OSTEOARTHRITIS AND THE EFFECTS ON THE ACCURACY OF AGE AT DEATH ESTIMATION

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Abstract

Samantha Wiedre. OSTEOARTHRITIS AND THE EFFECTS ON THE ACCURACY OF AGE AT DEATH ESTIMATION.

(Under the direction of Dr. Sara Juengst)

There are many methods by which forensic anthropologists and bioarchaeologists estimate the age at death of an individual. Many of these methods, however, are flawed. Currently, anthropologists within these fields are researching which of these methods are accurate, which are flawed and how flawed they are, how to fix these inaccuracies, and creating new methods of age at death estimation. The pelvis is the second most accurate age identifier after dentition, but there are many aspects of life that can change the physical appearance of the specific age identification features. Osteoarthritis is a degenerative bone disease that affects joints. This pathology usually appears in individuals 50 years of age and older but hard labor, trauma, and disease can cause osteoarthritis to form earlier in life. Early onset osteoarthritis is being seen in more of today's youth due to the high physical activities within their lives. This can cause errors to be made when estimating age at death of an individual younger than 50 that has joint diseases or traumas. This study seeks to find how osteoarthritis affects how we estimate chronological age at death. Using the Suchey-Brooks (1982) and Buckberry-Chamberlain (2002) methods of age estimation, age at death was estimated for 30 individuals of the Western Carolina John A. Williams collection. Known age was compared to estimated age to calculate error. Osteoarthritis was then observed on the vertebral column, pelvis, and femora. I found that there were many inaccuracies in age estimation that did indeed correlate to the presence of osteoarthritis in the individual.

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Dedication

I dedicate this project to my fellow Graduate Anthropology students. We have been through a lot together. Some of us have crossed what seemed like an unreachable finish line and some of us are just around the corner. I believe in all of us. We are smart, kind individuals that have a passion to help shape the future and that is what we will do. Whenever you hit a bump in the road remember that we are all in this together and that even if you don't believe in you I do, and so do all of our professors at UNC Charlotte. I also would not have gotten through these past two years without my sweet baby Emily. You were an amazing cat and companion, whenever I was down or lonely it was you that helped me. Emily, you didn't get to see this final project but it was because of you that it got done. I love and miss you, always.

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CHAPTER 1: INTRODUCTION

There are many ways forensic anthropologists can estimate age at death. Currently, anthropologists are trying to find which methods are best, which methods have flaws, how to make certain methods more reliable, and how to modify these methods. The pelvis is the second most accurate age identifier in the body after dentition, but there are many factors that can affect the physical appearance of the age estimation features, such as life experiences of labor and trauma. Our entire lives can change how our skeletons look, altering the features that forensic anthropologists use to identify bodies after death. If a young adult sustains enough injury or develops a disease at a young age and dies, how are we going to estimate their age differently? These injuries and traumas at a young age can make the skeleton look chronologically and biologically "older" because certain diseases and pathologies are used as age markers. Osteoarthritis usually develops after the age of 50 but trauma and disease can cause it to develop earlier. This study uses the Suchey-Brooks (1982) and Buckberry-Chamberlain (2002) to age 30 individuals from the donated JAW collection at Western Carolina University. Then, using Buikstra and Ubelaker (1994) osteoarthritis was observed in the vertebral column, pelvis, and femora. The error between estimated and known age was then calculated to analyze whether the presence of osteoarthritis affects the accuracy of age at death estimations.

CHAPTER 2: LITERATURE REVIEW

Why Age Matters

Age and age at death estimations are extremely important for a multitude of reasons including, medico-legal matters, status within the familial and societal systems, and biological characteristics. Biological characteristics and processes affect how we see age in the body. This study focuses on skeletal characteristics of age, but biological characteristics extend past this. Body hair, growth of certain body parts, development of hormones and associated features are related to age. While these changes vary among chronological age within populations, chronological age is generally universal (Lawrence, et al. 2015). Biological age, which is what bioarchaeology and forensic anthropologists identify, is how an individual's body changes as they go through life. Chronological age is measured in days, weeks, months, and years; according to Kertzer and Keith (1984) sometimes biological age and chronological age align but biological age can be variable based on an individual's environment and lifestyle. Cultural or social age is how an individual is seen in their own society, which is very variable and is measured in terminology rather than an actual measurement of time (Kertzer and Keith 1984).

In the modern day, age and age at death estimation are important for medico-legal reasons. Our age regulates what we can and cannot do; in the United States, a minor is an individual 17 years of age and younger while an adult is defined as an individual 18 years of age or older, varying state to state (Sironi, et al. 2021). Achieving adult status through chronological age allows an individual to be able to do certain things, like purchase firearms, drink and purchase alcohol, and vote. Drugs are illegal for minors but legal for adults; this varies by the drug and the state (Sironi, et al. 2021). Medically, doctors can legally give a minor's information to a parent or guardian without your permission if you are a minor but not as an adult. You cannot get married until a certain age, etc. Additionally, the law and legal systems affect minors

and adults differently; when a minor commits a crime, they may be charged differently and their punishment may also be different than if the same crime were to be committed by an adult. These legal regulations related to chronological age reflect social expectations of maturity and responsibility; in the US, once you are above 17 years of age, you are expected to behave differently than someone younger (Sironi, et al. 2021).

Age is also important for cultural reasons. Different cultures see and measure age in various ways, reflecting their ideals and values about maturity, responsibility, and socialization. There are many ways an individual can identify their own age; one can simply say they are older or younger than another individual, life stages can be identified by height, and transitions can be identified by events in the life course. Life stages are also not defined universally. Childhood, adolescence, and adulthood vary in chronological age based on the culture of an individual's population (Berman 2019). Marshallese individuals do not measure age chronologically. Instead if asked how old an individual was they would hold their hand in the air to demonstrate height of the individual and then state what stage of life the individual was in at the time, such as being able to talk, going to school, or getting a job. Western African individuals measure age based on the individual's focus; if their perspective is led by their heart they are mature individuals (Berman 2019).

Age is fairly new as a research topic in anthropology, new in terms of the anthropological discipline. The rise of feminist theories within the anthropological field in the 1970's allowed an interest for childhood archaeological studies (Halcrow and Tayles 2011). In particular, subadult remains have proven to be useful for studying patterns of health and disease because they are the most demographically variable and sensitive to biocultural change. Diseases, genetic disorders, traumas, and nutrient information can leave evidence on developing dentition and bones

providing clues to the population's aspects of health and their environment (Halcrow and Tayles 2011). For example, nutrition affects our teeth based on the chemical makeup of food, acids break the enamel down causing the tooth to wear away; disease and trauma can affect the teeth by causing abnormalities in the teeth, called linear enamel hypoplasia (Halcrow and Tayles 2011).

Though there are now many studies on childhood and age, there are still inconsistencies with terminology, making discussion and comparison of methodologies difficult. As Halcrow and Tayles (2011) state, there are multiple terms for age stage terminology in use. This is unfortunate because there is a lack of consistency within the discipline and often there is individual bias when choosing terminology. For example, the terms "subadult", "non-adult", "juvenile", and "child" are all used interchangeably for individuals who have not reached adulthood. The term subadult implies that these individuals are hierarchically inferior to adults; with the same issue being presented with the term non-adult (Halcrow and Tayles 2011).

Age matters outside of humanity as well. Primatologists study age, major life stages, and life cycles of living primates. This can help us better understand how ancient *Homo sapiens* and ancestral humans lived and aged. Kertzer and Keith (1984) discuss primate life cycles, and how they are similar to ours; they are identified as immaturity (infant and juvenile), adolescence (subadult), and adult (sometimes divided into young, middle, and old). These life stages are consistent throughout nonhuman primate species, unlike human age definitions. Human age definitions and the linguistics around age differ between disciplines and culture (Kertzer and Keith 1984).

Age at Death Estimation Methods

Age at death estimation is important to forensic anthropologists and bioarchaeologists as it is a key strategy for identifying deceased-individuals of an unknown origin. There are seven general age estimation methods: cranial suture closure, dental eruption, dental attrition, epiphyseal fusion, pubic symphyseal appearance located on the pelvis, auricular surface appearance located on the pelvis, and long bone length. Dental eruption, epiphyseal fusion, and long bone length are used to estimate age during skeletal growth and development, whereas, cranial suture closure, dental attrition, pubic symphyseal appearance, and auricular surface appearance are used to estimate degenerative changes to the skeleton that normally occur later in life. Dentition has been proven to be the most accurate method of age estimation, in part because teeth preserve better than some of the other features used in age estimation (Ubelaker and Khosrowshahi 2019).

Ubelaker and Khosrowshahi (2019) discuss the historical development of age at death estimation methods and future considerations. When identifying an individual's age, one must first consider the skeletal remains that are present. Different methods are used in different stages of life, relying on skeletal growth and development during early life and skeletal degeneration during later years. The growth period is the period in which an individual's skeletal system is still developing and growing, whereas the degeneration period is the period in which an individual's skeletal system is no longer developing new cells and the structure of the bone begins to deteriorate (Ubelaker and Khosrowshahi 2019).

When estimating age at death of a non-adult, one would use long bone measurements, dental development and eruption, and epiphyseal fusion as these are all measures of development and/or growth. Long bone measurements are used to age fetal, neonatal, and infant individuals; the clavicle, humerus, radius, ulna, femur, fibula, and tibia are measured, then the measurement

of the specific bone is compared to a chart to assess age in weeks to months of development. Dental development and eruption assess the development of the crown and roots of dentition to determine age from around a year old to about 18 to 30 years of age. Epiphyseal fusion analyzes the physiological development of certain bones and their epiphyses, usually useful from about one year to 25 or 30 years of age (Ubelaker and Khosrowshahi 2019).

Adult age at death identification methods include cranial suture closure, pelvic feature assessment, sternal rib end development, dental analysis, and degenerative changes. Cranial suture closure analyzes the development of closure of the cranial bones and includes four relative phases of aging individuals, from around 30 to around 50 years of age. Since these measures are relative (open sutures vs closed sutures) rather than exact, this is usually used in conjunction with other methods (Ubelaker and Khosrowshahi 2019).

The pubic symphyseal method and the auricular surface method (both forms of pelvic feature assessment) observe the physical changes of these features, respectively. These changes occur due to developmental changes but they can also be affected by trauma, pathologies, or environmental factors. These methods can be used to estimate ages for individuals from approximately 20 to 80 years of age and use age ranges, rather than precise ages, thus they should be used alongside other methods when possible (Ubelaker and Khosrowshahi 2019). Pelvic age estimation methods are one of the more accurate age estimation features. The Todd (1920) method observed 306 male pubic symphyses. Four basic parts of the pubic symphysis were identified: the ventral border, the dorsal border, the superior extremity, and the inferior extremity. Todd (1920) noted evidence of billowing, ridging, ossified nodes, and texture for each of the four parts of the pubic symphysis. Todd (1920) recognized 10 phases ranging from 18 to 50+ years old, noting that these age indicators were more reliable for individuals between the

ages of 20 and 40. Phases 1-3 comprised the post-adolescent and young adult stage, 4-6 were build up stages, and 7-10 represented degenerative stages (Todd 1920) (Figure 1).

The Suchey-Brooks (1982) method modifies the Todd (1920) method by creating six stages instead of 10; they also age males and females separately. This separation is due to the aging methods being affected by lived experiences. They state that pregnancy can cause pitting to appear on the pubic symphysis, auricular surface, and the preauricular area of the female pelvis (Figure 2).

Phase one is categorized by the symphyseal surface.

- There is a billowing surface that usually extends to the pubic tubercle
- The horizontal ridges are well-marked, ventral beveling might be starting
- There is no delimitation of the upper or lower extremity
- Phase one age ranges are 15-24 for females and 15-23 for males

Phase two is categorized by the start of the delimitation process.

