was a distinct S-shape, the individual was identified as likely male.

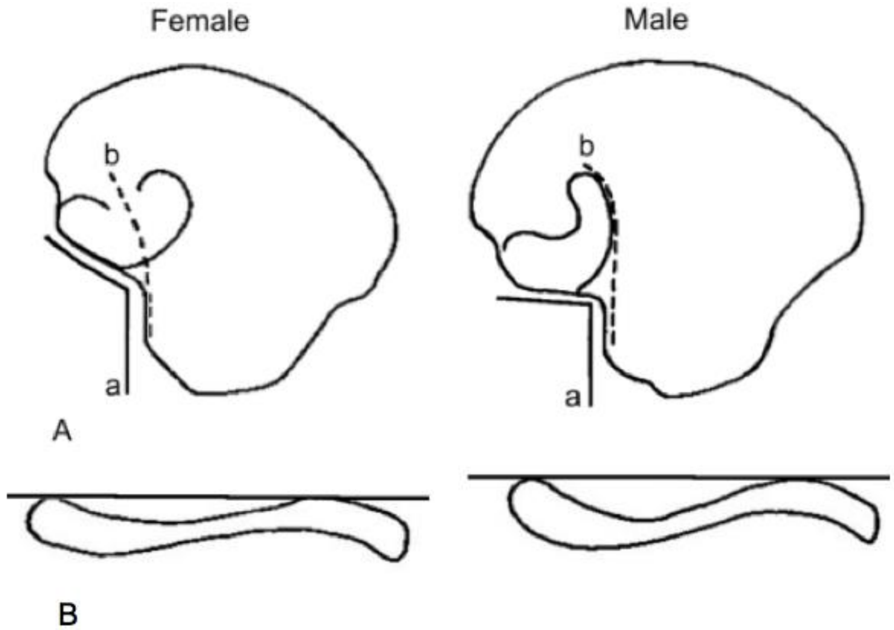
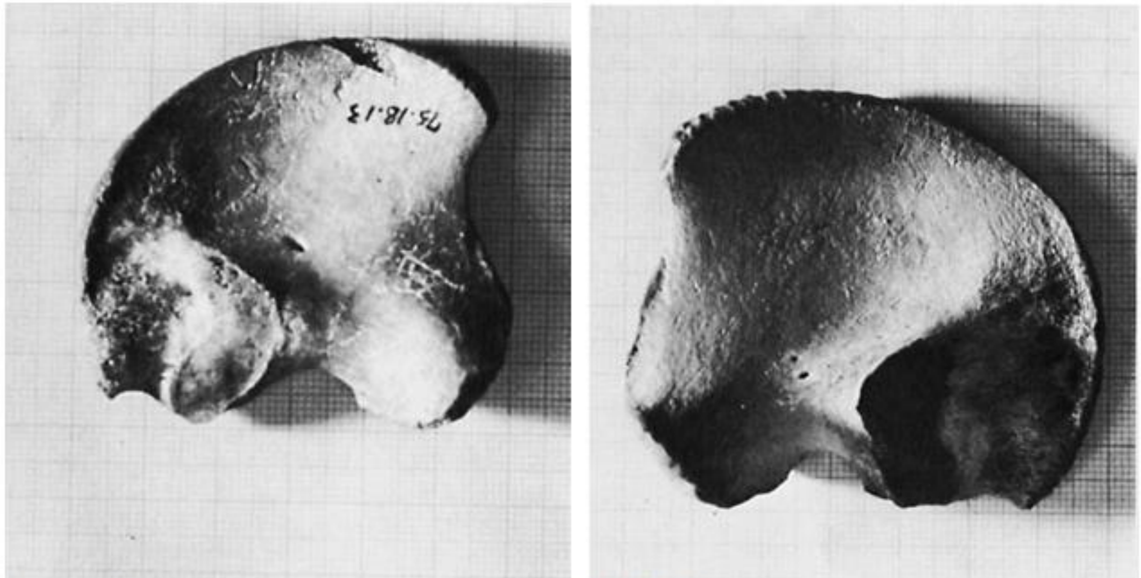


Figure 21. Ilial morphology, females (left) and males (right), greater sciatic notch(angle Aa), arch criteria (Ab), curve of the iliac crest (B). From 'Sex determination of infant and juvenile skeletons: I. morphognostic features' (p.201). by Schutkowski, 1993. *Am J Phys Anthropol 90.* Reprinted with permission.

The final non-metric method applied to the ilium was observing the auricular surface (Weaver, 1980). Observing the auricular surface with this portion facing superiorly and the gluteal surface placed on the table, if the surface was elevated along the anterior and posterior edge and the entire length, the auricular surface was considered elevated, whereas if there was no elevation, the surface was considered not elevated. An elevated surface was identified as female and a non-elevated surface was identified as male. Figure 22 exhibits this, taken from Weaver (1980, p.193).



A) Female B) Male

Figure 22. Image of female (left) and male (right) auricular surface morphology. From 'Sex differences in the ilia of a known sex and age sample of fetal and infant skeletons. (p.193), by Weaver, 1980, *Am J Phys Anthropol 52.*Reprinted with permission.

The metric methods tested were those of Weaver (1980) that Vlak et al. (2008) retested and redefined. The measurements of the ilium (Weaver, 1980; Vlak et al., 2008) were taken with sliding calipers and included the maximum breadth and maximum length (Figure 23A), the breadth and depth of the greater sciatic notch (Figure 23B), and the anterior and posterior lengths (Figure 24). The maximum breadth and lengths were taken at the most maximum points of the ilium. The greater sciatic notch breadth was measured as the maximum breadth of the greater sciatic notch. The depth was taken by placing the ilium on a flat surface (e.g., table) with both the superior and inferior spines of the greater sciatic notch touching the surface of the table and measuring the depth from the greater sciatic notch to the table (Figure 24B). The anterior length (AL) extended from the furthest point of the anterior superior iliac spine to the auricular surface, and the posterior

length (PL) extended from that same point on the auricular surface used to measure AL to the most posterior aspect of the ilium (Figure 24).

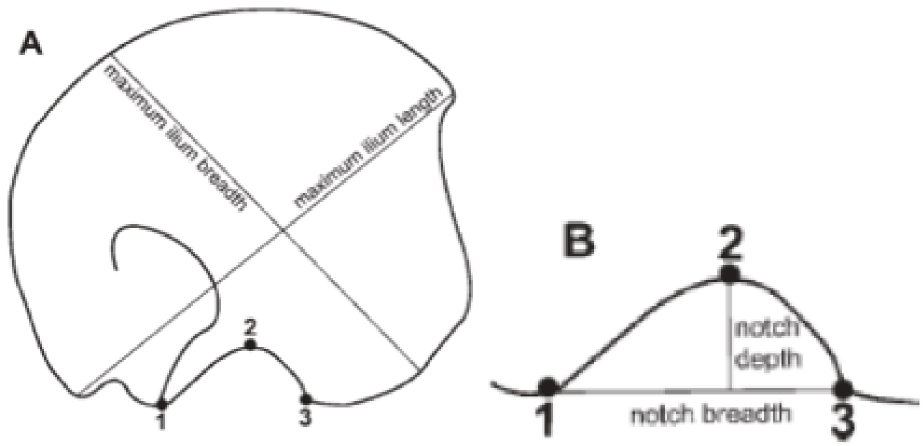


Figure 23. Ventral surface of ilium measurements; maximum ilial length and breadth (A), greater sciatic notch depth and breadth (B). From 'Greater sciatic notch as a sex indicator in juveniles' (p.311), by Vlak et al., 2008, *Am J Phys Anthropol 137.* Reprinted with permission.

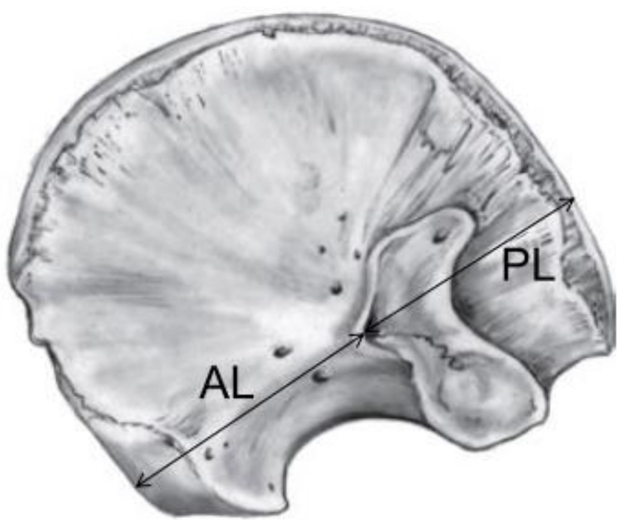


Figure 24. Ventral surface of ilium; anterior length (AL) and posterior length (PL). From *Developmental Juvenile Osteology* (p.363), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Adapted with permission.

Long Bones

The long bones examined included the humerus, radius, ulna, femur, tibia, and fibula, focusing on the diaphysis. The measurements were taken from the left elements; however, if the left were not present, then the right elements were examined. Only the diaphysis was measured; therefore, no measurements were obtained if the epiphyses were partially or fully fused. Measurements were taken with an osteometric board for the diaphyseal length and sliding calipers for the breadth measurements.

The measurements, following Stull et al. (2017), included the humeral diaphyseal length, humeral proximal breadth, humeral distal breadth, humeral midshaft breadth, ulnar diaphyseal length, ulnar midshaft breadth, radial diaphyseal length, radial proximal breadth, radial distal breadth, radial midshaft breadth, femoral diaphyseal length, femoral distal breadth, femoral midshaft breadth, tibial diaphyseal length, tibial proximal breadth, tibial distal breadth, tibial midshaft breadth, and fibular diaphyseal breadth. Figure 25 shows an example of these measurements exhibited on the humerus.

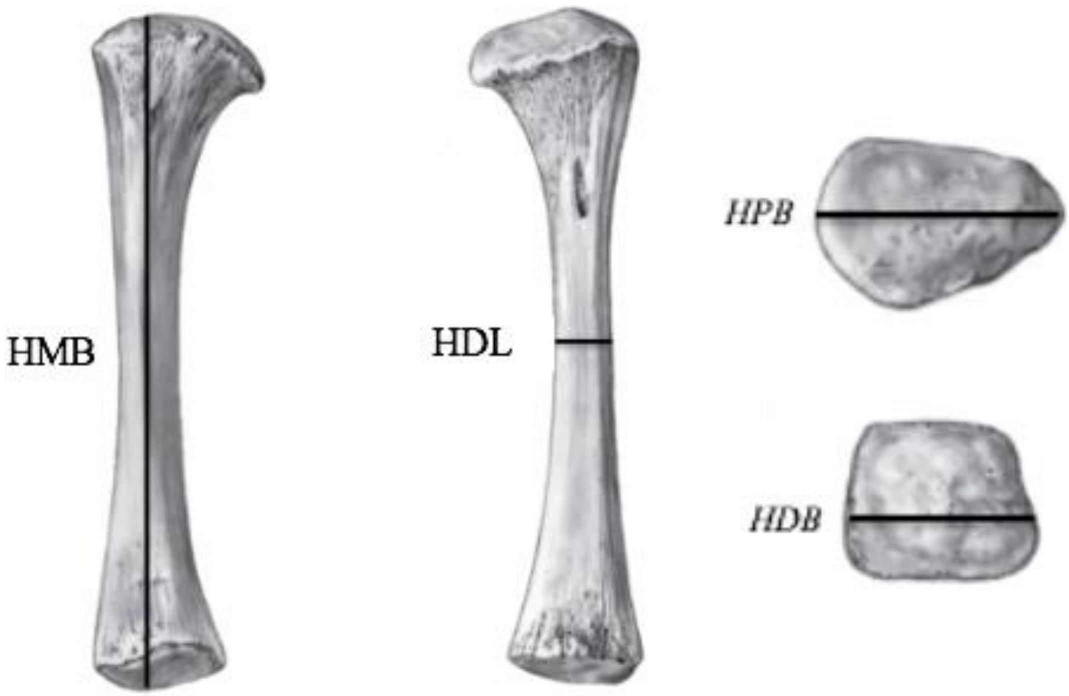


Figure 25. Humerus; anterior aspect (left); posterior aspect (right). Dimensions include: diaphyseal length (HDL), proximal breadth (HPB), distal breadth (HDB), & midshaft breadth (HMB) (H = humerus). From *Developmental Juvenile Osteology* (p.394), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Adapted with permission.

Tarsals

The two tarsals examined were the calcaneus and talus, which were measured using sliding calipers. Measurements of the calcaneus included (Figure 26a, Table 8): the minimum width (MW), anterior to the tuberosity and posterior to the talar facet; the body height (BH), which is the inferior aspect of tuberosity to superior point of talar facet; the load arm length (LAL), measured from the posterior aspect of most posterior point of the talar articular surface to the most anterior and superior point of the cuboidal facet; and the load arm width (LAW), which is the lateral dimension from the posterior point of the articular surface to the medial point of the sustentaculum. Measurements for the talus

(Figure 26b, Table 9) included: the maximum length (ML), measured from the sulcus from the flexor hallucis longus at the posterior aspect to the most anterior point on the articular surface for the navicular; the maximum width (MW), which is maximum distance in the sagittal plane; the body height (BH), the maximum height of the body from inferior to superior; and the maximum width of trochlear (MWT), which is the width of the trochlear surface at the midline perpendicular to the maximum length.

