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THE EFFECTS OF PARTURITION ON PELVIC AGE INDICATORS

By

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Dissertation

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The effects of parturition on pelvic age indicators

Chair: Ashley McKeown, PhD

Estimating age from skeletal remains provides a critical component of the biological profile of an individual. To date, there are different methods used on select parts of the skeleton to assess the age of the individual, and currently, the pelvis is relied upon heavily to obtain accurate and reliable age ranges (Berg 2008; Brooks and Suchey 1990; Buckberry and Chamberlain 2002). Many have stated that age related changes follow different trends in males and females, with parity presented as one of the possible causes for such differences (Berg 2008; Meindl and Lovejoy 1989; Resnick and Niwayama 1998; Suchey and Katz 1998). There is reason to believe that parturition may increase the rate at which the areas of interest of the pelvis degenerate. However, this hypothesis has yet to be formally tested on a recent skeletal collection. The purpose of this study, therefore, is to assess the effects of pregnancy and parturition on the pubic symphysis and auricular surface and determine whether it influences the morphology of the pelvis enough to effect the physiological age of the individual.

Data were collected from the William M. Bass Skeletal Collection located at The University of Tennessee, Knoxville. The study contained 434 individuals (males: 234/females: 200/parous: 157/nulliparous: 43). This is a collection of modern forensic skeletons with known age at death, ancestry, sex, and medical background. The features of the pubic symphysis were noted and matched with the best fitting phase in both the Suchey-Brooks and Todd pubic symphysis scoring systems (Brooks and Suchey 1990; Buikstra and Ubelaker 1994; Todd 1921). Next, the features of the auricular surface were noted and matched with the best fitting phase in the system presented by Lovejoy and colleagues and were individually scored resulting in a composite score following the method proposed by Buckberry and Chamberlain (Buckberry and Chamberlain 2002; Meindl and Lovejoy 1989; Lovejoy et al. 1985). Time was designated at the beginning of the second and third days to employ the test-retest method to calculate the intra-observer error rate and ensure reliability of these assessments.

In this study, a statistical comparison was made between females who have given birth and those who have not to determine whether this process affects the rate of degeneration of the areas of interest of the pelvis. The male sample was used as a control for these age assessment techniques. A transition analysis, also known as a cumulative probit analysis, was conducted on the data in order to establish the age-at-transition distributions between the stages of each age estimation method. The results were then compared between the males and the nulliparous and parous female groups using likelihood ratio tests. The purpose for this comparison is to observe whether the age-at-transition distributions differs between sexes and/or the two groups, with the focus being on whether the parous group illustrates a difference in rate of degeneration, or transition to subsequent observable stages, when compared to the nulliparous and male groups.

The data was entered into the statistical software program R version 3.0.2. The transition analysis produced significantly different results between parous and nulliparous females using the pubic symphysis but not the auricular surface when the likelihood ratio test were taken into account. The male group and the nulliparous female group transition around the same age, while the parous females transition at an earlier age. An investigation was made into the implications these findings have for age estimation. The current research suggests that parturition affects the

pubic symphysis more so than the auricular surface when determining age at death. While the error rate was found to be within the normal range, a suggestion may be made to use the auricular surface age indicators when assessing age of females presumed to be parous.

The present results are significant in that they represent a noteworthy find within the realm of forensic anthropology and similar professional fields that may utilize this information on modern cases from the United States today. The current project addresses several issues by employing transition analysis to 1) utilize an appropriate age-at-death distribution for the reference sample, 2) combat the issues inherent in linear regression analyses including biased age estimations and lumping older individuals into terminal categories such as 50 years plus, and 3) generate appropriate age-at-transitions for females who have had children, given their rate of degeneration of pelvic age indicators increase due to such a naturally traumatic event. A large part of forensic anthropology is providing a positive identification of the individual from the recovered remains. Inaccurate age determination of a skeleton can result in the remains being misidentified or unidentified. This project indicates that parturition affects the pubic symphysis and not the auricular surface when estimating age at death. This may lead to future estimations or correction factors that allow age estimation to be done more reliably.