- In most cases, the upper and/or lower extremities with or without ossified nodes present
- The ventral rampart may be in beginning phases of extension of bone growth
- Phase two age ranges are 19-40 for females and 19-34 for males

Phase three is categorized by the lower extremity and ventral rampart in the completion process.

- This can be continued fusing ossific nodes forming on the upper extremity and along the ventral border
- The symphyseal face may show signs of smoothing over
- The dorsal plateau is complete and there is an absence of lipping on the dorsal margin of the symphysis
- Phase three age ranges are 21-53 for females and 21-46 for males

Phase four is categorized by the symphyseal face being fine grained.

- remnants of the old ridges is still present
- the oval outline of the symphyseal face has been complete
- the pubic tubercle is fully separated and the symphyseal face may have a distinct rim
- Phase four age ranges are 26-70 for females and 23-57 for males

Phase five is categorized by the symphyseal face to be completely rimmed.

- The symphyseal face is slightly depressed
- There is moderate lipping on the dorsal border
- Little to no rim erosion
- Phase five age ranges are 25-83 for females and 27-66 for males

Phase six is categorized by the symphyseal face being depressed as the rim erodes.

- Ventral ligament attachments are marked
- The pubic tubercle often appears as a separate bony knob
- The symphyseal face is pitted and porous, it may also be irregular at this phase
- Phase six 42-87 for females and 34-86 for males (Suchey-Brooks 1982) (Figure 3).

The Buckberry-Chamberlain (2002) method observes the topographical changes to the auricular surface as an individual goes through life; unlike Suchey-Brooks (1982) this is not separated by sex. First, the auricular surface is observed for transverse organization, surface texture, microporosity, macroporosity, and apical changes. These characteristics are scored, then added to create a composite score that correlates to a phase which has a correlating age range. Transverse organization is scored from 1-5

- (1) being 90% or more of the auricular surface being transversely organized
- (2) 50-89

- (3) 25-49%
- (4) less than 25% of the surface transversely organized
- (6) no transverse organization

Surface texture is scored from 1-5.

- (1) being 90% or more of the auricular surface being finely granular
- (2) 50-89% of the surface is finely granular, there may start to be development of coarsely granular bone, and no dense bone is present.
- (3) consists of 50% or more of the surface is coarsely granular but no dense bone is present.
- (4) dense bone is present but only covers less than 50% of the surface and composite score five displays 50% or more of the surface being affected by dense bone.

Microporosity is scored 1-3.

- (1) being no microporosity
- (2) microporosity is present on one demiface
- (3) microporosity is present on both demifaces.

Macroporosity is scored 1-3.

- (1) no macroporosity
- (2) macroporosity on one demiface
- (3) macroporosity on both demifaces.

Apical changes are scored 1-3 in the following manner.

- (1) the apex of the auricular surface is sharp and distinct
- (2) there is some lipping present at the apex but the shape is still distinct and smooth

- (3) there are irregular contours on the auricular surface and the apex is no longer smooth in shape.

These topographical changes are added up to a composite score with a correlating age range..

- Phase one consists of scores five or six with the age range 16-19 years
- phase two is scores seven or eight with the age range 21-38
- phase three is nine or 10 with the age range 16-65
- Phase four is 11 or 12 with the age range 29-81
- Phase five is 13 or 14 with the age range 29-88
- Phase six is 15 or 16 with the age range 39-91
- Phase seven is a composite score of 17, 18, or 19 with the age range 53-92 years of age (Buckberry-Chamberlain 2002) (Figures 4 and 5).

Sternal rib end development analyzes when the rib and sternum meet for fusion of the joint. This method can be used to estimate ages for individuals between approximately 30 and 50 years of age. These changes are due to skeletal development and cartilaginous ossification that naturally occurs as we age. The ribs connect via cartilage with the sternum and as we age, the cartilage can harden and ossify, sometimes fully (Ubelaker and Khosrowshahi 2019).

Dental analysis of adults uses patterns of eruption and wear on dentition, including the enamel and dentine present, to approximate age. Maxillary and mandibular dentition are analyzed separately, aging individuals from about 18 to about 60-80 years of age. Dental analysis is the most reliable age at death estimation method for non-adults (Ubelaker and Khosrowshahi 2019). Dental analysis age estimation methods can be affected by the foods ingested by individuals during life and lifestyle behaviors of an individual. For example, acidic foods can

wear away the enamel, living near a coast can cause wear on the teeth because of the sand in the air, disease can cause hypoplasia or abscesses (Verett 2001).

Degenerative changes to the skeleton can aid in assessing age at death of the individual, as pathology such as osteoarthritis tends to accumulate over the life course. Osteoarthritis and other degenerative pathologies are part of modern human life. Most individuals develop osteoarthritis at the age of 50 or older, but some can develop osteoarthritis much earlier. This can be due to genetics, occupation, and life activities. This method is usually used on individuals over the age of 50 years, as it is believed that 50 years is when most average individuals begin to develop these changes. One limitation of this method is that trauma and life experiences can cause degenerative changes to develop earlier in life (Ubelaker and Khosrowshahi 2019). The formation of osteoarthritis can cause pain for the individual and can also make age estimation of the individual more difficult (Jurmain and Kilgore 1995). Joints need to be exercised and proper, moderate use will slow the rate of osteoarthritis formation in individuals, but when used improperly and strenuously, joints can start to show signs of osteoarthritis sooner than fifty years of age (Altman, et al 1991).

These methods of subadult and adult aging have been developed over the last 150 years and are regularly used by bioarchaeologists and forensic anthropologists during the course of their work. However, like most scientific methods, there have been a lot of changes to age identification methods over this time (Ubelaker and Khosrowshahi 2019). In 1955, it was realized that biological sex can have an effect on age estimation methods (Ubelaker and Khosrowshahi 2019). The accuracy of age at death estimation methods came into question in the 1980s, by bioarchaeologists, and continues to be questioned. The methods have been questioned because of individual bias, need for replication, pathological or trauma inaccuracies, in addition

to other factors. (Ubelaker and Khosrowshahi 2019). The 1990s brought comparative studies into view, comparing methods and modifications, which methods were accurate and which worked well together to create the most accurate age at death estimation. There is presently support for a multimethod approach, not only using multiple skeletal age at death estimation methods but also considering taphonomy, post mortem changes, bone histology, dental pulp chamber analysis, and biochemical analyses (Ubelaker and Khosrowshahi 2019).

Although many aging methods are used, some methodologies will be more accurate than others and universally there are instances where the environment needs to be considered. Gowland (2015) highlights the need for environment and environmental changes to be considered during age estimation. This is partially due to the phenotypic plasticity that humans possess, or our ability to react to an internal or external environmental change. Phenotypic plasticity can correlate to epidemiology and disease risk throughout life as well. Gowland (2015) states that skeletal plasticity differences, specifically of the vertebral column, correlate with age at death. This skeletal plasticity and the skeleton's ability to retain environmental evidence is important in bioarchaeology when interpreting social interactions of the past. However, it also may complicate age estimation methods if environments of development and adulthood are not accounted for (Gowland 2015).

Some age at death estimation methods cannot be used on all individuals. Ice (2005) discusses why biological archaeologists specifically need to be interested in age, studying age, and specifically studying old age. Ice (2005) states, "As students of human variation, biological anthropologists should find the study of aging of interest, given that variation is greater among older populations compared to younger groups on almost anything measured—socio-cultural, psychological, economic, physiological, and phenotypic" (p. 88). This is particularly important

for individuals over the age of 55 as age at death estimation methods for this age group are severely lacking as they have not been robustly studied and therefore our methods do not include them.

Milner and Boldsen (2012) state that there are many inaccuracies with age at death estimation methods. They list many reasons for this such as: using fixed length interval, no matter the actual shape of the bone itself; no cohesive way to combine information within methods and method to method; "an inability to say anything useful about the ages of old people; biased estimates for adults, particularly a tendency to underestimate the ages of people beyond about 50 years" (Milner and Boldsen 2012: 89). They also mention the necessity of knowing a population's age structure before identifying the age of an individual as the population's environment can affect the skeletal structure and how the skeleton develops as we age. These inaccuracies lead to large age ranges spanning 10+ years or even open-ended intervals such as: 50+ years old. Age also seems to be generalized for individuals over the age of 50 with few age estimation methods reaching 60+ years old. Even though the pelvic joint methods and modifications are fairly new, they mostly follow the earlier methods' layout and terminology, calling a need for more research to be done on these methodologies (Milner and Boldsen 2012).

Pelvic Age at Death Estimation Methods

In this study, I focus on the pelvic feature assessment methods. The pubic symphyseal method and the auricular surface method observe the physical changes of these features. One of the most prominent pubic symphyseal methods is the Todd (1920) method which observes the pubic symphysis and the changes that occur to it during an individual's life. This method ages individuals from about 20 to about 60-80 years of age. This method identifies age ranges and should be used alongside other methods when possible (Ubelaker and Khosrowshahi 2019).

Christensen, Passalacqua, and Bartelink (2013) detail each of these methods as well as their inaccuracies. The Todd (1920) and Buckberry and Chamberlain (2002) methods are explained in detail below. Both methods are used to estimate age at death by observing an area of the pelvis (Christensen, et al. 2013).

The Todd method looks specifically at the pubic symphysis; this feature changes in appearance and texture over time. Four basic parts of the pubic symphysis were identified: the ventral border, the dorsal border, the superior extremity, and the inferior extremity. Todd (1920) noted evidence of billowing, ridging, ossified nodes, and texture for each of the four parts of the pubic symphysis. Todd (1920) recognized 10 phases ranging from 18 to 50+ years old, noting that these age indicators were more reliable for individuals between the ages of 20 and 40. Phases 1-3 comprised the postadolescent and young adult stage, 4-6 were build up stages, and 7-10 represented degenerative stages (Todd 1920) (Figure 1).

The Todd (1920) method does have its flaws and multiple modifications have been made to create a more accurate estimation. I will be focusing on the Suchey-Brooks (1990) modification of the Todd method. The Suchey-Brooks (1982) method modifies the Todd (1920) method by creating six stages instead of 10; they also age males and females separately. This separation is due to the aging methods being affected by lived experiences. They state that pregnancy can cause pitting to appear on the pubic symphysis, auricular surface, and the preauricular area of the female pelvis (Figure 2). Phase one female correlates to the age range 15-24 and male 15-23, phase two age ranges are 19-40 female and 19-34 male. Phase three age ranges are 21-53 female and 21-46 male, phase four 26-70 female and 23-57 male. Phase five age ranges are 25-83 female and 27-66 male, stage six 42-87 female and 34-86 male (Suchey-Brooks 1982) (Figure 3). Savall, et al. (2017) tests the accuracy of the Suchey-Brooks (1982)

modifications on the contemporary French male population. They state that inter-population variability can cause these inaccuracies. They studied 680 male pubic symphyses and the Suchey-Brooks (1982) method was tested by error of inaccuracy, bias between the individuals' real and estimated ages, the mean age of each stage, and the mean stage for each 10 year interval. Inaccuracy and bias in age estimation increased with age and exceeded 20 years for individuals over the age of 65. Savall, et al. (2016) state that this is consistent with overestimation of the real age for stages 1 and 2 and an underestimation of real age for stages 4, 5, and 6. The mean age for this sample was significantly lower for the 14-25-year-old age group and higher for individuals over 35 years of age. They mention that the Suchey-Brooks method states that caution should be taken when using the method in France because of these inter-population inaccuracies and this study helps support that (Savall, et al. 2016). Similarly, Xanthopoulou, et al. (2018) observed 140 individuals within the modern Greek population, testing the accuracy of the pelvic and cranial age estimation methods. The pubic symphysis produced accurate age estimations for young adults but inaccurate for those who's known ages were over 45 years of age. These inaccuracies resulted in underestimating ages for the older adult group (Xanthopoulou, et al. 2018). Meindl, et al. (1985) observed the pubic symphysis using the Todd method for age estimation. After using the Todd method, a revised method was used; they found that the Todd method was more reliable than the revised method they created due to the resulting age ranges and mean ages. This study found that using the pubic symphysis as an age estimation feature tends to underage all individuals (Christensen, et al. 2013).