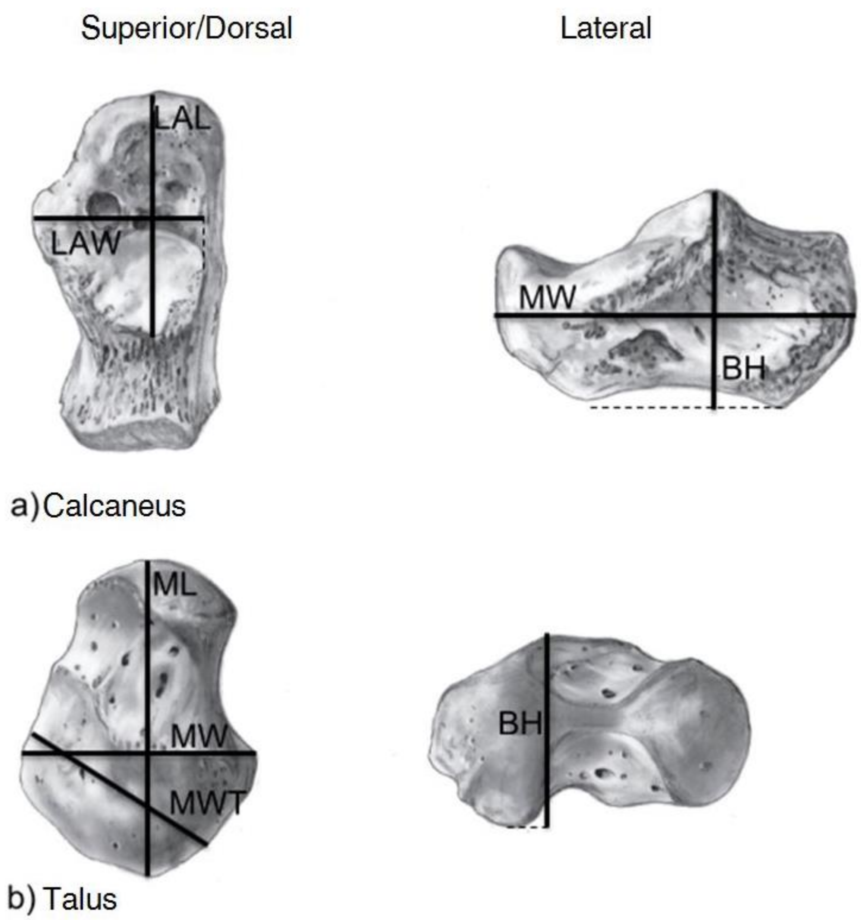


Figure 26. Calcaneus and talus; superior (left) & lateral (right) view; Measurements taken. From *Developmental Juvenile Osteology* (p.455), by Cunningham et al., 2017; London, Sara Tenney. Copyright 2016 by Elsevier Ltd. Adapted with permission.

Table 8. Calcaneal measurements as described by Steele (1976).

Measurement	Description
Minimum width (MW)	Anterior to the tuberosity and posterior to the talar facet.
Body height (BH)	The inferior aspect of tuberosity to superior point of talar facet.
Load arm length (LAL)	From the posterior aspect of most posterior point of the talar articular surface to the most anterior and superior point of the cuboidal facet.
Load arm width (LAW)	The lateral dimension from the posterior point of the articular surface to the medial point of the sustentaculum.

Table 9. Talar measurements as described by Steele (1976).

Measurement	Description
Maximum length (ML)	Measured from the sulcus from the flexor hallucis longus at the posterior aspect to the most anterior point on the articular surface for the navicular.
Maximum width (MW)	The maximum distance on the sagittal plane.
Body height (BH)	The maximum height of the body from inferior to superior.
Maximum width of trochlear (MWT)	The width of the trochlear surface at the midline perpendicular to the maximum length.

Analytical Methods

The HT Collection had a small number of subadult individuals per age group and sex (Table 1). Overall, each measured dimension was described by the number of individuals, by the minimum, the maximum, and the mean/median per age and sex. These statistics were calculated in Microsoft Excel using formulas and verified with a calculator to ensure each formula was input properly. The percentage of males that were larger than females for a particular measurement were also considered. For the dentition, age groups could be combined given that a tooth is not, within reason, expected to continue growth

once fully formed (Cunningham et al., 2017) – this enabled additional analysis across age groups. Therefore, for the dentition only, all like dimensions for a tooth (i.e., permanent maxillary left central incisor) were compared between males and females of all ages.

Where the sample size was at least two per sex for the long bones and dentition, T-tests (for normally distributed data) or Mann-Whitney U-tests (for nonparametric data) were employed to test if the female and male means were different. F-tests were employed to determine if T-tests for equal or unequal variances should be employed. When the results of the T-tests or U-tests indicated a significant difference (significance was defined as $p \leq 0.05$) between the means of each sex, a discriminant function analysis (DFA or DA) (for dentition and long bones) was run using the program XLStat (XLStat, 2020). The parameters chosen for DFA are as follows: sex was selected as the dependent variable and the measurements taken were selected as the independent variables; the option for 'classes weight correction' was selected to balance the data; a leave-one-out cross-validation procedure was employed.

Sample sizes of or near four (the minimum used for the aforementioned analysis) are very low and the results of statistical tests on such small samples could be meaningless despite significant p-values (Smith, 2018). Therefore, in the case of a significant p-value, the relationship was evaluated with a Pearson correlation coefficient (r), with $r \geq 0.5$ defined as a large effect size (Cohen, 1988).

RESULTS & DISCUSSION

The following section encompasses both the results and the discussion. It was decided to organize as such because it was felt it is much simpler to understand the results with the discussion in the same section. For each method tests, first is a description of the results followed by the tables to explain the results; this is followed by a discussion of the results including a comparison with the original researcher's findings. The organization of the skeletal elements follow the methods section, starting with the dentition and concluding with the tarsals.

Dentition

The results for the analysis of the dentition are shown in Tables 10-13. For dentition, intraobserver error between each of the three repeated measurements ranged from 0.00-0.52mm (mean=0.05mm) for permanent dentition and 0.00-0.38mm (mean=0.07mm) for deciduous dentition. The trends that are apparent for the dentition are that males tend to be larger than females; however, these differences are not significant for most measurements, likely owing at least in part to sample size but also because the ranges between females and males overlapped substantially. Only the mesiodistal dimension of the left deciduous maxillary lateral incisor (i^2) showed a significant difference with a p-value equaling 0.02, a Pearson coefficient correlation of 0.81, and through DFA cross-validation, sex was estimated 73.3% accuracy (80.0% females; 66.7% males) (Table 13).

Table 10. Permanent dentition, buccolingual dimensions. n=number of individuals, min=minimum, max=maximum, mean=average. T=T-test, U= U-Test. Measurements in mm. f = female, m = male.

	I^1L	**I^1 R**	**I^2 L**	**I^2 R**	**C^1 L**	**C^1 R**	**I_1 L**	**I_1 R**	**I_2 L**	**I_2 R**	**C_1 L**	**C_1 R**
n (f)	9	10	10	9	8	9	14	17	13	12	8	7
min (f)	6.10	6.04	5.44	5.12	7.15	7.13	4.61	2.73	5.01	5.06	6.74	3.73
max (f)	7.30	7.49	6.96	7.03	8.70	8.73	7.85	7.56	6.75	7.03	8.03	8.19
mean	6.85	6.93	6.38	6.45	8.21	8.00	5.77	5.65	6.11	6.18	7.39	6.88
n (m)	5	4	6	7	4	4	5	6	5	6	4	4
min (m)	5.85	5.90	6.32	6.38	7.97	4.93	5.31	5.40	5.99	5.79	6.65	5.72
max (m)	7.51	7.58	7.41	7.67	10.26	10.12	7.38	7.35	6.72	6.88	8.39	8.43
mean (m)	6.95	6.97	6.84	6.83	8.46	8.37	6.07	6.02	6.43	6.27	8.14	7.70
T-stat (T)		0.13	-1.69	-1.35		0.31		-0.81	-1.52	-0.35	1.24	
p-value (T)		0.90	0.11	0.20		0.78		0.43	0.15	0.73	0.28	
p-value (U)	0.52				0.21		0.15					0.16

Table 11. Permanent dentition, mesiodistal dimensions. n=number of individuals, min=minimum, max=maximum, mean=average. T=t-test, U=U-Test. Measurements in mm. f = female, m = male.

	I^1 L	**I^1 R**	**I^2 L**	**I^2 R**	**C^1 L**	**C^1 R**	**I_1 L**	**I_1 R**	**I_2 L**	**I_2 R**	**C_1 L**	**C_1 R**
n (f)	4	8	8	8	7	8	12	18	13	11	8	
min (f)	6.71	5.80	4.81	5.52	6.15	6.21	3.03	2.76	4.84	4.83	5.6	3.49
max (f)	9.11	8.89	7.45	7.45	7.97	7.82	5.75	9.10	6.49	6.53	7.50	7.65
mean	8.29	7.87	6.64	6.69	7.17	7.13	5.11	5.51	5.81	5.77	6.66	6.07
n (m)	4	2	5	6	4	4	5	6	5	6	4	5
min (m)	5.32	7.83	5.81	6.05	5.77	5.87	4.54	3.94	5.45	5.54	6.31	6.58
max (m)	9.54	8.02	7.07	7.03	8.82	9.17	8.27	8.27	7.29	7.37	8.31	7.94
mean (m)	7.96	7.93	6.69	6.83	7.37	7.72	5.61	5.65	6.02	6.06	7.28	7.10
T-stat (T)	-0.31	-0.06			0.33	0.83		0.21	0.69		-1.45	-1.93
p-value (T)	0.77	0.95			0.75	0.45		0.83	0.50		0.18	0.08
p-value (U)			0.83	0.98			0.73			0.53		

Table 12. Deciduous dentition, buccolingual dimensions. n=number of individuals, min=minimum, max=maximum, mean=average. T=t-test. Measurements in mm. f=female, m = male.

	i^1 L	i^1 R	i^2 L	i^2 R	c^1 L	c^1 R	i_1 L	i_1 R	i_2 L	i_2 R	c_1 L	c_1 R
n (f)	3	3	5	3	9	3	2	3	2	3	10	9
min (f)	4.38	4.46	4.24	4.59	4.34	4.59	3.34	3.32	3.73	3.86	5.10	5.08
max (f)	5.00	5.12	5.32	4.76	6.34	4.76	3.70	3.84	4.09	4.10	6.34	5.88
mean	4.79	4.83	4.74	4.68	5.93	4.68	3.52	3.61	3.91	3.95	5.58	5.44
n (m)	2	1	3	2	3	2	2	2	2	2	4	5
min (m)	4.98	5.20	4.62	4.80	5.57	4.80	3.95	3.95	4.26	4.14	4.89	4.95
max (m)	5.20	5.20	4.98	5.00	6.01	5.00	3.99	4.11	4.30	4.32	5.42	5.56
mean (m)	5.09	5.20	4.79	4.90	5.82	4.90	3.97	4.03	4.28	4.23	5.17	5.34
T-stat (T)			-0.21		0.54						1.65	0.70
p-value (T)			0.83		0.60						0.123	0.50

Table 13. Deciduous dentition, mesiodistal dimensions. n=number of individuals, min=minimum, max=maximum, mean=average. T=t-test, DFA=discriminant function analysis, C= Pearson correlation coefficient. Measurements in mm. f = female, m = male.

	i^1 L	i^1 R	i^2 L	i^2 R	c^1 L	c^1 R	i_1 L	i_1 R	i_2 L	i_2 R	c_1 L	c_1 R
n (f)	3	3	5	3	9	10	2	3	2	3	10	9
min (f)	5.74	6.00	4.92	5.04	5.59	5.55	3.88	3.82	4.53	4.62	4.86	5.28
max (f)	6.89	6.98	5.55	5.48	7.29	7.41	4.50	4.41	4.69	4.84	7.06	6.25
mean	6.39	6.43	5.31	5.25	6.53	6.66	4.19	4.04	4.61	4.75	5.99	5.77
n (m)	2	0	3	2	3	2	2	2	2	2	4	5
min (m)	5.83		4.25	4.54	6.15	5.89	4.02	3.96	4.42	4.26	5.56	5.56
max (m)	5.83		5.00	4.58	6.75	6.73	4.48	4.50	4.89	4.70	6.07	6.20
mean (m)	5.83		4.57	4.56	6.49	6.46	4.25	4.23	4.66	4.48	5.83	5.90
T-stat (T)			-3.36		0.11						0.71	-0.81
p-value (T)			0.02		0.91						0.49	0.43
% correct (C)			73.3									
p-value (C)			0.02									
r-value (C)			0.81									

The methods retested for the dentition (Black III, 1978; De Vito & Saunders, 1990) examined the left and right maxillary and mandibular dentition of the central and lateral incisors and canines of both deciduous and permanent dentition. The results of this thesis showed that males are larger than females for both permanent dentition (95.8% of the time) and deciduous dentition (54.2% of the time), which supports the original researcher's conclusions (Black III, 1978; DeVito & Saunders, 1990). Observations of the data, measurement-by-measurement, per tooth and per sex (Tables 10-13), indicate that the buccolingual dimensions for permanent dentition were larger for males 100% of the time and the mesiodistal dimension 91.7% of the time. For deciduous dentition, 75% of male individuals were larger than females for the buccolingual dimensions of all the teeth, and for mesiodistal dimensions, males were larger 33.3% of the time. The data for this study indicated that Black III's (1978) hypothesis, that male dentition is larger than female dentition, in particular, for the buccolingual dimension of permanent dentition, is generally supported based on the Hamman-Todd skeletal sample population. However, the results for the deciduous dentition did not reach a high percentage of accuracy when compared to permanent dentition, which could be in part be because this thesis only examined three teeth while Black III (1978) examined all dentition (i.e. including molars). Overall, it is evident that the buccolingual dimensions are more accurate for estimating sex than the mesiodistal, and there is a higher percentage of accuracy obtained with permanent dentition.

In conclusion for the dentition, this thesis focused on each tooth independently in order to ascertain if a single tooth could provide a higher accuracy for estimating a

subadult decedent's sex. Based on this study's sample population, only the mesiodistal dimension of the left maxillary lateral incisor (i^2) (Table 13) produced substantial results ($p = 0.02$, $r = 0.81$, 73.3%) which coincides with De Vito and Saunders (1990) who also concluded that the dimension of lateral incisors evinced the highest level of sexual dimorphism. More studies need to be conducted to test the conclusion that male dentition are larger than females. For example, DeVito and Saunders (1990) examined three-to-five measurements of dentition concurrently which resulted in higher accuracies for estimating sex (76-90%).

Mandible

Table 14 provides results for the six non-metric methods of the mandible that were tested for this thesis. The methods resulted in a relatively low level of accuracy for estimating sex, ranging from 39.1-69.6% correct for females, 42.9-71.4% for males, and 51.4-64.9% for the pooled results. The highest percentage of accuracy for females (69.6%) was for the anterior dental arcade and eversion of gonion region. For males, the highest percentage of accuracy (71.4%) was achieved by examining the mentum (Table 14).

Table 14. Non-metric mandibular methods: MM=Mandibular morphology, Loth & Henneberg, 2001; Me=Mentum, MA=Mandibular Angle, Molleson & Cruse, 1998; Ch=Protrusion of Chin, AGA=Anterior Dental Arcade, Go=Eversion/Gonion Region, Schutkowski,1993. f = female, m = male, IND=indeterminate.