Forensic anthropology, Age estimation, Pelvis, Parity

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TABLE OF CONTENTS

	Page
LIST OF TABLES	viii
LIST OF FIGURES	ix
CHAPTER	
I. INTRODUCTION	1
Thesis Statement	4
Implications of Research.....	4
II. LITERATURE REVIEW	5
Age Assessment.....	5
Pubic Symphysis.....	5
Auricular Surface	17
Issues with Determining Age-at-Death.....	23
Use of Appropriate Reference Sample	24
Asymmetry of Elements	28
Statistical Analysis in Age Estimation.....	29
Parity.....	33
III. MATERIALS & METHODS	39
Research Design.....	39
Materials	40
Data Collection	41
Methods Used to Score Age Indicators	43
Methods.....	48
Intra-observer Accuracy Study	48
Transition Analysis	49
Likelihood Ratio Test	53
Analysis of Incorrectly Assessed Individuals.....	55

IV. RESULTS	57
Intra-observer Accuracy Study	57
Transition Analysis	58
Likelihood Ratio Test	72
Analysis of Incorrectly Assessed Individuals	74
V. DISCUSSION	78
Transition Analysis & Likelihood Ratio Test	79
Implications for Age Estimation	81
Role of Parity on Physiological & Morphological Changes of the Pelvis	87
Future Areas of Research	93
VI. CONCLUSION	94
REFERENCES	98
APPENDIX A	105

LIST OF TABLES

Table	Page
1. Sex, age-at-death, and ancestry of the test sample.....	40
2. Description of the Todd (1920, 1921) scoring system.....	44
3. Description of the Suchey-Brooks (Brooks and Suchey 1990, Suchey and Katz 1986) scoring system.	45
4. Description of the Lovejoy (Lovejoy et al. 1985) scoring system.	46
5. Description of the Buckberry-Chamberlain (2002) scoring system.	47
6. Transition analysis parameters for each group using the Todd scoring system. Shaded rows indicate parameters used in study.	60
7. Transition analysis parameters for each group for the Suchey-Brooks scoring system. Shaded rows indicate parameters used in study.	63
8. Transition analysis parameters for each group for the Lovejoy scoring system. Shaded rows indicate parameters used in study.	66
9. Transition analysis parameters for each group for the Buckberry-Chamberlain scoring system. Shaded rows indicate parameters used in study.	69
10. Likelihood ratio test results for each comparison by age indicator scoring system.	73
11. Age ranges and direction of bias of incorrectly assessed individuals for the Todd scoring system (- = under-aged / + = over-aged).	74
12. Age ranges and direction of bias of incorrectly assessed individuals for the Lovejoy scoring system (- = under-aged / + = over-aged).	75
13. Age ranges and direction of bias of incorrectly assessed individuals for the Buckberry-Chamberlain scoring system (- = under-aged / + = over-aged).	76

LIST OF FIGURES

Figure	Page
1. Todd's (1920) ten-phase scoring system. Picture adopted from White and Folkens (2000: 352).....	6
2. Suchey-Brooks' (Katz and Suchey 1986, Brooks and Suchey 1990) six-phase scoring system. Picture adopted from White and Folkens (2000: 356).....	12
3. Berg's (2008) revised Suchey-Brooks phases. The top row depicts phase 5, middle row phase 6, and bottom row phase 7 (Berg 2008: 575).	16
4. Lovejoy et al. (1985b) eight-phase scoring system. Picture adopted from White and Folkens (2000: 358).	18
5. Sample distribution separated by sex. Age ranges include all individuals within that decade.	42
6. Female sample age distribution separated into parous and nulliparous groups. Age ranges include all individuals within that decade.....	43
7. Estimated age-at-transition distribution for each group for the Todd scoring system.	61
8. Estimated probability of each group being in stages 8, 9, and 10 for the Todd scoring system. Probabilities based on known ages of individuals in sample and assigned phase during assessment.	62
9. Estimated age-at-transition distribution for each group for the Suchey-Brooks scoring system.	64
10. Estimated probability of each group being in stages 4, 5, and 6 for the Suchey-Brooks scoring system. Probabilities based on known ages of individuals in sample and assigned phase during assessment.	65
11. Estimated age-at-transition distribution for each group for the Lovejoy scoring system.....	67
12. Estimated probability of each group being in stages 6, 7, and 8 for the Lovejoy scoring system. Probabilities based on known ages of individuals in sample and assigned phase during assessment.	68
13. Estimated age-at-transition distribution for each group for the Buckberry-Chamberlain scoring system.	70