Hens and Belcastro (2012) use the Buckberry and Chamberlain (2002) method to estimate age; this looks specifically at the auricular surface of the pelvis. They suggest a revised method as there are inaccuracies found, stating that fewer auricular surface stages with a wider

age range should be implemented. In general, they found this method overestimates age in individuals under 59 and underestimates age in individuals over 60 (Hens and Belcastro 2012).

Xanthopoulou, et al. (2018), mentioned previously, also studied inaccuracies in the Buckberry-Chamberlain (2002). They found that the Buckberry-Chamberlain (2002) method was the most accurate of the pelvic age at death estimation methods but gets less accurate as individuals observed get older. They state that older adult individuals were not included in the original Buckberry-Chamberlain (2002) study and so the method is less accurate as the age group was not original taken into account (Xanthopoulou, et al. (2018). Her (2021) compares auricular surface age estimation methods on White and Black populations. They examined 460 individuals from the Terry collection, finding that individuals under the age of 59 were generally overestimated and individuals 60+ were generally underestimated (Her 2021).

There is currently support for a multimethod approach, using multiple skeletal age at death estimation methods and including taphonomy, post mortem changes, bone histology, dental pulp chamber analysis, and biochemical analysis (Ubelaker and Khosrowshahi 2019). Christensen, et al. (2013) also describes other age estimation methods, such as: cranial suture closure, dental eruption, dental attrition, and epiphyseal fusion. The text goes into detail on the inaccuracies of these methods and says that, when possible, they should be used together as one multi-factorial method for age at death estimation (Christensen, et al. 2013). Milner and Boldsen (2012) also mention the necessity of knowing a population's age structure before identifying the age of an individual and point out that the population's environment can affect the skeletal structure and how it develops as we age. These inaccuracies lead to large age ranges and open-ended intervals. Milner and Boldsen (2012) state that even though the pelvic joint methods and

modifications are fairly new, they mostly follow the earlier methods' layout and terminology, demonstrating a need for more research to be done on these methodologies.

Joint Diseases

Osteoarthritis is just one of many joint diseases that can affect humans throughout life. These other diseases can look like osteoarthritis and affect age at death estimation as well. Thus, it is necessary to describe the other three joint diseases affecting these areas, including diffuse idiopathic skeletal hyperostosis (DISH), ankylosing spondylitis, and rheumatoid arthritis. These joint diseases are distinguished by factors such as: the affected area; the presence of porosity, extent of porosity, location of porosity; the affected bony structure; and growths present (Waldron 2019). In this thesis, I am going to focus on osteoarthritis in the vertebral column, pelvis, and proximal femur, as these joints are mostly closely related to pelvis age estimation methods.

DISH is a noninflammatory, chronic joint disease that is characterized by the bony growths along the anterolateral surface of the vertebral column, particularly in the region of the thoracic vertebrae. DISH is diagnosed once there is a flowing mineral formation along four articulating vertebrae (Fournier, et. al. 2020). Although considered a joint disease, DISH does not actually affect the intervertebral joint. Mader, et al. (2021) observed DISH and the possible causations of the condition. They state that DISH is a metabolic condition characterized by new bone formation on the axial skeleton, more specifically the vertebral column, and can often resemble inflammatory diseases. Mader, et al. (2021) discusses the possibility that inflammation may promote new bone formation. They conclude that local inflammation of the joints affected contributes to new bone formation as the inflammation leads to degeneration of the joint affected (Mader, et al. 2021).

Ankylosing spondylitis and rheumatoid arthritis are both inflammatory diseases that cause the immune system to attack joints, bones, muscles, and organs. The distinction between ankylosing spondylitis and rheumatoid arthritis is that rheumatoid arthritis affects the body symmetrically while ankylosing spondylitis tends to be unilateral. Rheumatoid arthritis can affect large and small joints and can form between the ages of 30 and 50 (Majithia and Geraci 2007). Ankylosing spondylitis forms asymmetrically on the lower limbs, causes back pain, and is usually associated with inflammatory bowel disease, psoriasis, and a disease of the eye known as anterior uveitis (Braun and Sieper 2007).

Osteoarthritis

One of the most common skeletal pathologies is osteoarthritis. Osteoarthritis, or inflammation of a joint, has a very extensive history within bioarchaeology and paleontology and has been observed in human bone, animal bone, and even dinosaur fossils (Jurmain and Kilgore 1995). The study of pre-industrial human groups suggests that osteoarthritis is one of the most common forms of pathological lesions (Jurmain and Kilgore 1995). Webb (2010) states that arthritis is the leading cause of disability in Western societies; osteoarthritis is the single leading cause of disability in individuals aged 30 and older in the United States, United Kingdom, Australia, and Canada. Developmental causes of osteoarthritis in the modern day are believed to be linked to weight, age, occupation, and sports during childhood (Webb 2010).

Osteoarthritis is a joint disease that is characterized as the destruction of articular cartilage in a joint and the formation of adjacent bone, usually in the form of lipping or spur formations around the joint. This is also known as degenerative bone disease. Osteoarthritis is usually found in load bearing joints such as the vertebral column, knees, and hips, but can occur in any joint. In the most severe cases osteoarthritis causes the bone to be completely worn giving

it a “shiny” and smooth appearance, called eburnation. Osteoarthritis is also a natural part of the aging process as bodies degenerate over time, and can thus be used to confirm that an individual is over the age of 50, which is when osteoarthritis usually starts to develop in humans (Webb 2010).

Osteoarthritis can form in any joint but is most commonly found in the vertebral column, acetabulum of the pelvis, head of the femur, distal condyles of the femur, and head of the humerus (Jurmain and Kilgore 1995). Osteoarthritis can be classified two ways, either primary or secondary (Brennaman 2014). Primary osteoarthitis results from factors such as age, sex, hormones, mechanical stress, and genetic disposition. Secondary osteoarthritis results from trauma or bacterial infections in the joint, such as sepsis.

Osteoarthritis is most commonly evaluated using the “ordinal scaling” system which includes the categories none, slight, moderate, and severe (Jurmain and Kilgore 1995: 444). This system scores marginal changes (lipping or bone growth) and articular surface changes (pitting) (Jurmain and Kilgore 1995). The Buikstra and Ubelaker (1994) method of classifying osteoarthritis is a clear, descriptive scoring system. This system first scores a given joint that is affected by one of four features: 1) lipping, 2) degree type of porosity, 3) abnormal compact bone growth, and 4) eburnation. In addition to these four features, they advise recording the extent of the joint surface affected: 1) less than one-third is affected, 2) one-third to two-thirds is affected, and 3) more than two-thirds of the joint surface is affected. Buikstra and Ubelaker use age ranges of: 20-34 as young adult, 35-49 as middle adult, and 50+ as old adult. Osteoarthritis usually starts to form at fifty years of age or older and is seen by analysts as a confirmation that an individual is fifty or older (Buikstra and Ubelaker 1994).

Osteoarthritis can occur in any individual but certain jobs and activities can increase an individual's likelihood of osteoarthritis formation. Franklin and Wilson (2020) studied differences in individuals living in rural and urban areas. They found that rural women were more likely to develop osteoarthritis and both rural and urban men were likely to develop osteoarthritis. Most urban men and women developed moderate to severe osteoarthritis by the age of 45, while rural men and women displayed these same symptoms at the age of 50. This was an unexpected result as rural individuals are usually working on farms from a young age and thus the authors expected rural populations to develop arthritis at a younger age (Franklin and Wilson 2020). Instead, this finding supported evidence that frequent and proper use of joints delays osteoarthritis onset while extreme and repetitive use of joints, even for short periods, such as in factory labor settings, causes early onset of osteoarthritis.

Physical activity in life like sports can also affect osteoarthritis formation. Modern children, in the United States, participate in sports roughly from the age of five until they are about 18. Sports can create strain on muscles, ligaments, tendons, and the skeletal system. High intensity and frequency of athletic activity can increase a child's likelihood of developing osteoarthritis (Maffulli and King 1992).

While osteoarthritis usually forms in older individuals, a significant trauma or stress can cause osteoarthritis to form in younger individuals as well. Joints need to be exercised, proper and moderate use will slow the rate of osteoarthritis formation in individuals. However, improper and/or strenuous joint use can create signs of osteoarthritis sooner than fifty years of age (Altman, et al 1991). Unfortunately, we are now seeing more young individuals with signs of osteoarthritis formation (Maffulli and King 1992). Modern adolescents and young adults are

showing some signs of osteoarthritis, and so although useful, Brennaman's (2014) method should only be used in individuals determined to be over the age of fifty by other methods first.

Currently, more and more adolescents have injuries that can lead to osteoarthritis formation, and many of these children are being injured multiple times the same way. This is due to the high intensity at which modern adolescents play sports. Shevchenko (2013) studied the knees of 51 adolescents between the age of 12 and 18. Their study was performed to try to prevent the progression of osteoarthritis in adolescents that already showed symptoms of osteoarthritis on their distal femurs. They specifically look at immunological characteristics, genetics, and the biomechanics of the knee. This study found that 60.7% of 31 females under the age of 14 show the osteoarthritis formed as reactive arthritis in the knee joint, shortening the height of the cartilage. Shevchenko (2013) argues that osteoarthritis formed so early in these individuals due to "changes in various systems of homeostasis" (Shevchenko 2013).

Kang, et al. (2017) discuss how malnutrition can affect osteoarthritis formation in Korean females under eighteen. They specifically studied the temporomandibular joint osteoarthritis and its relation to temporomandibular disorders. In this study, 95 females between the ages of 11 and 15 were studied; fifteen of these individuals were used as a control and had no signs of temporomandibular disorders or osteoarthritis, 39 individuals had temporomandibular disorder but not osteoarthritis, 17 had temporomandibular disorder and initial signs of osteoarthritis development, and 27 individuals showed advanced osteoarthritis and temporomandibular disorders. After using Demirjian's stages to age the dentition of these individuals, the authors realized that the females' dental age was significantly lower than their chronological age. In this case, they argued that the presence of temporomandibular disorders and osteoarthritis affects age estimation (Kang, et al., 2017).

Brennaman (2014) hypothesized that because osteoarthritis develops at the age of 50, it could be used to determine age in older individuals as most age estimation methods stop at fifty. Examining osteoarthritis in the clavicle, humerus, vertebral column, acetabulum, and femur, she explains that the presence and severity of osteoarthritis can help to narrow down age for those over 50. Her findings suggest that this is a useful method for creating a more accurate age estimation for older individuals (Brennaman 2014).

However, osteoarthritis should not be used alone as an age estimation method (Brennaman 2014). Calce, et al. (2018) observed osteoarthritis in the acetabulum, proximal and distal femur, and proximal and distal humerus and found that severe osteoarthritis in these joints can cause an individual to be aged older than they were at death. After using the pubic symphysis, auricular surface, maximum diameter of the femoral head, and maximum diameter of the humeral head to estimate age, the authors concluded that osteoarthritis formation in the joints specified effects the age estimated, in particular making these areas appear more similar to older age categories. This means that the pubic symphysis and auricular surface for age should not be used in these individuals as they are based on the appearance of the joint surface itself. When osteoarthritis appears on the heads of the femur and humerus, this makes the surface of the bone look older but does not affect the method used for age. Instead, the pathology on the bone can make an analyst assume that the individual is older, especially since it is the current practice to identify all individuals with severe osteoarthritis as 50 or older (Calce, et al 2018).

Savall, et al. (2017) state that the consistency with overestimation of the real age for stages 1 and 2 and an underestimation of real age for stages 4, 5, and 6. The mean age for Savall, et al. 's (2017) sample was significantly lower for the 14-25 year old age group and higher for individuals over 35 years of age. They mention that the Suchey-Brooks method states that

caution should be taken when using the method in France because of these inter-population inaccuracies (Savall, et al. 2017).