Collections #	Sex (in records)	MM	Me	MA	Ch	ADA	Go
1606	f	f	m (1)	m (2)	m	m	f
1041	f	f	f (-1)	f (-2)	f	f	f
1232	f	f	f (-1)	m (2)	f	f	f
1156	f	m	m (1)	f (-1)	m	m	m
1115	f	f	m (2)	m (1)	f	f	m

Collections #	Sex (in records)	MM	Me	MA	Ch	ADA	Go
1240	f	m	f (-1)	f (-1)	f	f	f
1772	f	m	m (2)	f (-2)	m	m	f
2036	f	f	m (1)	m (3)	f	f	f
2118	f	f	f (-2)	f (-1)	m	m	f
2074	f	f	f (-2)	f (-1)	m	m	m
2141	f	f	m (2)	m (2)	f	f	m
1509	f	f	m (1)	m (2)	f	f	m
0633	f	f	m (2)	f (-2)	m	f	f
0485	f	ind	m (1)	f (-1)	f	f	f
0576	f	f	m (2)	f (-1)	f	f	f
1074	f	m	f (-2)	f (-1)	m	f	m
1098	f	m	f (-1)	f (-2)	f	m	f
0872	f	f	m (1)	f (-1)	f	f	m
0526	f	m	f (-1)	f (-1)	f	m	f
0632	f	f	m (2)	m (2)	f	f	f
0645	f	m	m (1)	m (2)	f	f	f
0624	f	f	m (1)	m (2)	m	f	f
0527	f	m	f (-1)	f (-1)	f	f	f
3112	m	m	f (-1)	m (2)	m	f	f
1589	m	f	f (-1)	m (2)	f	f	m
1441	m	m	m (2)	m (1)	m	m	f
1688	m	m	f (-2)	f (-1)	m	m	f
1784	m	m	f (-2)	f (-1)	m	m	m
1834	m	ind	m (1)	f (-1)	m	f	f
1950	m	f	m (1)	m (2)	f	m	f
2144	m	f	m (1)	f (-1)	m	f	m
1557	m	f	m (2)	m (2)	f	f	m
0548	m	ind	m (2)	f (-1)	f	f	f
0404	m	m	m (1)	m (1)	m	m	m
0710	m	f	m (1)	m (2)	f	f	f
1711	m	m	m (2)	f (-1)	m	f	f
3470	m	m	m (2)	f (-1)	m	m	m
	% Correct f	60.9%	39.1%	60.9%	65.2%	69.6%	69.6%
	% Correct m	50.0%	71.4%	50.0%	64.3%	42.9%	42.9%
	% Correct Combined	56.8%	51.4%	56.8%	64.9%	59.5%	59.5%

Comparing previous research to this study, Loth and Henneberg (2001) (Table 15) obtained a higher percentage of accuracy for mandibular morphology (Table 15) which may represent that this method does not work for the present sample population or that

the present study is affected by small sample size. Molleson and Cruse (1998) combined the mandibular and eye orbit morphologic results together; therefore, this was mirrored for this study. The resulting percentage of accurately estimating sex was 54.1%, which was lower than 78.0% from Molleson and Cruse (1998) (Table 15).

Compared to Schutkowski (1993) and Sutter (2003) (who retested Schutkowski's methods), this thesis produced varied results (Table 15). The highest percentage of accuracy was for the shape of anterior dental arcade and eversion of gonion region for males (69.6%) whereas Schutkowski's (1993) reported 59.3% accuracy for males for this feature (Table 15). Comparing the data from Sutter (2003) to this study, Sutter (2003) had a higher percentage of accuracy for males for the protrusion of the chin and the shape of the dental arcade 100.0%, 96.4% respectively), while this study showed females having a higher percentage of accuracy (64.3%, 42.9%, respectively) (Table 15). The results from this thesis compared to previous researchers (Schutkowski, 1993; Sutter, 2003) suggested that these methods produced varied results potentially because of the skeletal small sample for this study or due to the different ancestries of the collection examined (HT Collection) compared to Schutkowski (1993) and Sutter (2008).

Also, Schutkowski (1993) only examined individuals from the age of 0-5 years of age, while this study looked at individuals from 3-17 years of age. Following Sutter (2003) in comparing the data per similar age ranges, the data for this thesis was reduced to focus on ages from 3-5 years and compared this to Sutter's (2003) ages 2-5 years and Schutkowski's (1993) individuals ages 2-5 years (Table 16). Based on Table 16, the methods are more accurate for females than for males when looking at the protrusion of

the chin and the anterior dental arcade. However, for the present study, there were only 2 males within this age range for which data was able to be collected for these mandibular traits; therefore, it is difficult to fully evaluate the accuracy of the methods. What can be noted is that there is some validity in estimating sex from mandibular traits, and more research and retesting will need to occur on more expansive and diverse sample populations.

Table 15. Mandibular non-metric methods compared with previous studies. f=female, m=male.

Method	Original Results
Mandibular morphology	
Loth & Henneberg (2001)	89.4% (T1); 78.9% (T2); 73.7% (T3) (f&m)
T1 – Main Author	83.8% (f); 100.0% (m)
T2 – Osteologist 1	66.7% (f); 100.0% (m)
T3 – Osteologist 2	66.7% (f); 85.7% (m)
This study	60.9% (f); 50.0% (m); 56.4% (f&m)
Mandibular angle, Mentum, Eye Orbital	
Molleson & Cruse (1998)	78.0% (f&m)
This study	64.1% (f&m)
Protrusion of chin	
Schutkowski (1993)	92.3% (f); 59.3% (m)
Sutter (2003)	25.0% (f); 100.0% (m)
This study	65.2% (f); 64.3% (m)
Shape of anterior dental arcade	
Schutkowski (1993)	69.2% (f); 73.1% (m)
Sutter (2003)	31.3% (f); 96.4% (m)
This study	69.6% (f); 42.9% (m)
Eversion of gonion region	
Schutkowski (1993)	60.0% (f); 68.0% (m)
Sutter (2003)	56.3% (f); 60.7% (m)
This study	69.6% (f); 42.9% (m)

Table 16. Comparing Schutkowski's (1993) and Sutter's (2003) results with the data from this study on individual's ages 2-5 years (3-5 years for this study). f=female, m=male.

Method	Original Results
Protrusion of chin	
Schutkowski (1993) (7f, 14m)	85.7% (f); 57.1% (m)
Sutter (2003) (7f, 12m)	40.0% (f); 100.0% (m)
This study (5f, 2m)	80.0% (f); 0.00% (m)
Shape of anterior dental arcade	
Schutkowski (1993) (7f, 14m)	85.7% (f); 78.6% (m)
Sutter (2003) (7f, 12m)	42.9% (f); 91.7% (m)
This study (5f, 2m)	80.0% (f); 50.0% (m)
Eversion of gonion region	
Schutkowski (1993) (8f, 14m)	50.0% (f); 85.7% (m)
Sutter (2003) (7f, 12m)	85.7% (f); 41.7% (m)
This study (5f, 2m)	20.0% (f); 50.0% (m)

Cranial Metrics

Results for cranial metrics are shown in Tables 17-33, with the occipital addressed separately in the following section. This study did not collect/analyze all measurements used in the previous studies (i.e., Gonzalez, 2012) due to bisected crania (Figure 9, Figure 10). This resulted in a smaller number of individuals per age group and per sex (Tables 17-33). The only dimension that evinced a difference between females and males was the nasion-opisthiocranion length on individuals in the 12-17 year age range were combined (T-test p=0.03) – although note that combining these age groups may be problematic. A larger sample size of fully intact crania is needed in order to evaluate the efficacy of Gonzalez's (2012) methods for broad use.

A discriminant function analysis (DFA) of nine measurements (i.e., GOL, NOL, OBL, BPL, BNL, NPL, PBL, PPL, PNL, OPL) was performed on a sample of 10 individuals (F=5, M=5, age 4-17). The resulted discriminant function analysis was 100%

accurate when estimating sex with p=0.001. However, the results of the DFA need to be considered preliminary given that age was not controlled for nor evenly distributed among the sexes. This does however provide an understanding in that combining multiple measurements when running statistical analysis may prove beneficial versus a single dimension. Based on previous studies, craniometrics were seen to be sexually dimorphic (Langley et al., 2016) and are used to estimate the sex of adult decedents, which agrees with for the high percentage of accuracy found within this study. In any case, such a high accuracy is rare in a subadult sample population, and this result is particularly intriguing in that it was significant despite the combined ages. Thus, this is a promising route for future research.

Table 17. Glabella-Opisthiocranion length dimensions per age in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	107.00			1	161.40		
5	1	149.30			0			
8	2	163.20	159.90	166.50	0			
10	0				1	168.20		
11	1	168.60			1	181.50		
12	2	160.20	154.50	165.90	0			
16	2	173.50	170.20	176.80	0			
17	1	164.30			2	181.90	179.70	184.10

Table 18. Nasion-opisthiocranion length dimensions per age, in years. Females (left) compared to males (right). min= minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	162.70			1	156.50		
5	1	149.10			0			
8	2	162.00	159.70	164.30	0			
10	0				1	166.50		
11	1	167.40			1	181.30		
12	2	162.70	161.50	163.90	0			
15	0				1	179.00		
16	2	172.65	167.70	177.60	0			
17	1	165.60			2	181.20	179.00	183.40

Table 19. Nasion-Basion Length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
5	1	92.10			0			
8	2	97.85	97.60	98.10	0			
10	0				1	102.30		
11	1	98.70			0			
12	2	103.15	98.40	107.90	0			
17	1	105.00			0			

Table 20. Bregma-Opisthiocranion Length dimensions per age, in years. Females (left) compared to males (right). min =minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	124.90			0			
5	1	99.80			0			
8	1	112.20			0			
10	0				1	102.50		
11	1	130.50			0			
12	2	124.20	113.10	135.30	0			
14	1	131.10			0			
16	2	127.90	118.60	137.20	0			
17	1	107.90			0			

Table 21. Opisthiocranion-Basion Length dimensions per age, in years. Females (left) compared to males (right). min =minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	85.30			1	91.60		
8	1	100.10			0			
10	0				1	118.40		
11	0				1	118.90		
12	2	85.80	59.80	111.80	0			
14	1	111.70			0			
15	0				1	121.70		
16	3	97.60	97.50	110.80	0			
17	1	106.50			2	114.30	113.70	114.90

Table 22. Bregma-Basion Length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (per data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	133.10			0			
10	0				1	138.60		
12	2	136.15	135.80	136.50	0			
14	1	131.10			0			
16	2	124.70	122.00	127.40	0			
17	1	124.50			0			

Table 23. Bregma-prosthion length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	105.50			0			
8	1	83.40			0			
10	0				1	82.10		
11	0				1	87.30		
12	2	95.50	110.70	80.30	0			
15	0				1	91.80		
16	1	56.90			0			
17	1	42.97			3	95.70	89.70	96.00

Table 24. Bregma-nasion length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	111.80			1	73.80		
8	1	88.70			0			
10	0				1	87.40		
11	0				1	91.30		
12	2	107.65	93.10	122.20	0			
15	0				1	95.90		
16	3	97.20	93.32	100.50	0			
17	2	95.60	94.90	96.30	3	96.90	91.90	99.70

Table 25. Nasion-prosthion dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	45.44			0			
4	2	46.88	45.61	48.15	0			
8	3	51.07	47.91	59.27	0			
10	0				3	56.81	54.00	67.47
11	1	44.99			1			
12	2	58.31	57.74	58.87	0			
15	0				1	35.49		
16	2	64.06	63.68	64.43	0			
17	1	63.10			3	66.52	62.72	67.90

Table 26. PNS-basion length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	0				1	35.22		
8	1	41.25			0			
10	0				1	40.20		
11	0				1	43.82		
12	2	53.51	38.14	68.88	0			
15	0				1	41.79		
16	3	48.99	42.10	92.07	0			
17	2	42.10	41.66	42.53	3	42.63	39.40	42.90

Table 27. Prosthion-PNS length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	39.00			0			
4	2	45.80	42.00	49.60	0			
5	1	38.09			0			
8	2	41.84	40.07	43.60	0			
10	0				3	51.00	41.20	59.30
11	0				1	45.80		
12	2	62.60	40.07	43.60	0			
14	0				0			
15	0				1	50.10		
16	2	53.82	50.44	57.20	0			
17	1	52.40			3	53.00	49.40	59.60

Table 28. PNS-nasion length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	48.00			0			
4	2	51.40	49.60	53.20	1	48.00		
5	1	48.54			0			
8	2	58.05	56.60	59.50	0			
10	0				3	55.30	44.10	65.60
11	0				1	60.40		
12	2	77.85	62.90	92.80	0			
15	0				1	65.50		
16	3	61.10	60.80	63.70	0			
17	2	62.95	61.40	64.50	3	66.70	61.20	70.50

Table 29. Opisthiocranion-prosthion length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	146.70			0			
8	2	157.80	137.10	178.50	0			
10	0				1	190.80		
11	1	176.60			1	155.10		
12	2	174.15	164.70	183.60	0			
15	0				1	210.10		
16	1	210.10			0			
17	0				2	192.10	176.20	208.00

Table 30. Prosthion-bregma length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
8	2	141.40	136.90	145.90	0		2	141.40
10	0				1	150.00	0	
12	2	153.30	146.10	160.50	0		2	153.30
14	0				0		1	173.10
16	1	166.50			0		1	166.50

Table 31. Maximum diameter bi-zygomatic length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	90.40			0			
8	1	108.90			0			
10	0				1	93.00		
15	0				1	121.40		
17	1	122.50			2	122.55	117.80	127.30

Table 32. Nasion Breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	18.80			0			
4	1	21.27			0			
8	1	24.20			0			
10	0				2	22.55	21.70	23.39
11	0				1	23.37		
15	0				1	22.20		
17	1	22.00			2	24.20	24.00	24.40

Table 33. Opisthion-Forehead Length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
8	1	168.50			0			
11	0				1	178.50		

Temporal

The mastoid process of the temporal bone was not examined statistically with discriminant function analysis due to the minimal number of measurements obtained per each age. The main finding for this measurement was that females were larger than males 57.1% of the time (see Table 34).

Table 34. Mastoid Length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	15.66			1	14.91		
4	1	24.77			1	10.31		
5	2	20.19	18.31	22.06	0			
6	1	18.19			2	17.12	12.65	21.58
7	1	17.89			0			
8	3	23.07	19.41	23.88	1	31.47		
10	1	20.79			2	22.86	22.58	23.13
11	1	29.58			1	25.58		
12	3	22.92	17.83	26.32	0			
13	1	23.89			0			
14	1	30.40			0			
15	0				1	23.18		
16	4	28.57	23.57	29.80	0			
17	2	23.76	22.75	24.77	4	26.23	25.71	32.22

More data on a larger and more diverse population needs to be gathered to verify if the measurement of the mastoid length of the temporal bone are useful for estimating the sex of subadult decedents. Giles and Elliot (1963) compared 'black' and 'white' individuals which would not merit comparing the original authors results to this thesis's data because this study did not separate individuals by ‘race’ nor assumed ancestries.