14. Estimated probability of each group being in stages 5, 6, and 7 using the Buckberry-Chamberlain scoring system. Probabilities based on known ages of individuals in sample and assigned phase during assessment	71
15. Photographic exemplars of pubic symphyses of similarly aged nulliparous and parous females: Top row is of nulliparous females aged 46, 46, and 47 years, respectively; Bottom row is of parous females aged 47, 47 and 45 years, respectively.....	84
16. Illustration of the superior and inferior pubic ligaments (Gray, 1918).....	89
17. Illustration of the anterior view of the pelvic ligaments (Gray, 1918).	90
18. Illustration of the posterior view of the pelvic ligaments (Gray, 1918).....	90
19. Radiograph illustrating a 50mm diastasis of the pubic symphysis (A) and a 6-month follow-up radiograph where the gap is reduced to 10mm (B) (Chang and Markman 2002).	92

CHAPTER I

INTRODUCTION

Estimating age from skeletal remains provides a critical component of the biological profile of an individual. To date, there are different methods used on select parts of the skeleton to assess the age of the individual, and currently, the pelvis is relied upon heavily to obtain accurate and reliable age ranges (Brooks and Suchey 1990; Buckberry and Chamberlain 2002; Berg 2008). Other researchers have suggested that methods utilizing the pelvis, specifically the pubic symphysis, are not as reliable as previously believed due to large age ranges, lack of precision with older individuals, and failure to account for human variation (Meindl and Lovejoy 1989; Meindl and Russell 1998; Jackes 2000). Berg (2008) noted that older adult females as they have a propensity to follow a different trend than males and presented new categories of age estimation. The observed age related changes in females were conjectured to be a product of osteoporosis and osteopenia, which Meindl and Lovejoy (1989) stated are a consequence of postmenopausal osteoporosis. Berg (2008) notes that several researchers have suggested that parity may have an effect on bone health later in life, such as development of osteoporosis, but this has not been documented or researched at great length (Resnick and Niwayama 1998; Suchey and Katz 1998).

In the early 1900s, research began to be reported on the pelvis regarding its utility for sex estimation, which led to the eventual focus on skeletal alteration due to pregnancy and parturition (Ubelaker and De La Paz 2012). Ubelaker and De La Paz (2012) provide a historical review of the past century of literature on the research into skeletal evidence of pregnancy and parturition and the various interpretations forensic anthropologists may employ in their interpretations. This type of research, while invaluable to the proposed research, presents

different approach to the analysis of parity. For instance, Ubelaker and De La Paz (2012:1) list different skeletal indicators such as “the preauricular sulcus, separation of the pubic symphysis, osteitis condensans ilii, osteitis pubis, pubic pitting, bone density loss, and extension of the pubic tubercle.” The proposed research is not necessarily concerned with whether pregnancy and parturition leave a specific skeletal indicator, but rather whether these processes change the rate of degeneration of age indicators on the os coxae.

As early as 1976, research found that pubic symphyses of females appear ‘older’ than males of the same age due to the bony alterations caused by parity (Putschar 1976). This project aims to test these findings as well as understand the role parity plays in the morphological changes of the pelvis. This research will examine how day-to-day stressors affect the pelvis and whether pregnancy and parturition have differential effects on the two areas of interest on the pelvis, the pubic symphysis and the auricular surface. For example, the sacroiliac joint has the potential to be more greatly affected by pregnancy and parturition, as it is already directly responsible as the main support of body weight (Houghton 1974). On the other hand, pregnancy causes the release of hormones that promote the relaxing and stretching of the pelvic ligaments in order to prepare for delivery. The relaxing of the pubic ligaments generates instability in this joint that causes damage to the fibrocartilaginous disc that separates and cushions the joint (Becker et al. 2010).

When cartilage within a joint lessens in size, the cushion between the elements is also lessened, and subsequent damage to the bone will be incurred and observed as bony changes. The amount of cartilage found in joints is known to decrease as a function of age. This is true of the disc located at the pubic symphysis. The width of the disc is approximately 10mm around the age of 3 years, 6mm around the age of 20 years, and 3mm around the age of 50 years

(Putschar 1976; Becker et al. 2010; Khorashadi et al. 2011). While age related changes occur to this disc throughout one's lifetime, the additional trauma caused by pregnancy and parturition subject female pubic symphyses to additional alterations to the bone. Therefore, pregnancy and parturition are confounding factors to the aging process of this joint. These events increase the damage incurred to the disc, which then increases the rate of the bony alterations of the joint, and ultimately resulting in an older appearing surface of the symphyseal face when compared to other individuals of similar age.