Because increasing frequencies of young individuals develop osteoarthritis, it might be necessary to update current age estimation methods. It is clear that many of the age estimation methods used currently can be affected by trauma and disease which leads to individuals being aged incorrectly and causes critical problems in identifying individuals accurately. Thus, my research assesses the impact of OA on age estimation for adult individuals, in order to create more accurate methods or caution researchers when making age at death estimates.

CHAPTER 3: FOREST & WCHIL AT WESTERN CAROLINA UNIVERSITY

The Forensic Osteology Research Station (FOREST) and the Western Carolina Human Identification Laboratory (WCHIL) were founded in 2007 at Western Carolina University. These facilities allow forensic anthropology and biology students and faculty to study the decomposition of human remains. The bodies are donated to the school for scientific research; after decomposition, the skeletons are cleaned and analyzed by WCHIL to help advance human identification methods. The John A. Williams (JAW) collection includes 164 white individuals that were all 50 years and older at the time of death. I was granted access to this collection for my MA data collection, allowing me to independently estimate age from known-aged individuals and compare with their pathological profiles.

CHAPTER 4: METHODOLOGY

I analyzed 30 of the most recently donated individuals, including 15 males and 15 females. I chose the most recently donated individuals because more information was known about these individuals, including occupation and medical histories, and because they had definitive known ages, whereas some of the earlier donors lacked this more specific information. I also selected individual skeletons that included the skeletal elements I needed for the project, including the vertebral column, pelvis, and femora. This included making sure each individual had 50% of the vertebral column, at least one innominate, and at least one femur. I chose to observe the vertebral column, pelvis, and femur for osteoarthritis identification as I hypothesize pathologies associated with these joints would most directly affect the accuracy of pelvic age at death estimation methods.

First, I noted the general skeletal completion, condition, and known biological sex of the individual; next, I took inventory of the skeleton, cataloguing which bones were present. Then, I observed the vertebral column, pelvis, and femora for osteoarthritis and noted any other pathologies affecting the bone. After the in-depth inventory of these selected bones, I observed specific joints to identify if osteoarthritis was present and to what extent. For each vertebra, I observed the superior and inferior body and articular surfaces. I also observed the facet of the dens on cervical vertebra one and the dens on cervical vertebra two. I did this because I hypothesize that this joint would additionally affect the pelvic age estimation. I observed the acetabulum of the pelvis for osteoarthritis presence and extent and the correlating joint surface on the head of the femur. I observed up to 28 bones in each individual and 147 joint surfaces.

I primarily assessed age using the Suchey-Brooks (1982) modifications of the Todd (1920) pubic symphyseal age at death estimation method. The Suchey-Brooks (1982) method

modifies the Todd (1920) method by creating six stages instead of 10; they also age males and females separately. This separation is due to the aging methods being affected by lived experiences. They state that pregnancy can cause pitting to appear on the pubic symphysis, auricular surface, and the preauricular area of the female pelvis (Figure 2).

Phase one is categorized by the billowing surface, which usually extends to the pubic tubercle; horizontal ridges; and ventral beveling might be starting. Phase one female correlates to the age range 15-24 and male 15-23. Phase two is categorized by the start of delimitation of the upper and/or lower extremities. This can appear with or without ossified nodes present. The ventral rampart may be in beginning phases of bone growth. Phase two age ranges are 19-40 female and 19-34 male. Phase three is categorized by the lower extremity and ventral rampart in the completion process. Ossific nodes start forming on the upper extremity and along the ventral border. The symphyseal face may start be smooth, the dorsal plateau is complete, and there is an absence of lipping on the dorsal margin of the symphysis. Phase three age ranges are 21-53 female and 21-46 male. Phase four is categorized by the symphyseal face being fine grained. The oval outline of the symphyseal face has been complete. The pubic tubercle is fully separated and the symphyseal face may have a distinct rim. Phase four 26-70 female and 23-57 male. Phase five is categorized by the symphyseal face to be completely rimmed. The symphyseal face is slightly depressed. There is moderate lipping on the dorsal border, and little to no rim erosion. Phase five age ranges are 25-83 female and 27-66 male. Phase six is categorized by the symphyseal face being depressed as the rim erodes. Ventral ligament attachments are marked. The pubic tubercle often appears as a separate bony knob. The symphyseal face is pitted and porous and may also be irregular at this stage. Phase six 42-87 female and 34-86 male (Suchey-

Brooks 1982) (Figure 3). I scored the pubis symphyses based on comparisons with molds of the Suchey-Brooks (1982) stages (Figure 2).

I then assessed the auricular surface using Buckberry-Chamberlain (2002). The Buckberry-Chamberlain (2002) method observes the topographical changes to the auricular surface as an individual goes through life; unlike Suchey-Brooks (1982) this is not separated by sex. First, the auricular surface is observed for transverse organization, surface texture, microporosity, macroporosity, and apical changes. one demiface, and three: macroporosity on both demifaces to create a composite score that correlates to phases. Each phase correlates to age ranges. Phase one age range is 16-19 years, phase two is 21-38, phase three is 16-65, phase four is 29-81, phase five is 29-88, phase six is 39-91, and phase seven age range is 53-92 years of age (Buckberry-Chamberlain 2002) (Figures 4 and 5). I compared auricular surfaces with Buckberry-Chamberlain 2002 descriptions and photographs (Figure 6). I chose to use these age at death estimation methods as they are some of the least accurate and seem to be affected by pathologies and traumas to individuals. Despite this, these methods are still commonly used in forensic anthropology and bioarchaeology.

The Suchey-Brooks (1982) and Buckberry-Chamberlain (2002) methods both result in very large age ranges. I used the mean age of the left and right pubic symphysis and auricular surfaces. Then, I averaged the two means on one innominate, to get an innominate age. I then averaged them with the mean of the second innominate (when possible) to create an average age. I used the following formula: left pubic symphysis mean + left auricular surface mean = left innominate mean age, left innominate mean + right innominate mean = individual mean age. I photographed each bone when osteoarthritis was present and listed the photo numbers next to each bone and individual.

Using the Buikstra and Ubelaker (1994) method I observed and identified osteoarthritis. I chose to observe vertebral, proximal femoral, and acetabular joints, specifically because of the possible affect pathologies in these joints would have on pelvic age at death estimation methods. I analyzed each joint and joint facet for the presence of porosity, lipping, bone growth, and/or eburnation. I then assessed to what degree the porosity or other symptoms of osteoarthritis were present. Osteoarthritis severity was determined by the size of the porous lesions and the extent of the joint surface that it covered. Osteoarthritic porosity was considered minor when pores were less than one millimeter in diameter, slight when pores were one millimeter to two millimeters in diameter, moderate when pores were two to three millimeters in diameter, and severe when pores were three or more millimeters in diameter. Then, I assessed the percentage of the joint surface affected in increments of 25%.

Once the physical analysis was complete, I transcribed the results into a Microsoft Excel book with several sheets, including inventory, osteoarthritis joint surface, osteoarthritis severity, age at death estimation, other pathologies, and error. The inventory sheet included a record of the bones observed for osteoarthritis present and the general information of each donor individual. Osteoarthritis joint surface detailed each bone observed for osteoarthritis and the percentage of joint surface affected (1: 25%, 2: 50%, 3: 75%, 4: 100%). Osteoarthritis severity detailed the severity to which the joint surface was affected (1: minor, 2: slight, 3: moderate, 4: severe) based on the pores present. Age at death estimation displays the left and right pubic symphysis and auricular surface phases and the mean age of the individual. The other pathologies sheet details if the bone observer has other pathologies present. The error sheet displays the individual's known age, estimated age, error in estimation, and percent of osteoarthritis and other pathologies.

The pelvic age estimation methods used, as stated previously, are the Suchey-Brooks (1982) modifications of the Todd (1920) method using the pubic symphysis of the pelvis and the Hens and Belcastro (2012) modifications to the Buckberry-Chamberlain (2002) method using the auricular surface of the pelvis. Each method's stage and average age is listed for each pelvic innominate.

I hypothesize that if osteoarthritis is not present but a different pathology is, this will cause the same inaccuracies in age at death identification; more research needs to be done to prove so. The error sheet details the percentage of osteoarthritis, percentage of other pathologies, the estimated age at death, known age at death, and the error calculated between both ages. Using JMP version 16 statistical software, I used Spearman's Row to test for significant trends using the variables: skeletal completion, percent of osteoarthritis, known age, estimated age, and error in age estimation. The alpha level was set to $p <= 0.05$ and all results are two tailed. This means I am not predicting positionality or one variable always being more than the other, but just looking for a difference (JMP, Version 16, 2022).

CHAPTER 5: RESULTS

Overall, age-at-death estimations and known ages produced a variety of differences. There was one individual with no error in age at death estimation and seven individuals that have an error of +/- 1-5 years of age. There are five individuals that the error in age at death estimation

is +/- 6-10 years of age and +/- 11-15 years of age. There are seven individuals with an error of 16-20 years of age estimation at death and there are six individuals with an error of +/- 20-33 years of age at death estimation.

There is a significant correlation between skeletal completion and the amount of osteoarthritis observed ($r = 0.4421$, $p = 0.0144$). There is a significant correlation between the known age and the difference in age ($r = 0.4239$, $p = 0.0196$). While not significant, the trend between known age and the amount of osteoarthritis approached significance ($r = 0.3148$, $p = 0.0902$). There were no significant correlations between any other variables ($p \geq 0.05$).

There were two individuals in the project that were outliers, detailed below. These individuals' known age at death were 30 and 32, both individuals displayed osteoarthritis, and one of them also had other pathologies present. These individuals were aged in between 60 and 65 because the age at death estimation features corresponded to the older comparisons used.

One of the known outliers, Donor 2019-06 was a female, in good skeletal condition, with 100% skeletal completion. None of the seven cervical vertebrae had any signs of osteoarthritis or any other pathologies. Thoracic vertebrae four, five, and six were the only thoracic vertebrae that display osteoarthritis. Thoracic 4-6 had minor porosity on 25% of the surface of the left superior articular facet and right inferior articular facet. None of the lumbar vertebrae displayed any signs of osteoarthritis, but lumbar three, four, and five displayed other pathologies. Lumbar three had a bony growth not associated with osteoarthritis on the left and right articular facets. Lumbar four and five were fused by bony growths or a calcification between the inferior joint facets of lumbar four and the superior joint facets of lumbar five. Lumbar five was also calcified to the sacrum. These pathologies were not associated with osteoarthritis. There were no other pathologies or osteoarthritis on Donor 2019-06 (Photos 1-4).

The known age of death of Donor 2019-06 was 32 years. I estimated the left and right pubic symphysis as a stage 6 compared to the Suchey-Brooks (1982) molds based on the lack of a rim and the separation of the pubic tubercle. The age range associated with stage 6 is 42-87 years of age with a mean age of 60. I also estimated the left auricular surface as a stage 6 compared to the description of the Buckberry-Chamberlain (2002) scoring. The age range associated with stage 6 is 39-91 years of age with a mean age of 66. Given the mean ages and the physical appearance of the features, I estimated the age at death of the left innominate as 63 years of age. I estimated the right auricular surface as a stage 5 compared to Buckberry-Chamberlain (2002). The age range associated with stage 5 is 29-88 years of age with a mean age of 62. I estimated the age of the right innominate as 61 years of age at death. I then averaged the innominate ages to get an overall individual age at death of 62 for Donor 2019-06 (Photos 5-8).