Occipital

The results for the occipital bone are shown in Tables 35-41. Unfortunately, there was not enough data per sex, nor age, to run the statistical analysis employed for this thesis. What was indicated by the data was that males are often larger than females in a given age group. Although the results thus support the general validity of related methods for estimating the sex of subadult decedents, additional data and analysis are necessary to fully evaluate the methods, particularly for ages 3-11, prior to puberty.

Table 35. Foramen magnum length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	2	29.86	29.69	30.02	1	31.03		
5	2	37.78	31.15	44.41	0			
6	1	35.32			2	33.41	31.02	35.80
7	1	29.84			0			
8	3	33.96	30.05	36.02	1	33.39		
10	1	30.23			3	36.47	36.14	36.92
11	1	33.50			1	37.34		
12	3	34.23	33.11	34.33	0			
13	1	18.48			0			
14	1	33.39			0			
15	0				1	36.64		
16	4	31.91	29.54	36.46	0			
17	2	29.41	24.50	34.32	4	34.88	33.06	38.32

Table 36. Foramen magnum breadth (width) dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	23.76			1	34.43		
6	0				1	22.79		
8	1	24.76			0			
10	0				2	27.83	26.35	29.30
11	0				1	29.38		
15	0				1	26.60		
17	1	28.48			2	27.69	27.04	28.34

Table 37. Left occipital condyle length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	2	16.97	16.89	17.04	1	21.34		
5	1	21.80			0			
6	1	18.93			2	21.81	21.37	22.24
8	3	21.35	21.11	22.44	1	19.18		
9	0				0			
10	1	2.40			3	23.39	21.38	24.33
11	1	19.44			1	25.94		
12	3	22.38	20.78	24.58	0			
13	1	21.39			0			
14	21	22.83			0			
15	0				1	24.62		
16	4	22.83	21.45	24.94	0			
17	2	22.40	21.90	22.89	4	21.04	18.60	24.84

Table 38. Right occipital condyle length dimensions per age, in years. Females (left) compared to males (right). min= minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	21.11			1	20.44		
5	2	22.81	22.46	23.16	0			
6	1	17.08			2	21.94	20.59	23.28
7	1	24.22			0			
8	3	20.84	18.40	21.77	1	19.97		
10	1	20.50			3	23.16	10.85	25.56
11	1	17.28			1	22.57		
12	3	23.24	18.83	24.03	0			
13	1	21.03			0			
14	1	24.21			0			
15	0				1	11.25		
16	3	23.75	20.87	24.73	0			
17	1	11.32			4	22.63	11.36	24.34

Table 39. Left occipital condyle breadth (width) dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	10.28		
4	2	9.92	9.89	9.95	1	10.37		
5	1	10.58			0			
6	1	8.08			2	10.87	10.71	11.02
7	1	11.43			0			
8	3	11.00	9.75	11.38	1	9.96		
10	1	11.01			3	13.10	12.03	21.08
11	1	11.40			1	10.94		
12	3	10.57	10.56	12.15	0			
13	1	12.66			0			
14	1	11.24			0			
15	0				1	22.36		
16	4	12.63	11.28	15.06	0			
17	2	17.69	13.30	22.08	4	11.76	10.85	17.83

Table 40. Right occipital condyle breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	10.45		
4	1	9.54			1	10.79		
5	2	9.93	9.50	10.35	0			
6	1	9.50			2	11.11	10.36	11.85
7	1	9.15			0			
8	3	10.15	9.12	10.39	1	10.39		
10	1	9.06			3	11.58	10.99	13.44
11	1	10.35			1	12.18		
12	3	11.04	11.01	12.20	0			
13	1	11.74			0			
14	21	11.32			0			
15	0				1	12.92		
16	3	12.45	10.90	13.22	0			
17	2	10.61	9.30	11.91	4	12.28	11.11	13.18

Table 41. Bi-condylar breadth dimensions per age, in years. Females (left) compared to males (right). Min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	1	38.92			1	40.26		
6	0				1	37.56		
8	1	40.39			0			
10	0				2	48.07	45.23	50.90
11	0				1	48.50		
15	0				1	40.71		
17	1	40.39			2	44.95	44.09	45.81

Eye Orbits

Results for qualitative analysis of the orbits are shown in Table 42. This study reached 65.2% accuracy for estimating sex of females and 28.6% males (51.4% combined). The lack of useful accuracy could be due to an observer error, or it could be indicative that this method, as interpreted and employed, does not work well across sample populations.

Table 42. Non-metric methods, based on Molleson & Cruse (1998) in estimating sex from eye orbits. F = female, M = male, IND = indeterminate.

Collections #	Age (known)	Sex (known)	Estimated sex (score)
1509	3	F	F (-1)
2141	4	F	F (-1)
1074	4	F	F (-2)
1115	5	F	M (1)
1098	5	F	M (1)
0624	6	F	M (1)
2036	7	F	F (-1)
1156	8	F	F (-2)
2074	8	F	F (-2)
0872	8	F	F (-2)
0632	10	F	M (1)
0526	11	F	F (-2)
0645	12	F	M (1)
1240	12	F	F (-1)
1772	12	F	M (1)
2118	13	F	M (1)
0633	14	F	F (-1)
0527	16	F	F (-1)
1232	16	F	F (-2)
0485	16	F	F (-1)
0576	16	F	M (1)
1606	17	F	F (-1)
1041	17	F	F (-2)
1557	3	M	(F -2)
1950	4	M	M (1)
1784	6	M	F (-2)
2144	6	M	M (1)
1834	8	M	F (-2)
1441	10	M	F (-2)
1688	10	M	M (1)
0710	10	M	F (-1)
0404	11	M	F (-1)
1589	17	M	F (-1)
0548	17	M	M (2)
1711	17	M	F (-1)
3470	17	M	IND
3112	15	M	F (-1)
% Correct Females			65.2%
% Correct Males			28.6%
% Correct Overall			51.4%

In comparing the results from this study to the results of Molleson and Cruse (1998), which combined the non-metric methods for the eye orbit, mandibular angle, and the mentum, the percentage of accuracy was not similar. Molleson and Cruse (1998) reported 78.0% of subadults being sexed correctly, whereas this thesis reported 51.4% accuracy when combining the three traits. It is recommended that more research should be conducted to understand if a higher percentage of accurately estimating sex can be achieved on larger, more diverse sample populations.

Ilium

Results for the analysis of the pelvis are shown in Tables 43-50. The results for the non-metric methods are shown in Table 43 and Table 44. These results indicate that 46.4% (18.8% females, 83.3% males) were sexed correctly based on the greater sciatic notch angle, 57.1% were correctly estimated based on the arch criteria (43.8% females, 75.0% males), and 46.4% (37.5% females, 58.3% males) were estimated correctly via the curve of the iliac crest (after Schutkowski, 1993). For the auricular surface (Weaver, 1980), 53.6% of individuals (56.3% females, 50.0% males) were correctly assessed.

Table 43. Data for the non-metric methods in sexing subadults based on ilium. GSN Angle, Arch criteria, and Curve/iliac crest (Schutkowski, 1993); Auricular Surface (Weaver, 1980). F = female, M = male.

Collections #	Age (known)	Sex (known)	GSN Angle	Arch criteria	Curve/iliac crest	Auricular surface
2036	7	F	M	F	F	M
1156	8	F	F	F	F	M
2074	8	F	F	F	F	F
0872	8	F	M	M	M	M
0632	10	F	M	M	M	F
0526	11	F	M	M	M	M
1240	12	F	M	M	M	F
1772	12	F	M	M	M	M
0645	12	F	M	M	F	F
0633	14	F	M	F	M	M
1232	16	F	M	M	F	F
0485	16	F	M	M	M	M
0576	16	F	M	F	M	F
1041	17	F	M	F	M	F
4056	17	F	M	F	M	F
1606	17	F	F	M	F	F
1557	3	M	M	M	F	F
1784	6	M	M	M	F	M
2144	6	M	M	M	M	M
1834	8	M	M	M	F	F
1441	10	M	M	N/A	M	F
1688	10	M	M	M	M	F
0710	10	M	F	M	F	M
0404	11	M	M	M	M	F
3112	15	M	M	M	M	M
548	17	M	M	F	M	M
1711	17	M	M	M	M	F
3470	17	M	F	F	F	M
% Correct Females			18.8%	43.8%	37.5%	56.3%
% Correct Males			83.3%	75.0%	58.3%	50.0%
% Correct Overall			46.4%	57.1%	46.4%	53.6%

Comparing the results of this study to the original researchers (Table 44), for the greater sciatic notch angle, the females were estimated correctly 18.8% of the time which

is much lower than Schutkowski (1993) (95.2%), Sutter (2003) (78.6%), and Vlak et al. (2008) (52.2%).The results for the males were fairly high for this study with 83.3% of males being sexed correctly while the other researchers ranged from 54.5-71.4% (Schutkowski, 1993; Sutter, 2008; Vlak et al., 2008). The arch criteria (female 43.8%, male 75.0%) did not meet Schutkowski's (1993) original results (female 60.0%, male 81.5%). For the iliac crest, for male's accuracy was higher in this study (58.3%) than Schutkowski (1993) (54.2%), whereas for females' accuracy was lower in this study (37.5%) compared to 85.7% for Schutkowski (1993). Finally, for the auricular surface elevation, this study was much lower (female 56.3%; male 50.0%; combined 53.6%) than for the two previous studies discussed for this thesis (Weaver, 1980; Mittler & Sheridan, 1991) (Table 44). This could mean the elevation of the auricular surface is most likely not a good candidate for further testing, as Mittler and Sheridan (1991) concluded. The results of this study could not be reliably compared to those of Majó et al. (1993) because the article made it difficult to understand what the percentages encompassed.

Table 44. Comparing this studies data (ages 3-17) with Schutkowski (1993).

Method	Original Results
Greater Sciatic Notch Angle	
Schutkowski (1993)	95.2% (f); 71.4% (m)
Sutter (2003)	78.6% (f); 69.2% (m)
Vlak et al. (2008)	52.2% (f); 54.5% (m); 53.6% (f&m)
This study	18.8% (f); 83.3% (m); 46.4% (f&m)
Arch Criteria	
Schutkowski, (1993)	60.0% (f); 81.5% (m)
Sutter (2003)	85.7% (f); 54.2% (m)
This study	43.8% (f); 75.0% (m); 57.1% (f&m)
Curve of Iliac Crest	
Schutkowski, (1993)	85.7% (f); 54.2% (m)
Sutter (2003)	92.9% (f); 38.5% (m)
This study	37.5% (f); 58.3% (m); 46.4% (f&m)
Auricular Surface	
Weaver (1980)	57.7% (f); 87.5% (m); 73.5% (f&m)
Mittler & Sheridan (1991)	58.3% (f); 85.3% (m); 74.1% (f&m)
Sutter (2003)	60.9% (f); 77.8% (m)
This study	56.3% (f); 50.0% (m); 53.6% (f&m)

Tables 45-50 provide results for metric analysis of the ilium. No statistical analysis was done due to the minimal number of individuals per each age group. Comparing males to females with respect to induvial measurements, males tend to be larger 64.3% of the time. However, comparing males to females based on males being larger than females may not be the most accurate method for future research, given that females tend to have broader pelves with wider angles. Additional data are needed for future analysis.

Table 45. Sciatic Notch Width dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	14.61		
4	2	25.08	20.32	29.84	0			
5	2	21.25	19.17	23.32	0			
6	1	14.39			2	25.33	23.82	26.84
7	1	23.92			0			
8	3	27.51	25.85	29.60	1	22.75		
10	1	25.42			3	24.41	24.31	30.44
11	1	32.98			1	34.80		
12	3	32.06	23.71	50.05	0			
13	1	26.41			0			
14	1	48.92			0			
15	0				1	36.65		
16	4	51.15	41.90	56.16	0			
17	3	51.61	51.30	52.95	4	45.33	17.22	49.09

Table 46. Sciatic notch depth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	7.65		
4	2	7.81	6.67	8.95	0			
5	2	8.42	8.09	8.74	0			
6	1	8.81			2	9.55	9.24	9.85
7	1	8.15			0			
8	3	9.96	9.85	10.34	1	10.12		
10	1	10.30			3	12.10	11.53	15.29
11	1	12.86			1	15.04		
12	3	16.40	14.45	30.59	0			
13	1	10.94			0			
14	1	33.12			0			
15	0				1	19.17		
16	4	35.71	32.95	38.38	0			
17	3	33.57	23.37	35.32	4	34.01	16.23	40.74

Table 47. Anterior length of ilium dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	22.43		
4	2	24.95	22.30	27.60	0			
5	2	18.53	15.04	22.02	0			
6	1	20.02			2	40.57	18.64	62.49
7	1	21.95			0			
8	3	20.29	16.54	27.51	1	25.41		
10	1	24.43			2	26.69	20.93	32.44
11	1	28.98			1	29.02		
12	3	30.74	26.38	34.91	0			
13	1	22.03			0			
14	1	28.71			0			
15	0				1	31.90		
16	4	35.34	33.21	37.18	0			
17	3	27.38	22.65	33.22	4	27.53	10.67	44.51

Table 48. Posterior length of ilium dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	35.01		
4	2	37.51	26.20	48.81	0			
5	2	50.28	48.31	52.24	0			
6	1	58.91			2	33.08	18.46	47.69
7	1	59.22			0			
8	3	64.34	60.26	64.65	1	59.80		
10	1	60.92			2	60.29	53.11	67.46
11	1	71.68			1	70.65		
12	3	70.87	59.87	77.45	0			
13	1	62.54			0			
14	1	75.16			0			
15	0				1	64.83		

Table 49. Maximum width of ilium dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	60.80		
4	2	80.08	74.89	85.27	0			
5	2	68.52	68.07	68.96	0			
6	1	76.95			2	75.50	70.08	80.91
7	1	81.32			0			
8	3	85.08	80.52	94.08	1	86.86		
10	1	81.85			3	93.90	89.16	101.26
11	1	94.18			1	101.39		
12	2	104.77	96.89	112.64	0			
13	1	87.85			0			
15	0				1	101.39		
16	1	131.75			0			

Table 50. Maximum height of ilium dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	70.80		
4	2	87.46	80.57	94.35	0			
5	2	72.83	71.00	74.65	0			
6	1	90.17			2	76.23	72.93	79.53
7	1	80.52			0			
8	3	86.40	84.78	95.87	1	90.37		
10	1	93.91			3	96.20	93.75	105.33
11	1	109.28			1	118.22		
12	3	120.46	99.60	127.30	0			
13	1	91.96			0			
15	0				1	116.82		
16	3	136.08	135.60	148.24	0			
17	3	146.72	124.78	152.73	3	119.01	99.32	149.60

Long Bones

Tables 51-68 display the results from the measurements taken of the long bones (i.e. humerus, ulna, radius, femur, tibia, and fibula). There were not enough individuals per age and per sex to facilitate within-age-group statistical analysis of each metric with

the methods used in this thesis. However, in general, males were larger than females 71.1% % of the time within age groups. The mid-sagittal breadth dimensions were larger in the males than the females 72.4% of the time within each age group.