Due to the physiological changes during pregnancy, parturition, and the postpartum period, there is reason to believe that these events may increase the rate at which age indicators of the pelvis degenerate. This hypothesis has yet to be formally tested on a recent skeletal collection. The purpose of this study, therefore, is to assess the effects of parturition on pubic symphysis and auricular surface to determine whether it influences the morphology of the pelvis enough to effect the physiological age of the individual.

There is a clear need for this research because identifying missing persons in a forensic context relies on an accurate assessment of age at death. Forensic anthropologists understand there are extrinsic factors that may contribute to non-age related degeneration of the bone. Best practices for age estimation as reported by SWGANTH states potential sources of error are to be identified and the extent to which the appearance of the element is affected is to be quantified (SWGANTH 2013). If there is a process, i.e. parturition, that affects a morphological feature used to estimate age then it must be made known to therefore correct for the possible over-estimation of age. For example, if childbirth increases the rate at which the pubic symphysis degenerates, then for each subsequent pregnancy and parturition, the morphology/topography of the pubic symphysis will resemble that of an older individual at a later phase of the age

estimation method rather than the true chronological age of the individual. The question is whether this increase in degeneration is one that would be enough to result in an inaccurate or unreliable age estimate, which law enforcement would use to compare with missing person reports.

Thesis Statement

I propose that the pubic symphysis and auricular surface need to be analyzed in females who have experienced childbirth, parous, versus those who have not, nulliparous, in order to determine whether this process increases the degenerative changes in these areas. The null hypothesis is that there will be no differences observed in the rate of degeneration of the pubic symphysis and/or auricular surface between nulliparous females and parous females. The alternative hypothesis states that the pubic symphysis and/or auricular surface of parous females degenerate at a faster pace than nulliparous females. If evidence is found in support of the alternative hypothesis, my next research question is whether this difference in degeneration is enough to cause a significant difference in the assessment of the chronological age of the individual.

Implications of Research

An important goal of forensic anthropology is providing information that can lead to a positive identification of the skeletal human remains. Inaccurate age estimation for a skeleton can result in the remains being misidentified or left unidentified. This project will indicate whether parturition affects the areas of interest on the pelvis, and if so, may lead to future parameters for age estimations or correction factors that allow age estimation to be done more reliably.

CHAPTER II

LITERATURE REVIEW

Age Assessment

Pubic Symphysis

The skeletal age indicator that is considered the most reliable is the pubic symphysis (Stewart 1979; Meindl et al. 1985; Suchey et al. 1986; Steele and Bramblett 1988; Ubelaker 1989; Suchey and Katz 1998; Bass 2005). Due to this fact, it is also the most frequently applied skeletal age estimation technique (Aykroyd et al. 1999). Research has demonstrated that the morphological changes that occur on the pubic symphysis appear to travel along a distinct seriation that is irreversible (Meindl et al. 1985; Meindl and Lovejoy 1989; Berg 2008). Moreover, these changes occur throughout one's lifetime, well into old age, whereas skeletal age estimation techniques such as epiphyseal fusion and dental formation are considered early indicators.

Age related changes of the pubic symphysis began to be documented in 1920 by Todd. This research generated the first method for determining age-at-death using the os coxae. Todd generated a ten-phase system based on observations using the Hamann-Todd collection. Each phase is defined by a morphological description that corresponds to an age range. The early phases describe post-adolescence when the pubic symphysis expresses billowing. Then, the phases describe the changes that occur throughout middle-aged adults, which are characterized by definition of the upper and lower extremities and the formation of a symphyseal rim. The final phase encompasses all individuals 50 years and older. This is when features are no longer developing but rather degenerating. This final phase is defined by the break down of the

symphyseal rim, erosion of the symphyseal face, and lipping along the margins (Todd 1920) (Figure 1).

Figure 1. Todd's (1920) ten-phase scoring system. Picture adopted from White and Folkens (2000: 352).