The other outlying individual, Donor 2019-08 was a male, in good skeletal condition, with 100% skeletal completion. None of the seven cervical vertebrae had any signs of osteoarthritis or any other pathologies. Ten of twelve thoracic vertebrae displayed osteoarthritis. Thoracic one had minor porosity on 100% of the surface of both the superior and inferior body. Thoracic four had minor porosity on 100% of the surface of the superior body, minor porosity on 25% of the left and right superior articular facets, minor porosity on 100% of the inferior body, and minor porosity on 25% of the right inferior articular facet. Thoracic five had minor porosity on 100% of the superior and inferior bodies, and minor porosity on 50% of the right inferior articular facet. Thoracic six had minor porosity on 50% of the superior body. Thoracic 7-12 had minor porosity on 100% of superior and inferior bodies. There were no other signs of osteoarthritis, nor any signs of other pathologies on Donor 2019-08 (Photo 9-18).

The known age of Donor 2019-08 was 30 years old at death. I estimated the left pubic symphysis as a stage 6 based on the erosion of the rim and slight microporosity; the Suchey-Brooks (1982) age range is 34-86 years of age with a mean age of 61.2. I estimated the left auricular surface as a stage 6; the Buckberry-Chamberlain (2002) age range is 39-91 year of age at death with a mean age of 66. I then calculated the mean age of the left innominate to be 63 years of age at death. I estimated the right pubic symphysis as a Suchey-Brooks (1982) stage 6 and the right auricular surface as a Hens and Belcastro (2012) and Buckberry-Chamberlain (2002) stage 6, I calculated the mean age of the right innominate as 63 years of age at death. The mean estimated age at death of Donor 2019-08 was calculated to be 63 (Photo 19-22).

There are four individuals with an error of 20-29 years of age, detailed here. Donor 2019-14 was a female with a known age of 78 and an estimated age at death of 52 years old. The error of age at death estimation is 26 years. Cervical vertebrae three through six displayed minor to moderate porosity, thoracic vertebra one had slight porosity and lumbar vertebra five had severe porosity and eburnation present. The left innominate of Donor 2019-14 I aged as a Suchey-Brooks (1982) stage 5 and Buckberry-Chamberlain (2002) stage 6; these range in age from 25 to 91 years of age, the mean ages being 48.1 and 62 years of age. The right innominate I aged as a Suchey-Brooks (1982) stage 5 and a Buckberry-Chamberlain (2007) stage 4, these range in age from 25 to 83 years of age, the mean ages being 48.1 and 52 years of age (Photo 23-32).

Donor 2019-19 is a female with a known age of 86 and an estimated age at death of 59 years old. The error of age at death estimation is 27 years. Cervical vertebrae one through five have severe osteoarthritis, porosity and eburnation present. Lumbar vertebrae two, three, and five display severe osteoarthritis and eburnation. The left innominate I aged as a Suchey-Brooks (1982) stage 6 and Buckberry-Chamberlain (2007) stage 5, the stages range from 29 to 88 years

in age, the mean ages are 60 and 62. The right innominate Donor 2019-19 I aged as a Suchey-Brooks (1982) stage 5 and Buckberry-Chamberlain (2007) stage 6, these stages range in age from 25 to 91 years, the mean ages are 48.1 and 66 years (Photo 33-44).

Donor 2019-21 is a female with a known age of 85 and an estimated age at death of 60 years old. The error of age at death estimation is 25 years. Cervical vertebrae two, three, and five through seven display slight to moderate porosity and cervical three through five are fused by a pathology not associated with osteoarthritis. Thoracic vertebrae five, six, and twelve display minor to slight porosity. Lumbar vertebrae one through five display moderate to severe porosity with eburnation present. The left innominate I aged as a Suchey-Brooks (1982) stage 6 and Buckberry-Chamberlain (2007) stage 6, the age range is from 39 to 91 years of age, the mean ages are 60 and 66. The right innominate of Donor 2019-21 I aged as a Suchey-Brooks (1982) stage 5 and a Buckberry-Chamberlain (2007) stage 6, the age range is from 25 to 91 years, the mean ages are 48.1 and 66 (Photo 45-62).

The last of the four is Donor 2020-05. Donor 2020-05 is a female with a known age of 89 years and an estimated age at death of 60 years. The error in age at death estimation is 29 years. Cervical vertebrae one, four, and five display minor to severe porosity with eburnation present and cervical three, six, and seven display other pathologies not associated with osteoarthritis. None of the thoracic vertebrae display osteoarthritis but thoracic six through twelve display other pathologies not associated with osteoarthritis. Thoracic six and seven are fused with calcifications, along with eight and nine, and ten through twelve. The lumbar vertebrae do not display osteoarthritis but do display other pathologies not associated with osteoarthritis. The left innominate I aged as a Suchey-Brooks (1982) stage 5 and Buckberry-Chamberlain (2007) stage 6, the age ranges from 25 to 91, the mean ages are 48.1 and 66. The right innominate of Donor

2020-05 I aged as a Suchey-Brooks (1982) stage 6 and a Buckberry-Chamberlain (2007) stage 6, the age ranges from 39 to 91, the mean ages are 60 and 66 years (Photo 63-70).

CHAPTER 6: DISCUSSION

The age at death estimation methods used in this project are the least accurate aging methods for individuals over the age of 50. This is because the physiological changes to the features mostly occur before 50 years of age and the degeneration of the features after 50 years of age accelerates. Both the Suchey-Brooks (1982) and Buckberry-Chamberlain (2002) methods have large resulting age ranges that can span upwards of 20+ years. The mean ages for these age ranges rarely accurately represents the real age of the individual (Milner and Boldsen 2012).

The significant correlation between skeletal completion and presence of osteoarthritis follows logically as the more joints were present, the higher chance of a pathology being observable by the researcher. This included preservation issues caused by taphonomic changes or bone loss due to animal scavenging or lack of recovery. While not a methodological problem per

se, this result is important to note as researchers need to record skeletal inventory as part of their notes in order to control for this connection.

The trend between increased osteoarthritis and other pathologies with increased error of age at death estimation supports my hypothesis that the presence of osteoarthritis and other pathologies will cause an inaccurate age at death estimation when using the pelvic age at death estimation methods. These methods, specifically, need to be improved upon in order for forensic anthropologists and bioarchaeologists to accurately age older adult individuals. This study observes a combination of joint facets not observed together in other studies; the intent was that a combination would enlighten new information on the subject. Calce, et al. (2018) observed osteoarthritis in the acetabulum, proximal and distal femur, and proximal and distal humerus and found that severe osteoarthritis in these joints can cause an individual to be aged older than they were at death. They state that the development of osteoarthritis caused the younger individuals to appear similar in comparison to older individuals. They recommend that the pubic symphysis and auricular surface should not be used on individuals with significant osteoarthritis, as they are based on the appearance of the joint surface itself, since the pathology on the bone can make an analyst assume that the individual is older (Calce, et al. 2018).

Calce, et al. (2018) and this study support the same hypothesis: that osteoarthritis affects pelvic age at death estimation methods. This study demonstrates that even in young and middle adult individuals, osteoarthritis can cause observer error when using the pubic symphysis and auricular surface for age at death estimation. In bioarchaeology, this means that when a population displays osteoarthritis, the assumption should not be that the individuals are all older adults but instead that something in the individual's life course caused osteoarthritis to develop, whether that be old age or some other event during life. Forensic anthropology focuses on

identifying unknown individuals. Any and all information an individual's skeleton can give us is used to create an identity, that in forensic anthropology is used to narrow down who the missing individual is. If osteoarthritis is assumed to generally only be present on older adult individuals, an observer may misidentify an individual. If a younger individual displayed osteoarthritis, there is a possibility of this being in the medical history because it is a degenerative disease. The observer would have to realize that the other age estimation methods identified the individual as being younger than 50 years old rather than rely on the presence of osteoarthritis or the pelvic age at death estimation methods.

The age at death estimation methods for the older adult population are severely lacking in the fact that they have not been studied and therefore our methods do not include them (Ice 2005). Milner and Boldsen (2012) discuss that there seems to be an "inability to say anything useful" about the ages of older individuals. They go one to say that there is a susceptibility to underestimate individuals whose known ages are 50+ years (Milner and Boldsen 2012). This is supported by this study's results that older individuals generally had a larger error in age at death estimation. These methods need to be improved upon in order for forensic anthropologists and bioarchaeologists to accurately age older adult individuals.

For example, in my study, young individuals with osteoarthritis were estimated to be older than accurate at the time of death. Donor 2019-06 was a 32-year-old female with 100% skeletal completion who displayed 15% osteoarthritis and 15% other pathologies on the observed bones. I estimated the overall age at death of Donor 2019-06 to be 62 years old. Donor 2019-08 was a 30-year-old male with 100% skeletal completion, who displayed 40% osteoarthritis displayed on the observed bones I estimated the overall age of Donor 2019-08 to be 63 years old. I believe that the presence of osteoarthritis and the other pathologies for these two individuals

changed the physiological appearance of the pubic symphysis and auricular surface in significant ways, causing an error in age at death estimation. I hypothesize that the presence of osteoarthritis and other pathologies on the observed bones caused stress on the pelvic joints used for age estimation causing the appearance of features correlated with old age. If I were to have just taken the presence of osteoarthritis into account and not used other aging methods, I would have assumed that both of these donors were well over the age of 50 at the time of death.

Conversely, elderly individuals with little osteoarthritis were systematically aged younger than accurate. Donor 2019-14 was a 78-year-old female, estimated age of 52 years old, with osteoarthritis on 25% of the observed bones. Donor 2019-19 was an 86-year-old female, estimated age of 59 years old, with osteoarthritis on 30% of the bones observed and 5% other pathologies. Donor 2019-21 was an 85-year-old female, estimated age of 60 years old, with osteoarthritis and other pathologies on 25% of the bones observed. Donor 2020-05 was an 89-year-old female, estimated age of 60 years, with osteoarthritis on 35% of the observed bones and 70% other pathologies. These individuals had an error between 20 and 29 years of age. Whether or not this error is caused by the presence and extent of osteoarthritis and other pathologies, the extreme age of these individuals and their younger estimated ages show a trend. Osteoarthritis needs to be taken into account and not as an age identifier, but just as a pathology and a note that the individual in question might need to be aged with different or specific methods. I conclude that these individuals are further evidence to support my hypothesis that osteoarthritis on the vertebral column, acetabulum, and femoral head could cause stress to the pelvic joints used in the Suchey-Brooks (1982) and Buckberry-Chamberlain (2002) methods. I suggest that this stress causes the features observed to appear as though they correlate to the older adult stage comparisons. It is unclear if this result is due to less osteoarthritis than expected. The donors in

this group all displayed 25-30% osteoarthritis on the bones observed. Ice (2005) and Milner and Boldsen (2012) explain that older adult individuals, 50+, are often underestimated as the methodologies often do not include them.

Milner and Boldsen (2012) states that there is little to be said about the ages of older individuals and there is a bias when estimating age, particularly a likelihood to underestimate the age of individuals 50+ years old. Milner and Boldsen (2012) state that, while the pelvic joint methods and modifications are fairly new, they mostly follow the earlier methods' layout and terminology, calling a need for more research to be done on these methodologies. This specifically ties into my project because most individuals in my study are considered old adults, or over the age of 55 years. The age at death estimation methods for the older adult age group are severely lacking in the fact that they have not been studied and therefore our methods do not include them. These methods also provide age ranges that span years or end in open ended intervals causing inaccurate ages (Milner and Boldsen 2012).

Brennaman (2014) hypothesized that because osteoarthritis often develops after the age of 50, it can be used to determine age in older individuals. This study supports this, as most of the individuals in this study over the age of 50 displayed osteoarthritis. However, can just the presence of osteoarthritis be used to determine age? On the one hand, if there is evidence to prove that the individual is 50 years of age or older, then osteoarthritis can be used to help aid in age estimation. On the other, osteoarthritis cannot be used as an indicator that an individual is absolutely 50 or older, as seen with the two outliers in this study. Unfortunately, we are now seeing more young individuals with signs of osteoarthritis formation; some modern adolescents and young adults are showing some signs of osteoarthritis. Kang, et al. (2017) and Shevchenko (2013) both discuss the presence of osteoarthritis in non-adults or subadults. They state that the

presence of osteoarthritis as a degenerative disease makes the skeleton of the individual appear older, but that through other aging methods, analysts can determine that the individual is not an adult (Kang, et al. 2017 and Shevchenko 2013). Osteoarthritis is often looked at as an identifier of age; in these circumstances (young adults and non-adults), this can cause the individual to be aged older. Other methodologies should be taken into consideration in the presence of osteoarthritis for this reason. I believe that not just one age at death estimation method should be used but as many as possible to get the most accurate estimation of age at death.