A discriminant function analysis (DFA) was applied to eleven females and six males (n=17), and included twelve breadth measurements (distal, proximal, and mid-sagittal) across six long bones. The results were statistically significant (Wilks Lambda test, p-value = 0.0004, r = 0.94, 95.5% of individuals being sexed correctly). A second DFA was run on only the distal breadth of all six long bones on twelve females and six males (n=18) which resulted in slightly higher accuracy but a smaller effect size (p-value 0.0002, r=0.83, 95.8% individuals sexed correctly).

The present study also ran a DFA of the four measurements of the humerus (proximal breadth, distal breadth, midsagittal breadth, diaphyseal length) on 13 females and 6 males (n=19), given that Stull et al. (2017) reported that the humerus was the most promising in estimating sex. The results were significant (Wilks Lambda test, p-value = 0.003, 71.8% of the individuals being sexed accurately), but not as accurate as the DFA which included the breadth dimensions of all 6 long bones.

Table 51. Ulnar diaphyseal length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	109.55		
4	2	151.35	139.25	163.45	0			
5	2	129.16	126.75	131.57	0			
6	1	119.59			2	146.00	129.55	162.45
7	1	132.80			0			
8	3	176.25	164.25	275.60	1	164.99		
10	1	146.10			3	186.15	168.25	195.51
11	1	190.01			1	223.15		
12	2	237.50	196.10	278.90	0			
13	1	167.99			0			
15	0				1	223.25		
17	0				1	218.99		

Table 52. Ulnar mid-sagittal breadth per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	0				1	10.16		
4	2	8.62	7.44	9.79	1	9.95		
5	2	7.51	6.81	8.21	0			
6	1	6.82			2	9.35	8.61	10.09
7	1	8.16			0			
8	3	8.65	7.96	11.82	1	9.16		
10	1	12.76			3	8.45	8.37	11.84
11	1	9.59			1	14.58		
12	3	11.72	9.68	12.97	0			
13	1	8.07			0			
14	1	10.61			0			
15	0				1	12.50		
16	4	12.40	10.81	12.88	0			
17	3	11.73	9.85	9.85	4	13.75	11.35	16.14

Table 53. Humeral diaphyseal length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	133.25			1	122.40		
4	2	180.52	163.55	197.49	0			
5	2	161.81	158.10	165.52	0			
6	1	176.48			2	173.75	154.10	193.40
7	1	159.85			0			
8	3	209.99	195.99	219.12	1	218.40		
10	1	185.39			3	234.25	202.51	240.52
11	1	224.49			1	256.12		
12	2	238.55	211.45	255.61	0			
13	1	211.45			0			
15	0				1	243.45		

Table 54. Humeral proximal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	23.36			1	22.78		
4	2	26.72	24.66	28.77	1	21.02		
5	2	25.06	24.41	25.71	0			
6	1	28.55			2	25.96	25.92	25.99
7	1	23.13			0			
8	3	29.25	27.07	33.17	1	30.10		
10	1	39.58			3	34.46	30.47	36.42
11	1	32.98			1	35.10		
12	2	35.02	33.25	36.79	0			
13	1	28.12			0			
14	1	35.84			0			
15	0				1	34.21		
16	3	37.66	35.29	38.71	0			
17	3	36.28	33.93	37.76	3	41.05	32.67	46.13

Table 55. Humeral distal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	28.59			1	37.95		
4	2	36.47	34.99	37.94	1	30.49		
5	2	33.16	32.30	34.01	0			
6	1	35.97			2	38.53	34.85	42.21
7	1	38.01			0			
8	3	37.73	37.14	42.55	1	39.64		
10	1	30.30			3	45.89	40.15	46.61
11	1	46.46			1	48.31		
12	3	43.50	43.43	50.45	0			
13	1	40.19			0			
15	0				1	54.13		

Table 56. Humeral diaphyseal mid-sagittal breadth per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	11.08			1	12.17		
4	2	13.23	12.68	13.77	1	10.16		
5	2	11.56	10.40	12.71	0			
6	1	12.54			2	13.12	12.12	14.11
7	1	9.11			0			
8	3	13.13	11.47	15.99	1	13.05		
9	0				3	13.36	12.18	15.79
10	1	15.93			1	12.18		
11	1	15.49			1	15.04		
12	3	15.42	13.56	17.42	0			
13	1	11.97			0			
14	1	14.46			0			
15	0				1	16.53		
16	4	16.22	15.06	17.61	0			
17	3	17.02	16.74	18.23	4	20.95	15.91	24.42

Table 57. Radial diaphyseal length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	118.20			1	100.40		
4	2	138.68	126.85	150.50	0			
5	2	117.80	114.15	121.45	0			
6	1	133.33			2	132.75	116.55	148.95
7	1	115.45			0			
8	3	161.60	145.99	163.52	1	155.52		
10	1	134.05			3	168.10	152.99	182.56
11	1	175.25			1	201.51		
12	2	169.73	159.25	180.20	0			
13	1	149.10			0			
15	0				1	193.45		

Table 58. Radial proximal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	9.75			1	12.53		
4	2	12.98	12.71	13.25	0			
5	2	10.78	10.50	11.05	0			
6	1	12.00			2	12.96	11.66	14.26
7	1	11.69			0			
8	3	12.66	11.28	14.35	1	14.16		
10	1	14.04			3	15.28	13.52	15.45
11	1	15.85			1	16.11		
12	3	15.60	15.06	17.52	0			
13	1	12.54			0			
15	0				1	18.33		

Table 59. Radial distal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	14.76			1	17.84		
4	2	19.03	17.71	20.35	0			
5	2	15.77	15.58	15.95	0			
6	1	18.45			2	18.74	17.74	19.74
7	1	19.44			0			
8	3	19.69	18.81	21.45	1	20.70		
10	1	20.72			3	20.84	19.07	23.33
11	1	21.68			1	24.48		
12	3	22.36	21.04	23.64	0			
13	1	18.85			0			
14	1	23.49			0			
15	0				1	24.18		
16	2	24.15	23.45	24.85	0			
17	2	25.04	23.47	26.60	3	28.37	24.32	30.49

Table 60. Radial mid-sagittal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	6.95			1	9.86		
4	2	10.25	9.60	10.90	1	8.27		
5	2	8.43	8.32	8.53	0			
6	1	8.88			2	9.63	8.00	11.26
7	1	9.80			0			
8	3	11.60	8.85	19.29	1	10.81		
10	1	12.39			3	10.70	9.08	11.69
11	1	11.96			1	12.47		
12	3	13.29	11.35	13.44	0			
13	1	10.20			0			
14	1	12.89			0			
15	0				1	14.02		
16	4	13.45	12.13	22.24	0			
17	3	13.94	12.01	15.52	4	14.97	12.08	16.03

Table 61. Femoral diaphyseal length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med	min.	max.	n	med	min.	max.
3	1	183.99			0			
4	2	240.25	205.51	274.99	0			
5	1	219.75			0			
6	1	245.49			0			
7	1	211.99			0			
8	3	308.99	279.45	310.51	1	305.45		
10	1	253.51			3	305.80	288.10	363.57
11	1	321.99			1	351.41		
15	0				1	331.15		
17	0				1	370.57		

Table 62. Femoral diaphyseal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	39.42			0			
4	2	49.64	48.56	50.71	1	34.30		
5	1	41.60			0			
6	1	47.47			0			
7	1	46.64			0			
8	3	51.80	47.22	58.32	1	57.40		
10	1	53.02			3	58.75	56.54	62.53
11	1	26.18			1	65.50		
13	1	52.10			0			
14	1	65.24			0			
15	0				1	63.60		
16	2	63.94	62.37	65.51	0			
17	2	64.81	64.59	65.02	2	67.85	64.74	70.95

Table 63. Femoral mid-sagittal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	13.62			0			
4	2	16.04	15.78	16.30	1	10.07		
5	2	16.23	12.73	19.73	0			
6	1	15.69			0			
7	1	14.04			0			
8	3	15.78	15.73	18.96	1	18.16		
10	1	17.70			3	19.12	19.01	20.14
11	1	19.19			1	23.57		
12	2	27.54	19.99	35.08	0			
13	1	19.26			0			
14	1	21.79			0			
15	0				1	20.94		
16	4	23.12	22.76	24.41	0			
17	3	23.30	22.79	25.20	4	24.66	20.12	28.85

Table 64. Fibular diaphyseal length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	146.10			0			
4	2	202.01	178.57	225.45	0			
5	1	176.40			0			
6	1	202.31			0			
7	1	177.75			0			
8	3	249.15	230.52	261.10	1	243.20		
10	1	206.51			3	251.75	228.15	287.10
11	1	262.25			1	307.51		
12	1	249.10			0			
13	1	225.25			0			
14	1	321.15			0			
15	0				1	281.70		
17	0				2	303.68	302.30	305.05

Table 65. Tibial diaphyseal length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	153.10			0			
4	2	205.98	179.15	232.80	0			
5	1	183.10			0			
6	1	205.49			0			
7	1	186.10			0			
8	3	252.45	233.25	265.51	1	252.49		
10	1	210.51			3	255.15	237.99	291.11
11	1	269.21			1	306.15		
12	1	295.51			0			
13	1	232.99			0			
14	1	337.55			0			
17	0				2	308.76	305.99	311.52

Table 66. Tibial distal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	21.11			0			
4	2	26.71	23.78	29.64	1	19.74		
5	1	21.91			0			
6	1	25.47			0			
7	1	25.19			0			
8	3	29.92	29.13	30.28	1	30.72		
10	1	27.76			3	33.97	30.95	36.52
11	1	33.85			1	36.68		
12	2	33.02	29.13	36.90	0			
13	1	26.77			0			
14	1	34.56			0			
16	1	56.23			0			
17	0				2	40.25	40.00	40.50

Table 67. Tibial proximal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	33.74			0			
4	2	39.60	37.81	41.39	1	30.19		
5	1	32.25			0			
6	1	39.38			0			
7	1	39.23			0			
8	3	43.36	42.28	49.50	1	46.40		
10	1	43.48			3	48.34	44.57	55.58
11	1	50.59			1	58.60		
12	1	25.71			0			
13	1	45.49			0			
14	1	54.88			0			
16	2	48.87	39.12	58.61	0			
17	2	55.19	53.54	56.84	2	56.73	53.44	60.02

Table 68. Tibial mid-sagittal breadth dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	10.48			0			
4	2	13.88	13.44	14.31	1	8.47		
5	1	13.31			0			
6	1	13.31			0			
7	1	12.78			0			
8	3	15.47	13.41	17.64	1	16.30		
10	1	15.45			3	15.16	15.01	19.56
11	1	17.35			1	19.74		
12	1	17.83	16.55	19.11	0			
13	1	15.29			0			
14	1	18.66			0			
16	4	18.34	15.81	19.19	0			
17	3	19.90	19.42	20.59	4	20.45	18.12	25.69

The length and breadth measurements being larger in males than in females could be because males tend to have larger and thicker bones than females (Cunningham et al., 2017). The diaphyseal length did not have a high percentage of males being larger. This

could be due to males not going through a growth spurt until puberty (Cunningham et al., 2017), which accounts for why all females between 3-7 years old were larger than males. Although the DFA of the long bone breadth dimensions was based on a small sample that did not evenly represent all age groups, it does provide some promise of a potentially accurate method for estimating the sex of subadult decedents based off long bone measurements. That the method worked across age groups warrants further research. The uneven number of individuals, the small sample size, and methodological variation may have affected the results. More statistical analyses need to be implemented on larger and more diverse populations to further evaluate this method.

Tarsals

Tables 69-78 shows the results for the calcaneal and talar measurements. Due to the minimal number of individuals per age and per sex, no statistical analysis was implemented on the tarsals. Evaluating each measurement separately within each age group, on average, males were larger than females 82.6% of the time for the talar dimensions and 60.0% of the time for calcaneal dimensions. Thus, it may be fruitful to conduct further analysis on these elements, especially for the talus, for which males were 100% larger than females for the maximum width and length of the talus and maximum width of the trochlea. In order to fully examine if the measurements for the talus and calcaneus provide useful evidence for estimating sex, as suggested by Steele (1976), more data are needed (particularly for ages under 11), and additional statistical analysis needs to be completed (e.g., DFA).