The research began with a sample of Euro-American males and was followed up with further research including Euro-American females and African American males and females (Todd 1920; Todd 1921). Todd concluded that there was no difference between ancestries or sexes when observing the rate of degeneration of the pubic symphysis. Even though Todd admitted to the difficulties in obtaining parity information on the females in the collection, with that category of data largely unknown, he still concluded that the variation observed on female pubic symphyses was not due to the effects of parturition, a belief also supported later by Gilbert and McKern (1973). Stewart (1957), however, proposed two valid reasons for this observation. First he commented that parturition was in fact most likely the cause of the variation observed by Todd on female pelvises. He also states that it is possible that the females in the skeletal collection were nulliparous because offspring would have likely claimed the body of their mother rather than allowing her to go unclaimed.

Todd admitted there were problems with his study. One issue was the attempt to eliminate specimens that were in doubt. Eliminated specimens were those that expressed morphological characteristics that varied greatly from the chronological age of the individual. This, however, decreased the variation in degeneration observed at each age and consequently, this decision increased the success of Todd's phase system in a biased manner (Lucy 1996). Other acknowledged issues were that accuracy of the method decreased with increase of age and that the phases were based on the most typical specimen of each phase. The underlying cause of this issue may be due to the fact that the Hamann-Todd collection is comprised of mostly older individuals. Therefore, the spread of individuals available to generate the age ranges for each phase were biased with an older mean age. An additional problem that may increase error when utilizing this technique is the way it is recommended to select a phase. For instance, although the sequence of the development and degeneration of the ventral margin is mentioned in the phases, if another feature is present that correlates to a later phase, the ventral margin is to be ignored when choosing the phase with the best fit (Lucy 1996). Other issues regarding the collection are the low socio-economic demographic composition of the sample as well as the lack of known ages for a portion of the collection. Even with all these issues, Meindl et al. (1985) conducted a comparison study of three widely accepted subsequent techniques of the Todd ten-phase method as well as the Todd ten-phase method and concluded that the Todd method performed most accurately when comparing physical and chronological ages.

While research conducted and published by Todd was the initial attempt to determine the age of an individual based on the morphology of the pubic symphysis it stood uncontested and unaltered for around 30 years. Later studies and subsequent methods each have a foundation in the Todd ten-phase method; whether it is revised definitions or phase system, more recent age

estimation techniques utilizing the os coxae express some basis in the Todd ten-phase method. A strong push for advances in skeletal identification occurred following WWII and the Korean War due to such a great need to be able to accurately identify U.S. war dead (Brown 2009). The first to attempt to revise the Todd ten-phase method was Brooks (1955).

It was found that the Todd ten-phase system tended to overage male and females pubic symphyses, which spurred an attempt by Brooks (1955) to rectify this issue. Brooks' (1955) study applied the Todd ten-phase method to a sample of 103 male and 82 female skeletons from California. The issue with this sample is that the individuals are of unknown ages. Even still, Brooks was able to observe differences between pubic symphyseal surface morphology and cranial sutures and advised that the age ranges for each phase provided by Todd (1920) should be revised. Moreover, Brooks noted that there were sex differences in pubic symphysis development and degeneration rates that should be taken into account when determining age of an individual from this element. This is further supported by Gilbert and McKern (1973) whose research generated a female standard for age estimation from the pubic symphysis. In 1979, Suchey and a team of physical anthropologists tested Brooks' revised Todd method on the pubic symphyses of 11 females and found the results to be widely inaccurate. The results showed that the analysts were able to assess the age of the individual to within 15 years of the chronological age only 51% of the time (Suchey 1979; Lucy 1996). A sample size of 11 individuals, however, may not be large enough to accurately come to this conclusion. The main contribution from the Brooks (1955) study was the creation of casts of the pubic symphysis intended to represent the most typical specimens for each phase.

Next to devise a modified version of the Todd method was McKern and Stewart (1957). The researchers believed that the phases put forth by Todd (1920) were too specific and the age

ranges too narrow to accurately capture the variation observed at each age. Therefore, they wanted to create a technique that allowed for certain features to develop and degenerate at various rates, independently of one another, while still arriving at an accurate assessment of age of the individual.