CHAPTER 7: CONCLUSION

There are many ways forensic anthropologists can estimate age at death; currently, anthropologists are trying to find which methods are best, which methods have flaws, how to make certain methods more reliable, and find variations of methods. The pelvis is the second most accurate age identifier in the body after dentition, but there are many things that can affect the physical appearance of the age estimation features, such as life experiences. This study uses the Suchey-Brooks (1982) and Buckberry-Chamberlain (2002) pelvic age at death estimation methods. This study found four individuals with an age estimation error of +/- 20-29 years. There were two outlier individuals with an age estimation error of +/-30-32 years. All of these individuals displayed osteoarthritis. This is evidence supporting that the presence of osteoarthritis affects the accuracy of pelvic age at death estimation methods.

Looking forward, the Suchey-Brooks (1982) and Buckberry-Chamberlain (2002) age at death estimation methods should continue to be analyzed on older individuals to better understand how to include either new or modified stages of age estimation. These methods should also continue to be observed in populations with degenerative pathologies, such as osteoarthritis; the causation might not be known but there is an evident correlation between

pathological presence and an inaccuracy in age estimation. When using these methods to analyze older populations or heavily pathological populations, they should be used in conjunction with other age at death estimation methods.

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Appendix A

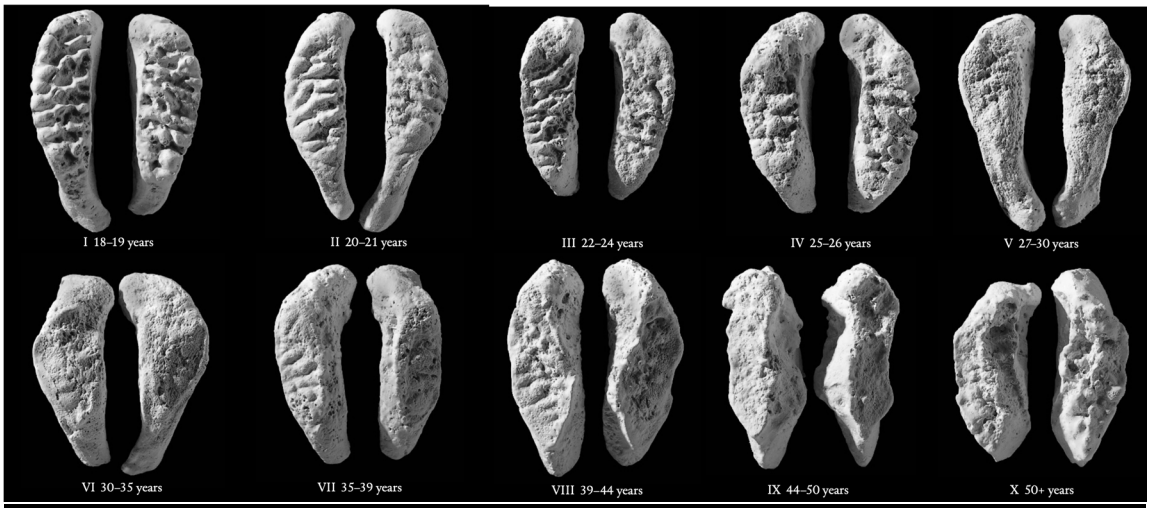

Figure 1: Photo comparisons of the Todd (1920) Method, from Todd 1920, taken from White, Black, and Folken's (2012).

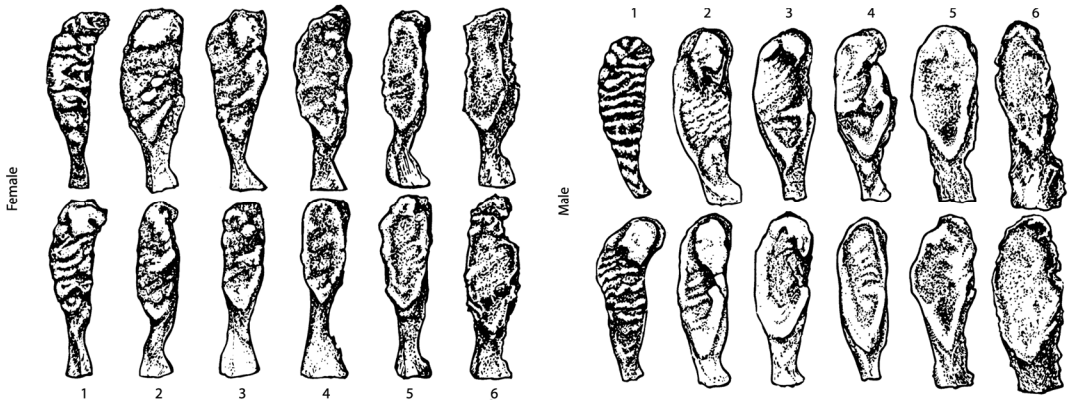

Figure 2: Photo comparisons of the Suchey-Brooks (1982) Method, from Suchey-Brooks (1982), taken from White, Black, and Folkens (2012).

Phase 1: Symphyseal face has a billowing surface (ridges and furrows), which usually extends to include the pubic tubercle. The horizontal ridges are well-marked, and ventral beveling may be commencing. Although ossific nodules may occur on the upper extremity, *a key to the recognition of this phase is the lack of delimitation of either extremity (upper or lower).*

Phase 2: The symphyseal face may still show ridge development. *The face has commencing delimitation of lower and/or upper extremities occurring with or without ossific nodules.* The ventral rampart may be in beginning phases as an extension of the bony activity at either or both extremities.

Phase 3: Symphyseal face shows lower extremity and *ventral rampart in process of completion.* There can be a continuation of fusing ossific nodules forming the upper extremity and along the ventral border. Symphyseal face is smooth or can continue to show distinct ridges. Dorsal plateau is complete. Absence of lipping of symphyseal dorsal margin; no bony ligamentous outgrowths.

Phase 4: Symphyseal face is generally fine grained although remnants of the old ridge and furrow system may still remain. *Usually the oval outline is complete at this stage, but a hiatus can occur in upper ventral rim.* Pubic tubercle is fully separated from the symphyseal face by definition of upper extremity. The symphyseal face may have a distinct rim. Ventrally, bony ligamentous outgrowths may occur on inferior portion of pubic bone adjacent to symphyseal face. If any lipping occurs, it will be slight and located on the dorsal border.

Phase 5: *Symphyseal face is completely rimmed with some slight depression of the face itself, relative to the rim.* Moderate lipping is usually found on the dorsal border with more prominent ligamentous outgrowths on the ventral border. There is little or no rim erosion. Breakdown may occur on superior ventral border.

Phase 6: *Symphyseal face may show ongoing depression as rim erodes.* Ventral ligamentous attachments are marked. In many individuals the pubic tubercle appears as a separate bony knob. The face may be pitted or porous, giving an appearance of disfigurement with the ongoing process of erratic ossification. Crenulations may occur. The shape of the face is often irregular at this stage.

Descriptive Statistics:

	Female (n = 273)			*Male (n = 739)*		
Phase	Mean	Standard Dev.	95% range	Mean	Standard Dev.	95% range
1	19.4	2.6	15–24	18.5	2.1	15–23
2	25.0	4.9	19–40	23.4	3.6	19–34
3	30.7	8.1	21–53	28.7	6.5	21–46
4	38.2	10.9	26–70	35.2	9.4	23–57
5	48.1	14.6	25–83	45.6	10.4	27–66
6	60.0	12.4	42–87	61.2	12.2	34–86

Figure 3: Description of phases, phases with correlating age ranges, and the mean age for each age range. Suchey-Brooks (1982) Method, taken from White, Black, and Folkens (2012).

Characteristic	Score	Description
Transverse organization	1	90% or more of surface is transversely organized
	2	50–89% of surface is transversely organized
	3	25–49% of surface is transversely organized
	4	Transverse organization is present on less than 25% of surface
	5	No transverse organization is present
Surface texture	1	90% or more of surface is *finely granular*
	2	50–89% of surface is *finely granular;* replacement of finely granular bone by coarsely granular bone in some areas; no dense bone is present
	3	50% or more of surface is *coarsely granular,* but no dense bone is present
	4	*Dense bone* is present, but occupies less than 50% of surface; this may be just one small nodule of dense bone in very early stages
	5	50% or more of surface is occupied by *dense bone*
Microporosity	1	No microporosity is present
	2	Microporosity is present on one demiface only
	3	Microporosity is present on both demifaces
Macroporosity	1	No macroporosity is present
	2	Macroporosity is present on one demiface only
	3	Macroporosity is present on both demifaces
Apical changes	1	Apex is sharp and distinct; auricular surface may be slightly raised relative to adjacent bone surface
	2	Some lipping is present at apex, but shape of articular margin is still distinct and smooth (shape of outline of surface at apex is a continuous arc)
	3	Irregularity occurs in contours of articular surface; shape of apex is no longer a smooth arc

Figure 4: Description of Buckberry-Chamberlain (2002) scoring method, taken from White, Black, and Folkens (2012).

Composite score	Stage	Mean age and standard deviation	Median age	Age range
5 or 6	1	17.33 ± 1.53 years	17 years	16–19 years
7 or 8	2	29.33 ± 6.71 years	27 years	21–38 years
9 or 10	3	37.86 ± 13.08 years	37 years	16–65 years
11 or 12	4	51.41 ± 14.47 years	52 years	29–81 years
13 or 14	5	59.94 ± 12.95 years	62 years	29–88 years
15 or 16	6	66.71 ± 11.88 years	66 years	39–91 years
17, 18, or 19	7	72.25 ± 12.73 years	73 years	53–92 years

Figure 5: Buckberry-Chamberlain (2002) score, stages, correlating age ranges, and mean ages. Taken from White, Black, and Folkens (2012).