Table 69. Talar maximum length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	25.41			1	25.36		
4	2	35.39	31.47	39.31	0			
5	2	31.98	31.68	32.27	0			
6	1	36.35			2	36.34	34.68	37.99
7	1	41.70			0			
8	3	43.22	38.78	48.03	1	44.65		
10	1	37.85			3	47.07	44.14	51.71
11	1	45.79			0			
12	3	49.54	46.10	55.38	0			
13	1	39.23			0			
14	1	50.87			0			
15	0				1	51.87		
16	4	51.61	46.98	54.03	0			
17	3	53.30	50.20	54.65	4	59.47	55.03	65.15

Table 70. Talar maximum width dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	17.50			1	20.74		
4	2	26.88	23.73	30.02	0			
5	2	22.09	21.65	22.53	0			
6	1	25.63			2	27.56	27.44	27.68
7	1	25.69			0			
8	3	32.40	25.58	35.73	1	37.88		
10	1	25.98			3	37.10	29.99	41.53
11	1	34.03			0			
12	3	35.05	35.02	35.71	0			
13	1	33.17			0			
14	1	39.11			0			
15	0				1	41.81		
16	4	37.61	36.59	40.58	0			
17	3	41.61	39.12	41.87	4	43.46	40.95	45.50

Table 71. Talar body height dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	12.99			1	15.14		
4	2	18.79	18.20	19.37	0			
5	2	15.82	15.46	16.18	0			
6	1	17.17			2	20.48	19.78	21.18
7	1	21.34			0			
8	3	25.49	21.13	26.29	1	23.96		
10	1	19.11			3	29.85	23.79	32.20
11	1	27.07			0			
12	3	27.97	25.31	33.04	0			
13	1	24.94			0			
14	1	32.56			0			
15	0				1	33.77		
16	4	32.88	31.77	34.87	0			
17	3	33.68	32.07	40.34	4	33.06	29.03	39.04

Table 72. Talar maximum width of the trochlea dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
4	2	22.21	20.47	23.94	0			
5	2	19.94	19.85	20.02	0			
6	1	23.99			2	24.65	21.97	27.33
7	1	21.60			0			
8	3	25.05	24.19	26.53	1	27.30		
10	1	20.53			3	26.39	25.69	27.13
11	1	27.58			0			
12	3	24.78	24.74	26.67	0			
13	1	24.11			0			
14	1	28.41			0			
15	0				1	29.44		
16	4	27.17	21.35	28.65	0			
17	3	29.58	27.75	30.30	4	32.80	28.85	34.21

Table 73. Talar maximum length of trochlea dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1. Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	10.59			0			
4	2	18.42	15.72	21.12	0			
5	2	15.11	12.66	17.56	0			
6	1	12.93			2	22.54	21.02	24.06
7	1	19.57			0			
8	3	25.58	22.64	28.02	1	26.91		
10	1	22.97			3	29.39	24.90	32.99
11	1	27.79			0			
12	3	31.56	28.99	33.04	0			
13	1	24.49			0			
14	1	31.95			0			
15	0				1	31.73		
16	4	30.88	29.78	33.40	0			
17	3	31.10	30.96	33.21	3	38.23	32.11	39.98

Table 74. Calcaneal load arm length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	22.34			1	27.76		
4	2	31.64	30.36	32.92	0			
5	2	30.79	29.10	32.47	0			
6	1	35.56			2	32.50	30.27	34.73
8	3	41.56	36.81	42.27	1	38.78		
10	1	32.69			3	42.73	41.53	47.53
11	1	41.04			0			
12	3	43.23	38.57	45.57	0			
13	1	37.26			0			
14	1	48.39			0			
15	0				1	48.03		
16	4	45.31	42.18	45.96	0			
17	3	49.11	43.84	50.85	4	53.57	47.19	59.79

Table 75. Calcaneal load arm width dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	16.78			1	18.99		
4	2	25.41	21.74	29.08	0			
5	2	22.48	20.97	23.98	0			
6	1	29.17			2	26.05	23.48	28.61
7	1	28.64			0			
8	3	30.18	25.51	35.36	1	31.29		
10	1	28.64			3	34.45	32.45	36.81
11	1	37.61			0			
12	3	36.61	34.48	37.95	0			
13	1	34.46			0			
14	1	38.52			0			
15	0				1	41.88		
16	4	38.73	37.84	39.48	0			
17	3	38.98	37.69	39.52	4	42.03	41.17	43.83

Table 76. Calcaneal maximum length dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	34.88			1	33.20		
4	2	44.19	42.27	46.10	0			
5	2	40.97	40.41	41.52	0			
6	1	46.98			2	44.52	40.94	48.10
7	1	51.66			0			
8	3	57.27	51.46	59.50	1	58.23		
10	1	49.47			3	62.75	57.65	64.18
11	1	58.50			0			
12	3	67.15	64.64	68.60	0			
13	1	56.69			0			
14	1	76.10			0			
15	0				1	38.85		
16	4	75.70	69.92	79.03	0			
17	3	78.72	70.98	78.78	4	74.66	39.14	80.05

Table 77. Calcaneal minimum width dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	12.02			1	14.78		
4	2	16.74	16.37	17.11	0			
5	2	14.94	13.59	16.29	0			
6	1	18.91			2	17.27	16.87	17.67
7	1	16.66			0			
8	3	19.22	19.12	24.14	1	21.29		
10	1	19.94			3	21.55	19.64	23.85
11	1	23.65			0			
12	3	24.25	22.24	26.13	0			
13	1	21.98			0			
14	1	24.23			0			
15	0				1	26.94		
16	4	24.31	23.03	29.96	0			
17	3	24.72	23.85	26.19	4	27.63	22.89	28.82

Table 78. Calcaneal Body Height dimensions per age, in years. Females (left) compared to males (right). min=minimum, max=maximum, med=median (or data point, for n=1). Measurements in mm.

age	n	med.	min.	max.	n	med.	min.	max.
3	1	22.09			1	20.91		
4	2	29.26	26.61	31.91	0			
5	2	24.86	23.71	26.00	0			
6	1	28.46			2	13.07	3.32	22.81
7	1	30.86			0			
8	3	35.45	31.26	35.48	1	33.37		
10	1	26.72			3	35.22	33.17	37.27
11	1	37.07			0			
12	3	45.24	29.62	46.08	0			
13	1	33.81			0			
14	1	37.32			0			
15	0				1	87.85		
16	4	42.43	38.74	44.64	0			
17	3	46.63	45.51	49.62	4	48.76	44.71	59.69

CONCLUSION & RECOMMENDATIONS

This thesis examined various methods to assess their validity for estimating the sex of subadult skeletal elements. The elements included are the skull, dentition, ilium, long bones, talus, and calcaneus. The methods evaluated in this thesis included those for which previous studies reported statistical significance and useful accuracy (Schutkowski, 1993; Weaver, 1980) and some that did not (Hunt, 1990). This thesis also included multiple methods for which previous authors suggested further testing on different and more diverse sample populations (Molleson and Cruse, 1998; Veroni et al., 2009).

The individuals examined were between 3 and 17 years of age (n=39, 25 females, 14 males) and were part of the Hamann-Todd Osteological Collection housed at the Natural History Museum in Cleveland, Ohio. This sample population is reported to include individuals identified as American, with presumed African and/or European ancestry. Previous researchers mainly used European sample populations; therefore, selecting a collection with a large number of individuals of probable (at least partial) African-American descent provided the opportunity for a more comprehensive evaluation.

Limitations

There are noteworthy limitations to the results of this study, in particular the small number of individuals within each age group. For most measurements/criterion, there were minimal-to-no females and/or males for each age group and rarely were there two or

more individuals per age and sex. Thus, for most cases, statistical analysis within each age group was not possible. Another drawback is that the methods employed by some previous studies could not be replicated due to not being able to reproduce the original researchers' methods (e.g., due to bisected crania). Further, the sample used for this study is not of a modern population and thus may not be an accurate model for modern forensic anthropology cases. Despite these issues, the studies reviewed in this thesis and the results of the analysis performed do provide a baseline for future research. It is advised that more research on more diverse and extensive subadult sample populations is pursued. A barrier to this is that many subadult sample populations are small and the collections are broadly located (e.g., Canada, England, France, South Africa, and United States of America).

Some individuals observed for this thesis exhibited evidence of skeletal growth and development abnormalities that likely contributed to marked reduction in measurements compared to other individuals within the same age range; therefore, those with marked variations were removed from the data (i.e., HTH 1589, HTD 0.207). The presence of skeletal abnormalities in the sample can likely be partially explained by skeletal collections being biased towards individuals representing marginalized groups and low socioeconomic classes that experienced more issues with access to quality food, housing, and healthcare (Latham et al., 2018; Muller et al., 2017). This could have contributed to the presence of certain diseases (e.g. TB), as well as conditions traced to nutritional deficiencies (e.g. rickets). It is possible that some conditions that affected

skeletal growth and development went undetected in the sample and influenced the results of this thesis.

Key Findings

This study found substantial variation in the characteristics and metrics employed to estimate sex, which supports that these traits present as a spectrum rather than easily dichotomized traits. Some methods directly tested produced statistically significant and reasonably accurate results when analyzed as separate variables (i.e., long bone breadths and maxillary lateral incisor dimensions) while others evinced very low accuracy, even less than 50.0%.

Analysis of dental metrics produced a significant result for the deciduous left maxillary lateral incisor ($p = 0.02$, $r = 0.81$, 73.3% individuals sexed correctly), while the remaining dimensions did not produce significant results when analyzed separately. Although previous researchers found that the permanent dentition (Garn et al., 1963), especially the canines (Hassett, 2011) produced the most statistically significant results, this thesis found that the deciduous lateral incisor produced the most significance, which differs from conclusions of some researchers (Cardoso, 2010; DeVito & Saunders, 1990). However, with the limited number of individuals per age and per sex, it was not possible to conduct statistical analysis across the age groups via the methods used for this thesis.

For the mandible, the highest level of overall accuracy was for the protrusion of the chin (64.9%) (after Schutkowski, 1993); however, per sex, the highest level of accuracy was 69.9% for females for both the anterior dental arcade shape and the gonion region (Schutkowski, 1993), while for males it was 71.4% for the mentum (Molleson &

Cruse, 1998). The results of this thesis are substantially lower than the original researchers are but still warrant more research of these traits for estimating the sex of subadult decedents.

The most accurate result for the cranial metrics was a discriminant function analysis (DFA) based on ten measurement (i.e., GOL, NOL, OBL, BPL, BNL, NPL, PBL, PPL, PNL, OPL) and 10 individuals (F=5, M=5) (p=0.001, 100% accuracy). However, this analysis was on a wide age range of individuals and of a small sample size; therefore, this result needs to be validated on larger sample and by analyzing the effects of controlling for age. The temporal bone, focusing on the mastoid length, was minimally analyzed due to the minimal number of decedents per age and per sex, as well with only 57.1% of females being larger than males (i.e., substantial overlap in the data). This could be due to the mastoid process not being fully developed at a young age (Cunningham et al., 2017). Analysis of the occipital bone encountered the same issue as the temporal bone with not enough decedents to run statistical analysis. Analysis of the eye orbits resulted in only 51.4% of decedents being sexed accurately.

For non-metric methods of the pelvis, results ranged from 46.4-53.6% accuracy, which was much lower than the original researcher's results (Schutkowski, 1993; Weaver, 1980). Although some analyses did produce somewhat accurate results per sex (e.g., 75.0% of males sexed correctly via the arch criteria), techniques are generally not useful if they only produce accurate results for one sex.

Analyses of the long bones did produce some accurate results, in line with what was noted by some previous researchers (Stull et al., 2017). A discriminant function

analysis of 12 breadth dimensions across the 6 long bones produced a highly accurate result (p = 0.0004, r = 0.94, 95.8% accuracy, n=11 females, 6 males). Also, a DFA of just the distal breadth dimensions of the six long bones produced an accurate result (p = 0.0002, r = 0.83, 95.8% accuracy, n=12 females, 6 males). For the talus and calcaneus (after Steele, 1976), males were predominantly larger than females, although no extensive data analysis was conducted due to the small sample sizes.

Recommendations for Additional Studies per Element

This thesis included substantial statistical analysis on only a few skeletal elements (i.e., cranium, dentition, long bones). Further analysis needs to take place on the remaining data to fully ascertain the degree to which the data may contribute to assessing methods for estimating sex in subadult skeletal remains. Such analysis could include combining data into different age groups or conducting analysis that controls for or is not sensitive to age variation within the sample. It is recommended to combine this study's data with data gathered from other collections to enable further statistical analysis, especially where such analysis was prevented due to a small sample size.

For the non-metric methods, it is recommended the eye orbits (after Molleson & Cruse, 1998) should be retested on more skeletal samples in order to understand why this study has a considerably higher rate of accuracy for females versus males. For the mandible, more tests are needed to identify whether the accuracy based on the three mandibular morphologic traits would stay consistent or change when retested on various sample populations (Schutkowski, 1993). The non-metric methods of the pelvis (i.e., depth of the greater sciatic notch, curvature of the ilium) resulted in low accuracy (50%

or less), and it is thus recommended that these methods not be applied without refinement or justification (Schutkowski, 1993). Further, it is recommended that the non-metric methods that resulted in low statistical significance when compared to the original studies (i.e., Schutkowski, 1993; Weaver, 1980) may need to be restricted towards historical populations of similar regions as the original research and not used for forensic cases.

It is further recommended that future studies include more analysis of deciduous dentition, possibly including the molars, in order to identify if a higher percentage of accuracy can be achieved to match that which was reported by the original researchers (i.e., Black III, 1978; De Vito & Saunders, 1990). It is also recommended that researchers more closely evaluate the mandibular dentition, in particular, and also compare the left versus right dentition. Future work on dentition might also focus on the buccolingual dimensions of the permanent dentition, for which males are consistently larger than females (DeVito & Saunders, 1990; Garn et al., 1964).

The results of the craniometric analysis evince that males tend to be larger than females; which is an expected result due to previous researchers' conclusions (e.g., Gonzalez, 2012). Thus, it is recommended that future studies collect additional data on more diverse populations and include additional statistical analyses, such as DFA. It is also recommended that more analysis of the cranial groupings identified as CAN1, CAN2, and CAN3 by Gonzalez (2012) be performed to test the author's conclusions more thoroughly. For the occipital bone and temporal bone, it is recommended that more tests of sexual dimorphism should be conducted, and the focus should be on foramen

magnum length and the breadth of the occipital condyles (Giles & Elliot, 963; Holland, 1986; Veroni et al., 2009).

For the ilium, research should continue for the sciatic notch measurements and maximum measurements of the ilium. Although the results T-tests did identify a significant difference between sexes, the measurements did show some differences between females and males; therefore, more research could help reveal if there are useful levels of sexual dimorphism with these four measurements when including various sample populations worldwide. For the long bones, based off this thesis and the significant findings of Stull et al. (2017), it is recommended that future research focuses on the breadth dimensions, in particular the mid-sagittal breadth dimensions, and on diaphyseal lengths, including in more diverse sample populations. It is also recommended that more studies focus on the talus and calcaneus due to the finding in this thesis that males are significantly larger than females in some dimensions.

Methodological Recommendations

Additional types of data analysis methods should be performed more regularly, including principal components analysis (PCA) and mixture discriminant analysis (MDA) as well as more detailed reporting of effect size and confidence intervals for evaluating the significance of findings (Smith, 2018). These methods have, at times, proven to be more accurate and should be employed to verify the validity of the results of discriminant analysis. Also, more combinations when running discriminant function analysis should be tested, incorporating features from different elements, to produce the most accurate models for estimating sex.

It is recommended that intraobserver error be tightly controlled when examining multiple populations and combining the resulting data to produce a larger sample size upon which to test the accuracy of methods. This might most readily be accomplished by a single researcher or by a team with highly detailed documentation of methods. Together, such studies can help continue the efforts to find a method to estimate the sex of subadult descendants with high accuracy.

Changes occur so rapidly in the subadult skeleton that understanding the growth and development of specific features used to estimate the sex of a descendent should be analyzed carefully to reveal how the features can be altered due to environmental influences. With this in mind, it is recommended that the focus in estimating sex should be on the 8-11 years age group, before the pubertal age when sex hormones are least active (Hochberg, 2012). This age group is where it is hardest to identify sex and should be focused on more intently.