The method proposed by McKern and Stewart (1957) utilized a component system based on the dorsal plateau, ventral rampart, and the symphyseal rim. This technique required each feature to be scored on a scale from 0-5 and the scores added to generate a composite score. The composite score is what is connected to age ranges, allowing the features to be scored independently. McKern and Stewart (1957) were aware of the problems associated with this research. One issue is the lack of any females in the sample. Gilbert and McKern (1973) tested this three-component system and concluded that it is applicable to a female sample. Another issue is the very narrow, and young, age range of the sample. This tended to underage the older individuals of the sample. And lastly, McKern and Stewart did acknowledge that, although the accuracy rate was 90%, the method was only tested on the population from which it was generated. As with Brooks (1955), the authors also produced casts of the pubic symphysis that they felt best represented each phase.

In 1960, Nemeskeri and colleagues published research on the pubic symphysis of 105 individuals. This sample consisted of 61 males and 44 females between the ages of 23 and 93 years. The sample was acquired from autopsies. Acsadi and Nemeskeri (1970) later used this sample to formulate a method for age estimation. Instead of following the trend of most recent studies and creating a component system, Acsadi and Nemeskeri revised the Todd ten-phase method and reduced the number of phases to five. A few flaws were found with this study such as the lack of utilizing casts for comparison when selecting phases, the use of skeletons with

unknown ages, and the fact that this study concentrated largely on the early and late developmental features. This caused many individuals to be categorized as being between phases (Brooks and Suchey 1990).

As noted above, Gilbert and McKern (1973) generated a female standard for age estimation utilizing the pubic symphysis. The sample consisted of 120 females aged 17 to 55 years. Gilbert and McKern (1973) applied the McKern and Stewart (1957) three-component method and generated mean age ranges and confidence intervals, for reference when the technique is used on a female individual. Gilbert and McKern also focused on the effects of parturition on the pubic symphysis. While they did note differences from male development, such as faster flattening of the dorsal surface and that the dorsal and ventral demi-faces are completely separated by the symphyseal rim, they concluded that the changes observed on the female pubic symphysis was not correlated to parity. This method was tested by Suchey (1979) who found the technique less than user friendly resulting in an accuracy rate of only 51%.

In 1985, Meindl and colleagues conducted a study with two goals. First, the authors wanted to perform a blind test of several widely used methods for age estimation using the pubic symphysis to find out which performed the most accurately. Then, the authors would take the best performing method and revise it with the best practice standards currently in use. The sample of this study consisted of 64 males and 32 females from the Hamann-Todd collection. The four methods tested with this sample were the McKern-Stewart, Gilbert McKern, Hanihara-Suzuki, and Todd. The results showed the most accurate method was the Todd ten-phase, even though it tended to overage individuals. Meindl and colleagues (1985) acknowledged the expectation for inaccuracy to increase with age and attempted to remove bias from age ranges by adjustments to the original Todd phases. While Meindl and colleagues (1985) found no

significant difference between ancestries; they conclude the systems tested lack the proper attention to differences due to ancestry. They recommend future research on the effects of sex and ancestry and believe age at death estimates should be based on multiple indicators, even if the pubic symphysis may have the highest correlation rates.

Shortly after Meindl and colleagues (1985) published their study, Katz and Suchey (1986) reanalyzed two of the methods, Todd (1920, 1921) and McKern and Stewart (1957), using a sample of 739 males aged 14 to 92 years. This was the first study utilizing a large sample of males with known age at death. The sample was acquired from the Department of the Chief Medical Examiner-Coroner for the county of Los Angeles (LA ME). The unique quality of this sample is that it represents 32 different birthplace countries, including the United States. The results from these two techniques on this sample expressed much wider age ranges than those put forward by the original studies. Katz and Suchey (1986) found that neither technique could adequately account for all the variation observed in the population, especially in older ages, and, in agreement with earlier reports, found that the Todd method tended to overage individuals. Despite earlier works that highly supported the McKern-Stewart (1957) technique (Webb and Suchey 1985), Katz and Suchey felt the features developed and degenerated individually and, moreover, the McKern-Stewart method proved to be too difficult to utilize for an inexperienced analyst. Therefore, Katz and Suchey decided a modified Todd system would be the best form of action.