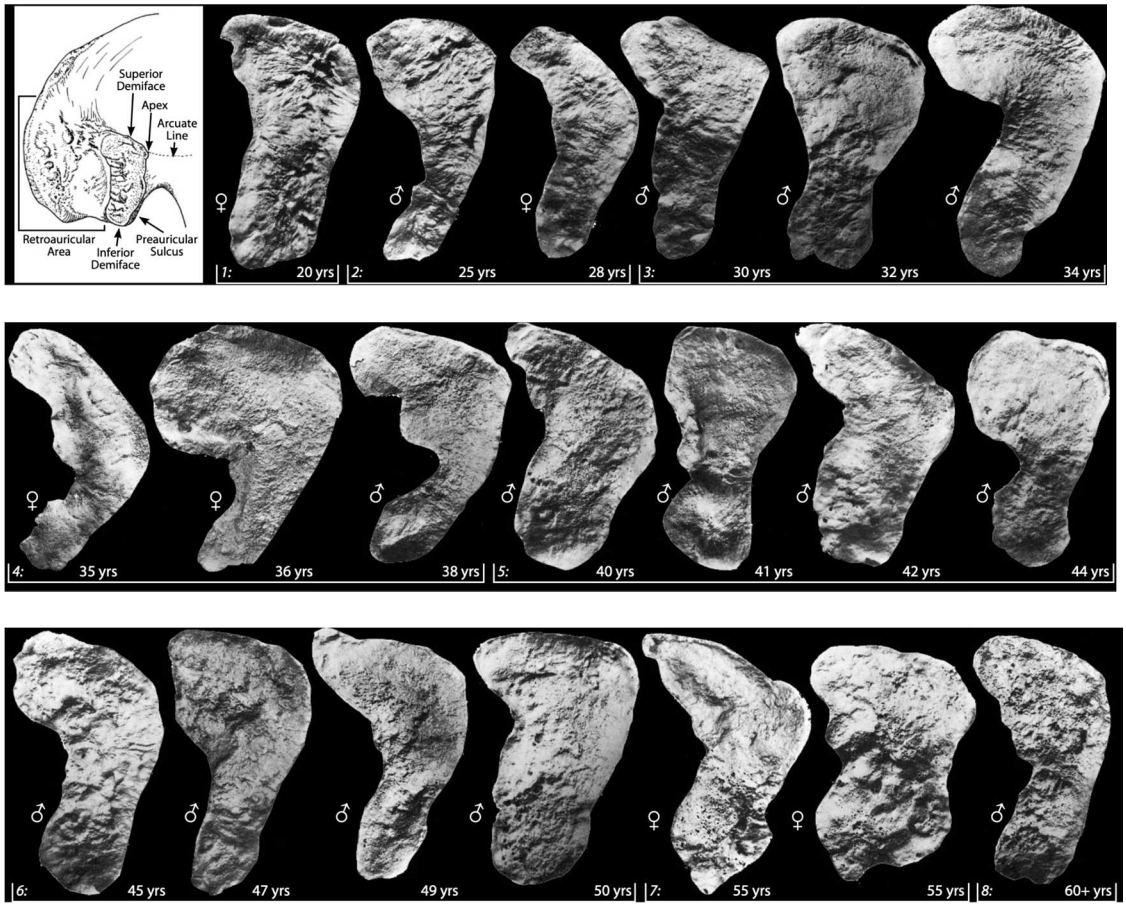

Figure 6: Comparison photos of Buckberry-Chamberlain (2002) stages. Taken from White, Black, and Folkens (2012).

Appendix B

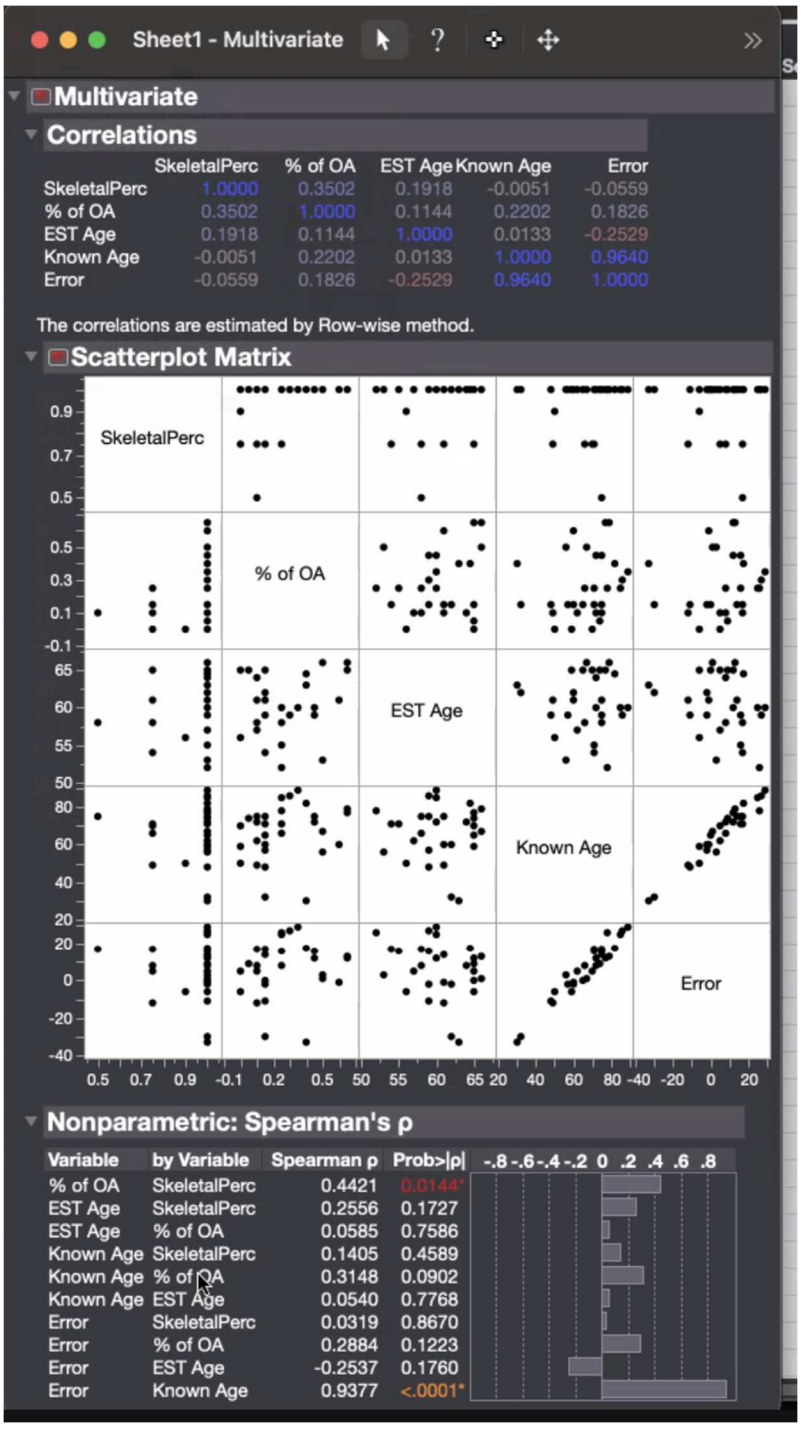

Figure 7: JMP Scatterplot Matrix, displays significant correlations and trends

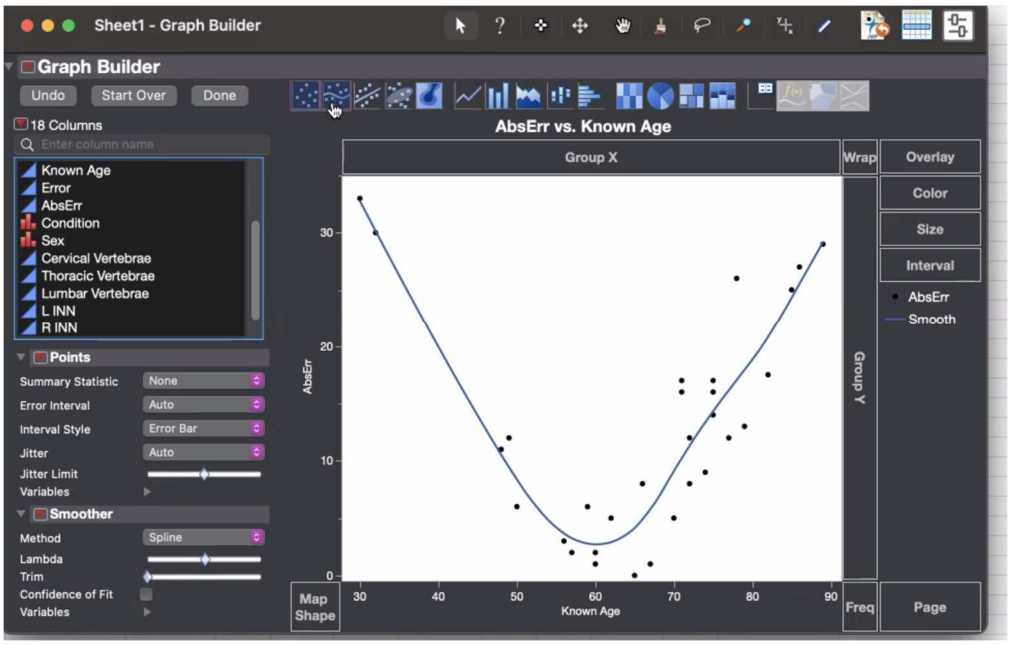

Figure 8: Plot graph, displays two outliers and trend of older individuals having a high error in age at death estimation.

Appendix C

Photo 1: Donor 2019-06, Thoracic Vertebra 4, Displayed minor osteoarthritis

Photo 2: Donor 2019-06, Thoracic Vertebra 5, Displayed minor osteoarthritis

Photo 3: Donor 2019-06, Thoracic Vertebra 6, Displayed minor osteoarthritis

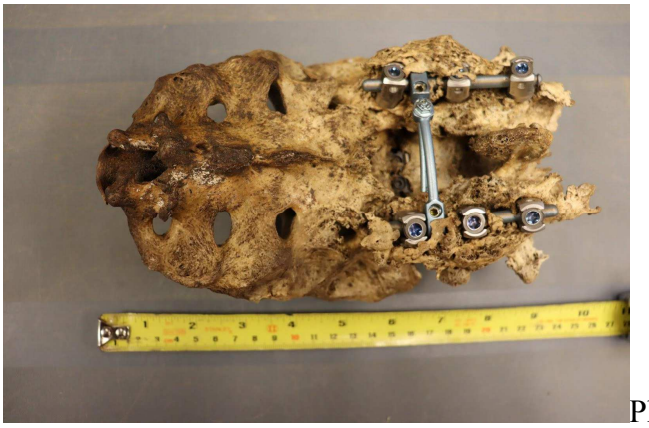
Photo 4: Donor 2019-06, Lumbar Vertebrae 4 & 5 & Sacrum, Displayed other pathologies not related to osteoarthritis