If sex is to be estimated for forensics cases, high accuracy is critically important to avoid erroneously limiting search parameters. Some methods tested in this thesis were found to produce reasonably accurate estimates of subadult sex, demonstrating that it may be possible to achieve a high level of accuracy for estimating subadult sex from skeletal remains. Because sexually dimorphic features may be population-specific, the accuracy of methodologies may be improved by employing methods that are either widely applicable or based on adults within the same population (e.g., Hassett, 2011). However, a problematic aspect of the latter approach is that it would require the estimation of ancestry prior to estimating sex, which may be neither possible nor ethical

(Bethard & DiGangi, 2020). These are aspects that need to be addressed by future research to continue the endeavor of finding a statistically sound method to estimate subadult sex across sample populations.

Reevaluating the Dichotomization of Sex

In closing, it is useful to reevaluate the utility of a binary methods for estimating and reporting biological sex. It is recommended that the methods that have a dichotomized classification of sex characteristics (female/male) (e.g., Schutkowski, 1993; Weaver, 1980) could be improved upon by altering the male/female categorization to a scaled system (i.e., -2, -1, 0, 1, 2) to reflect the continuum in how traits actually present. This could improve accuracy and potential implementation of these methods in forensic contexts. In addition, the greater use of scaled methods could facilitate additional research into how these traits vary across individuals as well as facilitate a potential reconsideration of utility, or lack thereof, of a binary classification of sex in the skeleton.

Along these lines, a change in descriptive terminology from 'feminine' and 'masculine' towards a scale from 'gracile' to 'robust' may facilitate efforts to employ scaled methods and re-evaluate how sex is evaluated and reported in forensics cases. Although it is the job of the forensic anthropologist to match skeletal remains to a government issued I.D. (e.g., driver’s license, birth certificate) which requires using the terminology these documentations use, it is also the responsibility of the anthropologist to be ethical and unbiased and scientifically accurate. Estimating 'sex' and 'race' as dichotomized needs to be reevaluated.

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APPENDIX

Data collected from Hamman-Todd Osteological collection for this thesis.

Table 79. Data for permanent dentition. DEC=Decedent based off collection #, buccolingual dimensions.

DEC	**6**	**7**	**8**	**9**	**10**	**11**	**22**	**23**	**24**	**25**	**26**	**27**
0624									5.52	5.53		
2036			6.73	6.78	5.78			6.25	5.79	5.88	6.29	
1156				6.10					7.61	7.56		
2074			7.47	7.08	6.96			5.91	5.63	5.51	5.86	
0872							6.74	5.93	5.22	5.35	6.07	7.14
0632										6.45	7.03	
0526		6.82	6.82	6.81	6.68			6.11	5.50	5.54	6.01	
1240	8.63				5.99	8.48				5.36		
1772	7.13	5.12	6.14		5.44	7.15	6.77	5.01	4.61	6.12	5.30	6.70
0645	7.70	5.90	7.09	7.1	6.04	7.47	7.15	6.00	5.27	5.19	5.99	7.32
2118	8.78	6.51	6.06	6.13	6.69	8.5			7.85			
0633				7.12				6.26	5.73	5.81	6.07	
2135	8.19	6.12			6.22	8.13	7.35		5.27	2.73		3.73
1232	8.62	6.8	7.49	7.30	6.51	8.7	7.82	6.59		6.15	6.75	7.79
0485	8.01	6.62	7.31		6.94	8.22	7.73	6.55			6.67	
0576	8.22	6.54	7.06	7.20		8.57	7.10	7.86	5.59			7.30
0527	7.58	7.03						6.04	5.42	5.42	5.84	
1606		6.73	7.11		6.79	12.85	5.47			6.18	6.56	
1041	7.42						8.03	9.01		7.13		8.19
4056												
1784			7.01	7.58						5.72		
2144												
1834	4.93	6.44	5.90	5.85	6.51	4.97	6.67	6.84	7.38	7.35	6.88	5.72
1441		6.38		6.97	6.34				5.31	5.40	5.79	
1688		6.63		7.17	6.32		8.09	8.01	6.01	5.79	6.19	8.26
0710		6.49						6.4			5.86	
1589	9.29	6.82	7.39	8.27	7.14	9.24	8.39	6.72	8	5.92	6.49	8.43
0548	9.12	7.36	7.58			9.35		5.87	5.62	8.39		
3470	10.12	7.67				10.26	8.31					

Table 80. Data for permanent dentition. DEC = Decedent based off collection #, mesiodistal dimensions.

DEC	6	7	8	9	10	11	22	23	24	25	26	27
1098									5.52	5.45		
0624									5.75	5.86		
2036			8.39					5.83	5.05	5.01	5.85	
1156			5.80							9.10		
2074		6.70			6.63			5.70	5.10	5.16	5.55	
0872							6.55	5.27	5.01	5.05	5.27	6.56
0632										5.87	6.53	
0526		7.45	8.89	9.11	7.45		6.84	6.41	5.66	5.58	6.40	6.70
1240	7.58				7.36	7.61				5.46		
1772	6.21		7.22		8.01	6.15	5.60	4.84	4.77	4.81	4.96	4.77
0645	6.93	5.52	6.88	6.71	5.37	6.77	5.88	5.12	3.03	3.61	4.83	5.68
2118												
0633								5.50	5.28	5.24	5.52	
2135	7.48	6.17			6.37	7.47	3.98		5.33	2.76		3.49
1232	7.82	7.30	8.69	8.81	7.42	7.72	21.11	6.49		5.30	6.46	7.03
0485	7.67	6.43			6.72	7.17		6.01				
0576	7.07	7.05	8.48	8.52		6.83	6.77	5.98	5.34			6.64
0527	7.26	6.09						5.91	5.20	5.41	5.72	
1606		7.00	8.64		10.75	7.97	7.04			5.53	6.36	
1041	6.44						7.5	6.47		7.91		7.65
4056												
1784			7.73	8.97				5.83		5.51	5.87	
2144												
1834	5.87	6.05		5.32	5.81	5.77	6.31	7.29	8.27	8.27	7.37	6.58
1441		6.91		9.54	6.81				4.22	5.72	6.25	7.94
1688		6.96			6.79		7.14		4.54	3.94		6.95
0710		7.03						5.45			5.56	
1589	8.11	7.02	8.04	8.00	7.07	8.02	7.34	6.00	4.71	4.82	5.74	7.26
0548	7.73	7.02			6.98	6.86		5.55	4.99	5.62	5.58	6.76
1711												
3470	9.17					8.82	8.31					

Table 81. Data for deciduous dentition. DEC = Decedent based off collection #, buccolingual dimensions.

DEC	C	D	E	F	G	H	M	N	O	P	Q	R
0624	6.10	4.68				6.12	5.21					5.76
0632	6.55					6.21						
0633	6.14				5.32	5.59						5.23
1074	6.45	4.76	5.12	5.00	4.83	6.34	5.70	4.09		3.84	4.10	5.59
1098	5.77					5.83	5.66					5.56
1115	6.02				4.85	5.98	5.22					5.25
1156							6.34					
1509	5.22	4.59	4.90	4.99	4.45	5.34	5.31		3.70	3.66	3.86	5.28
2036	6.05						5.74					5.88
2074	6.24					6.15	5.17					5.08
2141	5.82		4.46	4.38	4.24	5.80	5.10	3.73	3.34	3.32	3.88	5.34
0710							5.33					5.56
1557	5.94	5.00	5.20	5.20	4.98	6.01	5.04	4.30	3.95	4.11	4.14	5.22
1784	5.96				4.63	5.88						5.51
1950	5.13						5.42	4.26	3.99	3.95	4.32	5.45
2144	5.54	4.80		4.98	4.77	5.57	4.89					4.95

Table 82. Data for deciduous dentition. DEC = Decedent based off collection #, MD = mesiodistal dimensions.

DEC	C	D	E	F	G	H	M	N	O	P	Q	R
0624	7.00	5.04				6.89	5.82					5.45
0632	6.54					6.78						
0633	6.50				5.49	6.70						5.78
1074	6.66	5.24	6.31	6.54	5.31	6.66	5.88	4.53		3.82	4.79	5.81
1098	7.41					7.29	6.02					5.89
1115	6.81				5.55	5.59	6.11					6.25
1156							6.89					
1509	6.85	5.48	6.98	6.89	5.26	6.47	5.85		4.50	4.41	4.84	5.85
2036	6.78						5.65					5.77
2074	6.48					6.51	5.80					5.89
2141	5.55		6.00	5.74	4.92	5.85	4.86	4.69	3.88	3.89	4.62	5.28
0710							5.98					6.14
1557	6.65	4.58		5.83	5.00	6.75	5.72	4.42	4.02	3.96	4.26	5.56
1784	6.73				4.25	6.15						6.20
1950	5.89						6.07	4.89	4.48	4.50	4.70	5.87
2144		4.80		4.77	6.57				5.73			

Table 83. Data for cranial dimensions. DEC = Decedent based off collection #. L=length. GOL = glabella-opisthocranion, NOL = nasion-opisthocranion, BOL = bregma-opisthocranion, OBL – opisthocranion-basion, BBL =basion-bregma, BPL = basion-prosthion, BNL = nasion-nasion, NPL = nasion-prosthion, PBL = PNS(posterior nasal spine) – basion, PPL = PNS-prosthion, PNL = PNS-nasion, OPL = opisthocranion-prosthion, PBR = prosthion-bregma. Measurements in mm.

DEC	GOL	NOL	NBL	BOL	OBL	BBL	BPL	BNL	NPL	PBL	PPL	PNL	OPL	PBR
1074	107.00	162.70	155.50	124.90	85.20	133.10	105.50	111.80	45.61	39.90	49.60	179.90	146.70	
1098	149.30	149.10	92.10	99.80							38.09	48.54		
1772	154.50	163.90	107.90	113.10	111.80	135.80	80.30	93.10	58.87	38.14	81.40	92.80	183.60	160.50
1156	159.90	159.70	97.60	112.20					47.91				178.50	136.90
1950	161.40	156.50			91.60			73.80		35.22		8.00		
1041	164.30	165.60	105.00	107.90	106.50	124.50		94.90		41.66		64.50		
0645	165.90	161.50	98.40	135.30	59.80	136.50	110.70	122.20	57.74	68.88	43.80	62.90	164.70	146.10
0872	166.50	164.30			100.10		83.40	88.70	59.27	41.25	43.60	59.50	137.10	
1688	168.20	166.50	102.30	102.50	118.40	138.60	82.10	87.40	54.00	40.20	41.20	55.30	190.80	150.00
0526	168.60	167.40	98.70	130.50					44.99				176.60	
0527	170.20	167.70			97.50			97.20		42.10		60.80		
1232	176.80	177.60	104.80	118.60	110.80	127.40	56.90	100.50	64.43	48.99	57.20	61.10	210.10	166.50
0548	179.70	179.00			113.70		96.00	99.70	66.52	42.90	53.00	66.70	176.20	
0404	181.50	181.30			118.90		87.30	91.30	46.98	43.82	45.80	60.40	155.10	
3470	184.10	183.40			114.90		95.70	96.90	67.90	39.40	59.60	70.50	208.00	
3112	186.80	185.40			121.70		91.80	95.90	35.49	41.79	50.10	65.50	210.10	
1509									45.44		39.00	48.00		
2141									48.15		42.00	53.20		
2074			98.10						51.07		40.07	56.60		145.90
1441									56.81		59.30	44.10		
0710									67.47		51.00	65.60		
0633				131.10	111.70	131.10								
0485								93.32	63.68	92.07	50.44	63.70		
0576				137.20	97.60	122.00								
1606							42.97	96.30	63.10	42.53	52.40	61.40		
1711							89.70	91.90	62.72	42.63	49.40	61.20		

Table 84. Data for cranial dimensions. MW = maximum width, MDBZ = maximum diameter bi-zygomatic, NB = nasal breadth, OFL = Opisthion-forehead length, ML = mastoid length. Measurements in mm.

DEC	MW	MDBZ	NB	OFL	ML
1074					24.77
1098					18.31
1772					22.92
1156					23.07
1950					10.31
1041					22.75
0645					26.32
0872		108.90	24.20	168.50	19.41
1688					22.58
0526					29.58
0527					23.57
1232					29.67
0548					32.22
0404		112.20	23.37	178.50	25.58
3470		127.30	24.00		25.71
3112		121.40	22.20		23.18
1509		90.40	18.80		15.66
1557					14.91
2141			21.27		
1115					22.06
1784					21.58
2144					12.65
0624					18.19
2036					17.89
1834					31.47
2074					23.88
1441			23.39		188.90
0632					20.79
0710		93.00	21.70		23.13
1240					17.83
2118					23.89
0633					30.40
0485					27.47
0576					29.80
1606		122.50	22.00		24.77
1589					26.26
1711		117.80	24.40		26.20

Table 85.Data for occipital dimensions. DEC = Decedent based off collection #. PBW = pars basilaris width, PBL = pars basilaris length, FML = foramen magnum length, FMB = foramen magnum breadth, LOCL – left occipital condyle length, ROCL = right occipital condyle length, LOCB = left occipital condyle breadth, ROCB = right occipital condyle breadth, BCB = bicondylar breadth. Measurements in mm.

DEC	PB W	PB L	FML	FMB	LOCL	ROCL	LOCB	ROCB	BCB
1074		19.25	29.69		17.04		9.95		
2141	20.05	18.12	30.02	23.76	16.89	21.11	9.89	9.54	38.92
1115			31.15			23.16		10.35	
1098	`	18.97	44.41		21.8	22.46	10.58	9.50	
0624		18.72	35.32		18.93	17.08	8.08	9.15	
2036			29.84			24.22	11.43	11.43	
0872	25.85	22.69	30.05	24.76	21.11	18.4	11.38	10.15	40.39
2074		19.6	33.96		22.44	21.77	9.75	10.39	
1156			36.02		21.35	20.84	11.00	9.12	
0632			30.23		20.40	20.50	11.01	9.06	
0526		27.07	33.50		19.44	17.28	11.24	10.35	
0645		22.25	33.11		20.78	23.24	12.15	12.2	
1772		23.93	34.23		22.38	18.83	10.57	11.04	
1240		24.17	34.33		24.58	24.03	10.56	11.01	
2118			18.48		21.39	21.03	12.66	11.74	
0633		23.83	33.39		22.83	24.21	11.24	11.32	
0576			29.54		21.45	20.87	12.21	10.90	
0485		27.98	29.73		24.94		13.04		
1232		27.03	34.08		21.93	23.75	15.06	13.22	
0527			36.46		23.73	24.73	11.28	12.45	
1606			24.50	28.48	21.90	11.32	22.08	11.91	43.77
1041			34.32		22.89	20.57	13.30	9.30	
1557							10.28	1045	
1950	16.22	17.43	31.03	24.43	21.34	20.44	10.37	10.79	40.26
2144	16.91	17.78	31.02	22.79	22.24	20.59	10.71	10.36	37.56
1784		18.78	35.80		21.37	23.28	11.02	11.85	
1834		20.61	33.39		19.18	19.97	9.96	10.39	
1441	22.69	22.09	36.14	29.3	24.33	23.16	13.10	13.44	50.9
0710	27.31	23.01	36.47	26.35	21.38	25.56	12.03	11.58	45.23
1688		22.21	36.92		23.39	10.85	21.08	10.99	
0404	25.74	24.29	37.34	29.38	25.94	22.57	10.94	12.18	48.5
3112	22.02	25.83	36.64	26.60	24.62	11.25	22.36	12.92	40.71
1589		24.96	33.06		24.84	23.2	10.85	11.61	
0548			33.98		20.83	24.34	12.30	13.18	
1711	20.03	29.18	35.78	27.04	18.6	11.36	17.83	11.11	44.09
3470			38.32	28.34	21.25	22.06	11.21	12.94	45.81

Table 86. Data for long bone dimensions. dimensions. DEC = Decedent based off collection #. First letter indicates long bone: H = humerus, U = ulna, R = radius. The following 2 letters indicate dimension: DL = diaphyseal length, PB = proximal breadth, DB = distal breadth, MSB = midsagittal breadth. Measurements in mm.