The modification took the form of combining phases I-III, IV-V, and VII-VIII and leaving phases VI, IX, and X as they were originally written. These phases were combined due to the inconsistencies in the observer's ability to differentiate between these phases. A regression analysis was conducted and it was determined that the six phase system derived from

the original ten phases from Todd performed the most accurately (Figure 2). Casts were developed by France for the male phase descriptions that were made available at various anthropology conferences in 1986 (Brooks and Suchey 1990). Katz and Suchey (1986) warn against using this modified technique on females due to the greater amounts of variation observed on female pubic symphyses. This issue will be addressed in Brooks and Suchey (1990) and Berg (2008) below.

Figure 2. Suchey-Brooks' (Katz and Suchey 1986, Brooks and Suchey 1990) six-phase scoring system. Picture adopted from White and Folkens (2000: 356).

Katz and Suchey (1989) reexamined individuals from the above sample to see if ancestry has an effect on age indicators. The sample included of 704 individuals that consisted of individuals from three different ancestries, American white, American black and Mexican. While the results of a linear regression analysis indicated that there does seem to be a difference in mean age at death between ancestries, they found that individuals classified as American black and Mexican who exhibited advanced pubic symphyseal patterns tend to have lower ages than those individuals classified as American white. The authors state that the differences observed between groups may be due to intrinsic or extrinsic factors. There still needs to be a reliable technique using all ancestries since ancestry is not likely to be determined based on the pelvis alone. Katz and Suchey (1989) advise forensic anthropologists to determine the phase of the pubic symphysis based on the new 6-phase Suchey-Brooks method using the table they provide to estimate the age range of the individual if the ancestry is known. However, since there is so much racial mixture in the U.S., specimens may appear ambiguous, thus the need for general phases.

Brooks and Suchey (1990) acknowledged the need for a female standard and used a sample of 273 female pubic symphyses to generate a 6-phase system with sex specific age ranges. They recognized this was necessary because of the morphological differences observed due to pregnancy-related changes. As with the male sample, the female sample represents a diverse group of individuals. The individuals in the sample derived from four different continents, Asia, North America, South America and Europe as well as various socioeconomic backgrounds. Brooks and Suchey (1990) caution forensic anthropologists when debating between phase III and IV due to the large amount of variation observed in each and they encourage the use of multiple age indicators if at all possible in order to generate the most

accurate age range. There have been several revisions to the Suchey-Brooks method which include a seventh phase for females and individuals exhibiting the most advanced stages of degeneration (Berg 2008; Hartnett 2010). Today, the Suchey-Brooks method is the most commonly used for estimating age of the pubic symphysis (Brown 2009; Garvin and Passalacqua 2011).

Santos (1996) conducted a blind test of the Suchey-Brooks method and found significant differences in accuracy rates in males and females with very low accuracy rates for both. The author believes the low accuracy rate associated with the Suchey-Brooks method is due to the broad age ranges associated with each phase, and the low accuracy rate for females may be due to pregnancy. Santos (1996) concludes that this technique should only be used when supported by additional age indicators and should not be used on individuals over the age of 40 years.

Meindl and colleagues (1990) was essentially a rebuttal to the criticism by Katz and Suchey (1986) of their previous method proposed in Lovejoy and colleagues (1985). Meindl and colleagues argue that the Hamann-Todd collection represents a wide array of countries of origin just like the LA ME sample. The sample used by Meindl et al. consisted of individuals representing the U.S. and 27 other countries. A major criticism of this collection was that the age-at-death of the individuals was unknown. Meindl and colleagues however, claim that death certificates were used for their sample and any individuals whose ages were in question was removed from the sample. The authors admit that the time periods differ between the two collections, Hamann-Todd and the LA ME, but the procedures should work on both collections. Also, they do not believe the amount of variability in pubic symphysis morphology observed in each phase was compromised by removing individuals from the sample to ensure accuracy of the remaining specimens.

Meindl and colleagues (1990) tested the Suchey-Brooks method on the Hamann-Todd collection to see how it compared to their original study. The authors stated that one would never be able to estimate age at death of an individual within one to two years because features of the pubic symphysis develop and degenerate at different rates in different individuals. They concluded that no significant difference was discovered between the LA ME and the Hamann-Todd collections. Meindl and colleagues (1990) state that the best method for accurate age assessment using the pubic symphysis is one that is used by an individual who is knowledgeable, and yields a careful interpretation of the pubic symphysis, regardless of the sample on which it was tested.