Photo 5: Donor 2019-06, Left Pubic Symphysis, Stage 6


Photo 6: Donor 2019-06, Left Auricular Surface, Stage 6

Photo 7: Donor 2019-06, Right Pubic Symphysis, Stage 6

Photo 8: Donor 2019-06, Right Auricular Surface, Stage 5

Photo 9: Donor 2019-08, Thoracic Vertebra 1, Displayed minor osteoarthritis

Photo 10: Donor 2019-08, Thoracic Vertebra 4, Displayed minor osteoarthritis

Photo 11: Donor 2019-08, Thoracic Vertebra 5, Displayed minor osteoarthritis

Photo 12: Donor 2019-08, Thoracic Vertebra 6, Displayed minor osteoarthritis

Photo 13: Donor 2019-08, Thoracic Vertebra 7, Displayed minor osteoarthritis

Photo 14: Donor 2019-08, Thoracic Vertebra 8, Displayed minor osteoarthritis

Photo 15: Donor 2019-08, Thoracic Vertebra 9, Displayed minor osteoarthritis

Photo 16: Donor 2019-08, Thoracic Vertebra 10, Displayed minor osteoarthritis

Photo 17: Donor 2019-08, Thoracic Vertebra 11, Displayed minor osteoarthritis

Photo 18: Donor 2019-08, Thoracic Vertebra 12, Displayed minor osteoarthritis


Photo 19: Donor 2019-08, Left Pubic Symphysis, Stage 6


Photo 20: Donor 2019-08, Left Auricular Surface, Stage 6


Photo 21: Donor 2019-08, Right Pubic Symphysis, Stage 6

Photo 22: Donor 2019-08, Right Auricular Surface, Stage 6

Photo 23: Donor 2019-14, Cervical Vertebra 3, Displayed moderate osteoarthritis

Photo 24: Donor 2019-14, Cervical Vertebra 4, Displayed slight osteoarthritis

Photo 25: Donor 2019-14, Cervical Vertebra 5, Displayed slight osteoarthritis

Photo 26: Donor 2019-14, Cervical Vertebra 6, Displayed slight osteoarthritis

Photo 27: Donor 2019-14, Thoracic Vertebra 1, Displayed slight osteoarthritis

Photo 28: Donor 2019-14, Lumbar Vertebra 5, Displayed severe osteoarthritis


Photo 29: Donor 2019-14, Left Pubic Symphysis, Stage 5

Photo 30: Donor 2019-14, Left Auricular Surface, Stage 6


Photo 31: Donor 2019-14, Right Pubic Symphysis, Stage 5

Photo 32: Donor 2019-14, Right Auricular Surface, Stage 4

Photo 33: Donor 2019-19, Cervical Vertebra 1, Displayed severe osteoarthritis

Photo 34: Donor 2019-19, Cervical Vertebra 2, Displayed severe osteoarthritis

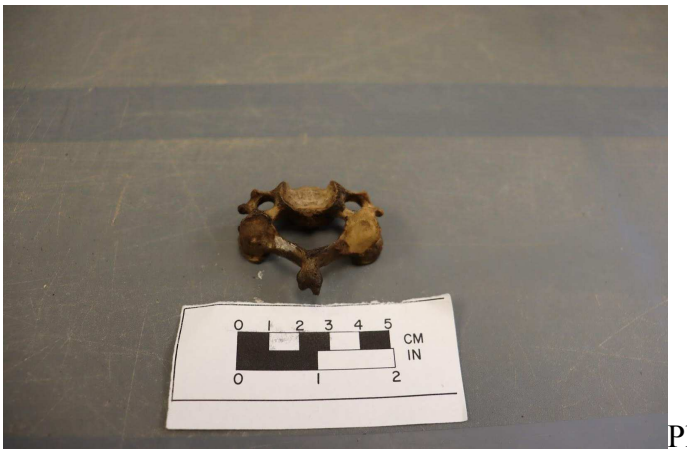

Photo 35: Donor 2019-19, Cervical Vertebra 3, Displayed severe osteoarthritis

Photo 36: Donor 2019-19, Cervical Vertebra 4, Displayed severe osteoarthritis

Photo 37: Donor 2019-19, Cervical Vertebra 5, Displayed severe osteoarthritis

Photo 38: Donor 2019-19, Lumbar Vertebra 2, Displayed severe osteoarthritis

Photo 39: Donor 2019-19, Lumbar Vertebra 3, Displayed severe osteoarthritis

Photo 40: Donor 2019-19, Lumbar Vertebra 5, Displayed severe osteoarthritis


Photo 41: Donor 2019-19, Left Pubic Symphysis, Stage 6

Photo 42: Donor 2019-19, Left Auricular Surface, Stage 5


Photo 43: Donor 2019-19, Right Pubic Symphysis, Stage 5

Photo 44: Donor 2019-19, Right Auricular Surface, Stage 6

Photo 45: Donor 2019-21, Cervical Vertebra 2, Displayed slight osteoarthritis

Photo 46: Donor 2019-21, Cervical Vertebra 3, Displayed moderate osteoarthritis

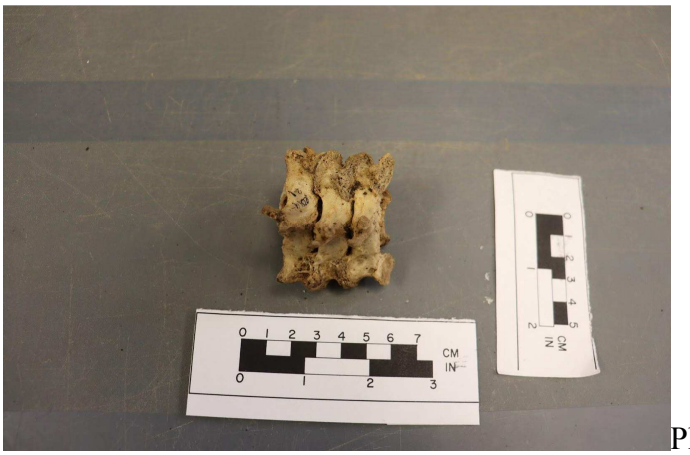

Photo 47: Donor 2019-21, Cervical Vertebrae 3-5, Displayed pathology not osteoarthritis

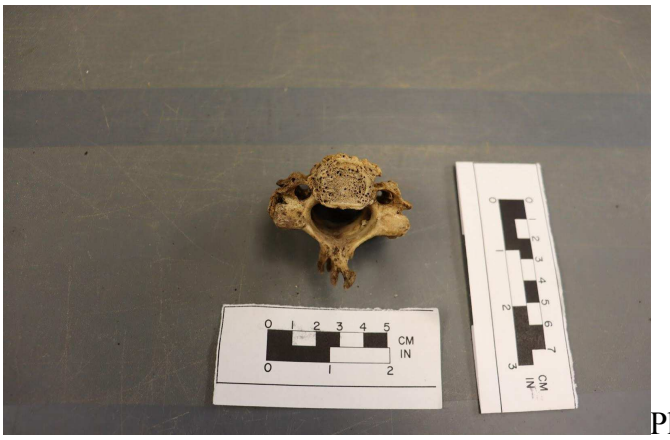

Photo 48: Donor 2019-21, Cervical Vertebra 5, Displayed slight osteoarthritis

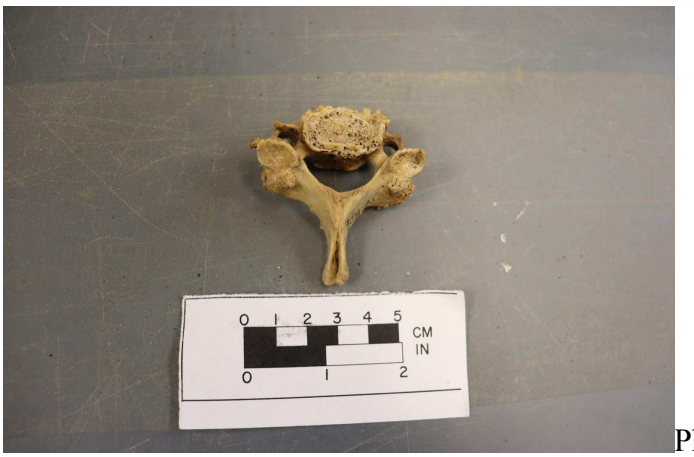

Photo 49: Donor 2019-21, Cervical Vertebra 4, Displayed severe osteoarthritis

Photo 50: Donor 2019-21, Cervical Vertebra 7, Displayed severe osteoarthritis

Photo 51: Donor 2019-21, Thoracic Vertebra 5, Displayed slight osteoarthritis

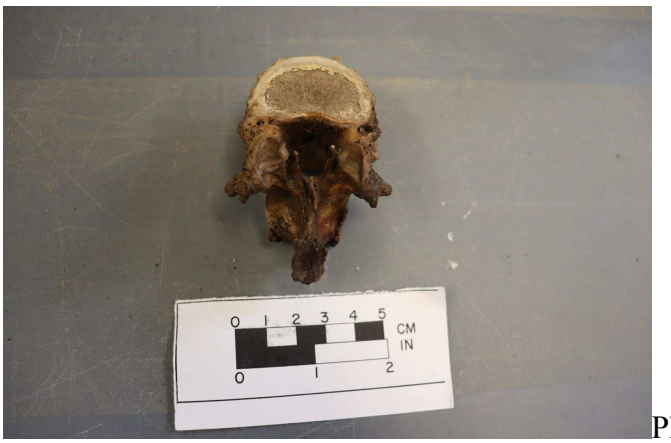

Photo 52: Donor 2019-21, Thoracic Vertebra 6, Displayed slight osteoarthritis

Photo 53: Donor 2019-21, Thoracic Vertebra 12, Displayed slight osteoarthritis

Photo 54: Donor 2019-21, Lumbar Vertebra 1, Displayed severe osteoarthritis

Photo 55: Donor 2019-21, Lumbar Vertebra 2, Displayed severe osteoarthritis

Photo 56: Donor 2019-21, Lumbar Vertebra 3, Displayed severe osteoarthritis

Photo 57: Donor 2019-21, Lumbar Vertebra 4, Displayed severe osteoarthritis

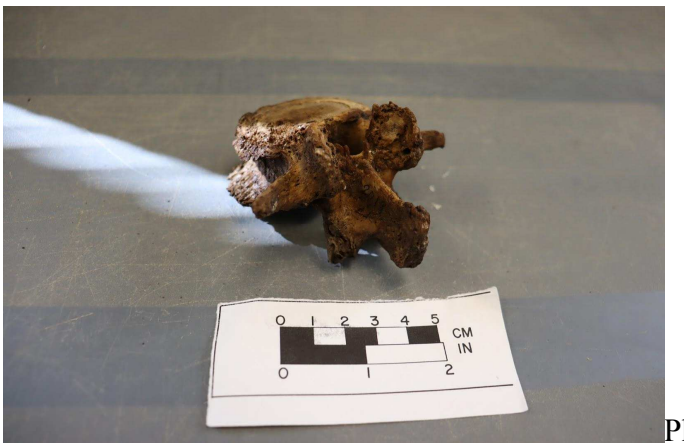

Photo 58: Donor 2019-21, Lumbar Vertebra 5, Displayed severe osteoarthritis


Photo 59: Donor 2019-21, Left Pubic Symphysis, Stage 6

Photo 60: Donor 2019-21, Left Auricular Surface, Stage 6

Photo 61: Donor 2019-21, Right Pubic Symphysis, Stage 5

Photo 62: Donor 2019-21, Right Auricular Surface, Stage 6

Photo 63: Donor 2020-05, Cervical Vertebra 1, Displayed severe osteoarthritis

Photo 64: Donor 2020-05, Cervical Vertebra 4, Displayed slight osteoarthritis

Photo 65: Donor 2020-05, Cervical Vertebra 5, Displayed slight osteoarthritis

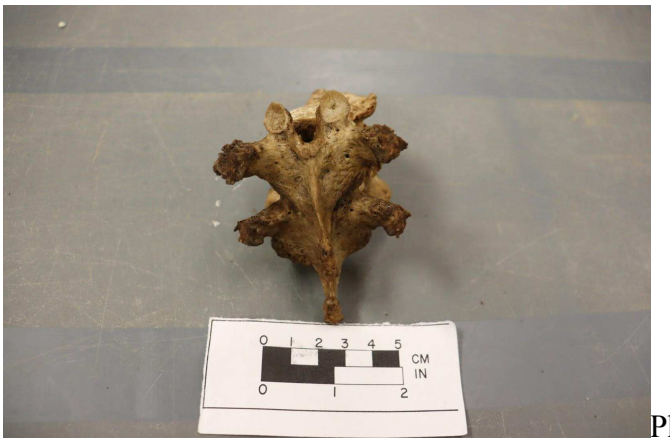

Photo 66: Donor 2020-05, Thoracic Vertebrae 9 & 10, Displayed severe osteoarthritis and other pathologies


Photo 67: Donor 2020-05, Left Pubic Symphysis, Stage 5


Photo 68: Donor 2020-05, Left Auricular Surface, Stage 6


Photo 69: Donor 2020-05, Right Pubic Symphysis, Stage 6

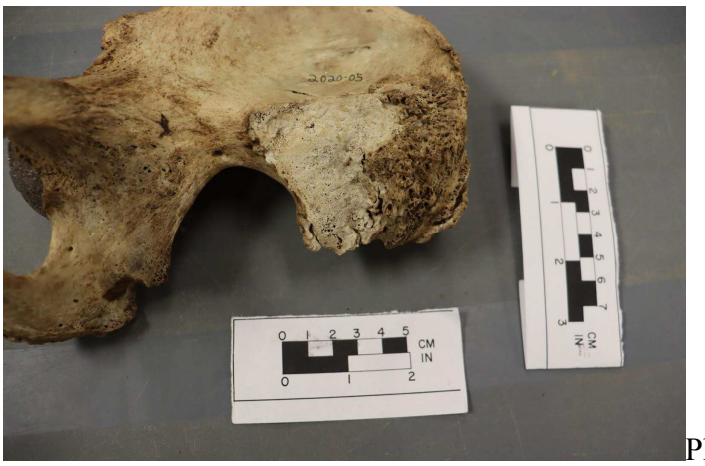

Photo 70: Donor 2020-05, Right Auricular Surface, Stage 6