DEC	HDL	HPB	HDB	HMSB	UDL	UMSB	RDL	RPB	RDB	RMSB
1509	133.25	23.36	28.59	11.08			118.20	9.75	14.76	6.95
1557	122.40	22.78	37.95	12.17	109.55	10.16	100.40	12.53	17.84	9.86
2141	163.55	24.66	34.99	13.77	139.25	9.79	126.85	12.71	17.71	10.90
1074	197.49	28.77	37.94	12.68	163.45	7.44	150.50	13.25	20.35	9.60
1950		21.02	30.49	10.16	94.64	9.95	84.06			8.27
1115	165.52	24.41	32.30	10.40	131.57	6.81	121.45	11.05	15.58	8.32
1098	158.10	25.71	34.01	12.71	126.75	8.21	114.15	10.50	15.95	8.53
0624	176.48	28.55	35.97	12.54	119.59	6.92	133.33	12.00	18.45	8.88
1784	193.40	25.92	42.21	14.11	162.45	10.09	148.95	14.26	19.74	11.26
2144	154.10	25.99	34.85	12.12	129.55	8.61	116.55	11.66	17.74	8.00
2036	159.85	23.13	38.01	9.11	132.80	8.16	115.45	11.69	19.44	9.80
1156	195.99	29.25	37.73	13.13	164.25	8.65	145.99	11.28	18.81	8.85
2074	209.99	27.07	37.14	11.47	176.25	7.96	161.60	12.66	19.69	19.29
0872	219.12	33.17	42.55	15.99	275.68	11.82	163.52	14.35	21.45	11.60
1834	218.40	30.10	39.64	13.05	164.99	9.16	155.52	14.16	20.70	10.81
0632	185.39	39.58	30.3	15.93	146.10	12.76	134.05	14.04	20.72	12.39
1441	234.25	36.42	46.61	13.36	186.15	8.45	168.10	15.28	23.33	11.69
1688	202.51	30.47	40.15	12.18	168.25	8.37	152.99	13.52	19.07	9.08
0710	240.52	34.46	45.89	15.79	195.51	11.84	182.56	15.45	20.84	10.70
0526	224.49	32.98	46.46	15.49	190.01	9.59	175.25	15.85	21.68	11.96
0404	256.12	35.10	48.13	15.04	223.15	14.58	201.51	16.11	24.48	12.47
1240			43.50	13.56		12.97		17.52	23.64	13.29
1772	221.49	36.79	50.45	17.42	278.9	9.68	159.25	15.60	22.36	13.44
0645	255.61	33.25	43.43	15.42	196.10	11.72	180.20	15.06	21.04	11.35
2118	211.45	28.12	40.14	11.97	167.99	8.07	149.10	12.54	18.85	10.20
0633		35.84		14.46		10.61			23.49	12.89
3112	143.45	34.21	54.13	16.53	223.25	12.50	193.45	18.33	24.18	14.02
1232		35.29		16.34		12.16			23.45	12.56
0485		37.66		16.10		10.81			24.85	x22.24
0576				17.61		12.88				14.33
0527		38.71		15.06		12.63				12.13
1606		36.28		18.23		9.85				15.52
1041		33.93		16.74		10.07			23.47	12.01
4056		37.76		17.02		13.60			26.60	13.94
1589		41.05		15.91	218.99	11.86			28.37	12.08
0548				24.42		16.14				15.08
1711		32.67		19.72		11.35			24.32	14.85
3470		46.13		22.18		15.64			30.49	16.03

Table 87. Data for long bone dimensions. dimensions. DEC = Decedent based off collection #. First letter indicates long bone, F = femur, T = tibia, FB = fibula. The following 2 letters indicate dimension: DL = diaphyseal length, PB = proximal breadth, DB = distal breadth, MSB = midsagittal breadth. Measurements in mm.

DEC	FDL	FDB	FMSB	TDL	TPB	TDB	TMSB	FBDL
1509	183.99	39.42	13.62	153.10	33.74	21.11	10.48	146.10
1557	152.99	48.91	13.10	141.60	37.83	24.52	12.29	133.10
2141	205.51	48.56	16.30	179.15	37.87	23.78	13.44	178.57
1074	274.99	50.71	15.78	232.80	41.39	29.64	14.31	225.45
1950		34.30			30.19	19.74		
1115	219.75	41.60	12.73	183.10	32.25	21.91	13.31	176.40
1098	191.12	40.69	19.73	167.10	35.51	21.01	10.86	158.12
0624	245.49	47.47	15.69	205.49	39.37	25.47	13.31	202.31
1784	244.20	50.69	19.53	225.51	42.59	24.18	14.15	219.99
2144	186.80	44.41	14.66	171.99	38.08	23.88	11.79	161.99
2036	211.99	48.64	14.04	186.10	39.23	25.19	12.78	177.75
1156	279.45	51.80	15.73	233.25	43.36	29.13	13.41	230.52
2074	308.99	47.22	15.78	252.45	42.28	30.28	15.47	249.15
0872	310.51	58.32	18.96	265.51	49.50	29.92	17.64	261.10
1834	305.45	57.36	18.16	252.49	46.40	30.72	16.30	243.20
0632	253.51	53.02	17.70	210.51	43.48	27.76	15.45	206.51
1441	305.80	58.75	19.12	255.15	48.34	30.85	15.01	251.75
1688	288.40	56.54	19.01	237.99	44.57	33.97	15.16	228.15
0710	363.57	62.53	20.14	291.11	55.58	36.52	19.56	287.10
0526	321.99	26.18	19.19	269.21	50.59	33.85	17.35	262.25
0404	351.41	65.50	23.57	306.15	58.60	36.68	19.74	307.51
1240			19.99			36.90	16.55	
1772	289.75	61.19	35.08	257.60	53.82	36.44	21.58	249.10
0645				295.51	25.71	29.13	19.11	278.51
2118	273.99	52.10	19.26	232.99	45.49	26.77	15.29	225.25
0633	394.99	65.24	21.79	337.55	54.88	34.56	18.66	321.15
3112	331.15	63.62	20.94	298.55	60.78	37.53	19.17	281.70
1232		62.37	22.99		x39.12	x56.23	19.19	
0485		65.51	22.76		58.61		18.94	
0576			24.41				17.74	
0527			23.25				15.81	
1606			25.20				20.59	
1041		64.59	23.30		53.54		19.90	
4056		65.02	22.79		56.84		19.42	
1589	370.57	70.95	20.12	311.52	60.02	40.50	18.12	302.30
0548			28.85				25.69	
1711		64.74	24.48	305.99	53.44	40.00	19.49	305.05
3470			24.84				21.41	

Table 88. Data for ilial dimensions. DEC = Decedent based off collection #. SNW = greater sciatic notch width, SND = greater sciatic notch depth, IAL = ilial anterior length, IPL = ilial posterior length, IMW = ilial maximum width, IMH = ilial maximum height. Measurements in mm.

DEC	SNW	SND	IAL	IPL	IMW	IMH
1557	14.61	7.65	22.43	35.01	60.80	70.80
2141	20.32	6.67	22.30	48.81	74.89	80.57
1074	29.84	8.95	27.60	26.20	85.27	94.35
1115	19.17	8.09	15.04	52.24	68.07	74.65
1098	23.32	8.74	22.02	48.31	68.96	71.00
0624	14.39	8.81	20.02	58.91	76.95	90.17
1784	26.84	9.24	62.49	18.46	80.91	79.53
2144	23.82	9.85	18.64	47.69	70.08	72.93
2036	23.92	8.15	21.95	59.22	81.32	80.52
0872	27.51	9.85	27.51	64.65	94.08	95.87
1156	25.85	9.96	16.54	60.26	80.52	84.78
2074	29.60	10.34	20.29	64.34	85.08	86.40
1834	22.75	10.12	25.41	59.80	86.86	90.37
0632	25.42	10.30	24.43	60.92	81.85	93.91
1441	24.31	11.53			93.90	96.20
1688	30.44	12.10	20.93	67.46	89.16	93.75
0710	24.41	15.29	32.44	53.11	101.26	105.33
0526	32.98	12.86	28.98	71.68	94.18	109.28
0404	34.80	15.04	29.02	70.65	101.39	118.22
1772	23.71	14.45	30.74	59.87	96.89	99.60
0645	32.06	16.40	34.91	70.87	112.64	120.46
1240	50.05	30.59	26.38	77.45		127.30
2118	26.41	10.94	22.03	62.54	87.85	91.96
0633	48.92	33.12	28.71	75.16		11.34
3112	36.65	19.17	31.90	64.83	101.39	116.82
0485	50.86	32.95	37.18			135.60
0576	51.43	33.87	37.16			148.24
1232	41.90	37.55	33.21		131.75	
0527	56.16	38.38	33.51			136.08
1606	52.95	23.37	33.22			146.72
4056	51.30	33.57	22.65			152.73
1044	51.61	35.32	27.38			124.78
1589	17.22	16.23	10.67			99.32
1711	41.88	28.55	31.33			119.01
3470	49.09	39.46	44.51			149.60
0548	48.78	40.74	23.73			

Table 89. Data for talar dimensions. DEC = Decedent based off collection #. ML = maximum length, MW = maximum width, BH = body height, MLT = maximum length of trochlea, MWT = maximum width of trochlea. Measurements in mm.

DEC	ML	MW	BH	MLT	MWT
1509	25.41	17.50	12.99	10.59	5.52
2141	31.47	23.73	18.20	15.72	20.47
1074	39.31	30.02	19.37	21.12	23.94
1115	32.27	22.53	16.18	12.66	19.85
1098	31.68	21.65	15.46	17.56	20.02
0624	36.35	25.63	17.17	12.93	23.99
2036	41.70	25.69	21.34	19.57	21.60
1156	38.78	25.58	21.13	22.64	24.19
2074	43.22	35.73	26.29	25.58	26.53
0872	48.03	32.40	25.49	28.02	25.05
0632	37.85	25.98	19.11	22.97	20.53
0526	45.79	34.03	27.07	27.79	27.58
1240	49.54	35.71	33.04	33.04	26.67
1772	46.10	35.02	25.31	31.56	24.74
0645	55.38	35.05	27.97	28.99	24.78
2118	39.23	33.17	24.94	24.49	24.11
0633	50.87	39.11	32.56	31.95	28.41
1232	54.03	37.34	32.08	30.94	26.14
0485	52.99	36.59	31.77	33.40	28.20
0576	46.98	40.58	34.87	30.81	21.35
0527	50.22	37.88	33.68	29.78	28.65
1606	53.30	41.61	33.68	31.10	30.30
1041	50.20	39.12	32.07	30.96	27.75
4056	54.65	41.87	40.34	33.21	29.58
1557	25.36	20.74	15.14		
1784	37.99	27.68	21.18	24.06	27.33
2144	34.68	27.44	19.78	21.02	21.97
1834	44.65	37.88	23.96	26.91	27.30
1441	44.14	41.53	32.2	29.39	26.39
1688	47.07	37.10	23.79	24.90	25.69
0710	51.71	29.99	29.85	32.99	27.13
3112	51.87	41.81	33.77	31.73	29.44
1589	58.06	40.95	31.61		32.64
0548	60.87	45.50	39.04	38.23	34.21
1711	55.03	44.21	29.03	32.11	28.85
3470	65.15	42.70	34.50	39.98	32.96

Table 90. Data for calcaneal dimensions. DEC = Decedent based off collection #. ML = maximum length, MW = minimum width, BH = body height, LAL = load arm length, LAW = load arm width. Measurements in mm.

DEC	ML	MW	BH	LAL	LAW
1509	34.88	12.02	22.09	22.34	16.78
1557	33.20	14.78	20.91	27.76	18.99
2141	42.27	16.37	26.61	32.92	21.74
1074	46.10	17.11	31.91	30.36	29.08
1115	40.41	16.29	26.00	32.47	20.97
1098	41.52	13.59	23.71	29.10	23.98
1784	48.10	17.67	3.32	34.73	28.61
2144	40.94	16.87	22.81	30.27	23.48
0624	46.98	18.91	28.46	35.56	29.17
2036	51.66	16.66	30.86		28.64
1834	58.23	21.29	33.37	38.78	31.29
1156	51.46	19.22	31.26	36.81	25.51
2074	57.27	19.12	35.45	41.56	30.18
0872	59.50	24.14	35.48	42.27	35.36
0632	49.47	19.94	26.72	32.69	28.64
1441	62.75	21.55	35.22	42.73	34.45
1688	57.65	19.64	33.17	41.53	32.45
0710	64.18	23.85	37.27	47.53	36.81
0526	58.50	23.65	37.07	41.04	37.61
3112	38.85	26.94	87.85	48.03	41.88
1240	67.15	24.25	45.24	45.57	37.95
1772	64.64	26.13	29.62	38.57	34.48
0645	68.60	22.24	46.08	43.23	36.61
2118	56.69	21.98	33.81	37.26	34.46
0633	76.10	24.23	37.32	48.39	38.52
1232	73.06	24.20	43.95	45.80	39.48
0485	79.03	24.41	40.90	44.81	39.25
0576	78.34	29.96	44.64	45.96	38.21
0527	69.92	23.03	38.74	42.18	37.84
1606	78.72	26.19	46.63	50.85	39.52
1041	70.98	23.85	49.62	43.84	37.69
4056	78.78	24.72	45.51	49.11	38.98
1589	75.78	28.43	47.74	50.28	41.17
0548	80.05	28.82	49.78	56.85	42.45
1711	73.54	26.83	44.71	47.19	41.61
3470	39.14	22.89	59.69	59.79	43.83