In 2004, Schmitt tested the Suchey-Brooks method on a sample of Asian individuals. And, even though the sample used to generate the Suchey-Brooks method includes individuals of Asian descent, Schmitt found that the Suchey Brooks method tended to underage individuals and was largely inaccurate when aging individuals in older cohorts. The author concluded that this method should not be utilized on individuals with Asian origins, as it would not produce accurate results (Schmitt 2004).

Schmitt (2004) also discussed the issue of asymmetry, which had yet to be mentioned in any prior research on the pubic symphysis (Brown 2009). Schmitt discovered asymmetries on both right and left sides of the pubic symphysis and the auricular surface and warned that elements from the same individual, if found separately, could result in the assessment of different phases of pubic symphysis morphology. Schmitt (2004) warns that this increases the error rate associated with age estimation when using the pubic symphysis or auricular surface.

In 2008, Berg published an article confronting the problem associated with aging older individuals, more specifically adult females. The difference in rate of change between males and

females was believed to be due to conditions such as osteoporosis and osteopenia, an observation previously made by Meindl and Lovejoy (1989). No research was conducted to address this issue for nearly 20 years after it was mentioned until Berg proposed the need for a new phase, phase VII, to be included in the Suchey-Brooks method as well as new definitions for Suchey-Brooks phases V and VI (Figure 3).

Figure 3. Berg's (2008) revised Suchey-Brooks phases. The top row depicts phase 5, middle row phase 6, and bottom row phase 7 (Berg 2008: 575).

Berg (2008) used data collected on two skeletal collections of known age, a Balkan sample and the William M. Bass Donated Collection (WBD) housed at the University of Tennessee. The sample consisted of 189 females with 39 individuals under the age of 40 years and 150 individuals over the age of 40 years. The Balkan sample is primarily made up of Eastern European individuals and the WBD collection is predominantly American whites.

Berg (2008) concluded that the revised Suchey-Brooks method proved a high degree of accuracy with a relatively low intra-observer error. The revised seriation produced r-values consistently higher than the correlation observed with the Suchey-Brooks method. Also, Berg promotes the use of transition analysis over a linear regression analysis due to the issue under-aging older individuals and over-aging younger individuals as demonstrated by Aykroyd and colleagues (1997). Lastly, Berg recommends further research on regional comparative samples as differences are expected due to environmental and genetic factors.

Auricular Surface

The auricular surface of the ilium often appears as a less accepted or used method of age estimation, especially when compared to the pubic symphysis (Brown 2009). The auricular surface is located on the ilium where it joins the sacrum. The morphological changes observed in this area are seen as a change to the surface of the joint or as fusion of the joint. As with the pubic symphysis, the auricular surface is another surface that includes age indicators based on human perception. The ability to accurately describe the morphological changes of a three-dimensional surface is difficult and, therefore, assessing age from the feature is problematic (Lucy 1996). While many early researchers have noted the changes occur at this joint, no attempt had been made to create a systematic technique for age assessment until Lovejoy et al. (1985b).

Lovejoy et al.'s (1985b) original intentions for this research were to assist analysts in paleodemography and archaeology. The authors felt the auricular surface had a higher rate of preservation over the pubic symphysis, as well as the expression of changes after 50 years of age. This method analyzed the morphological changes of the auricular surface and generated eight

phases. Phases I through VII are paired up with 5-year age increments and phase VIII is for individuals 60 years and older (Figure 4).

Figure 4. Lovejoy et al. (1985b) eight-phase scoring system. Picture adopted from White and Folkens (2000: 358).

The sample for this research consisted of 250 individuals from the Libben population collection, 500 individuals from the Hamann-Todd Collection, and 14 from forensic cases. The authors felt that this area of the pelvis expressed age related changes that were reliable enough to provide accurate estimates of age at death. The authors also state that the age related changes occurring on the auricular surface were more complex than those of other age indicators. More specifically, Lovejoy and colleagues (1985b) point out that while they created eight phases from

those auricular surfaces believed to be most typical, any individual auricular surface may exhibit features from various phases at any one age. Therefore, the analyst should be knowledgeable in the aging process and be able to select the most representative criteria for that age range. In addition, the authors note that female individuals may express a preauricular sulcus, which is to be ignored during analysis.

The prominent aging features of the auricular surface for young individuals are described as expressing a billowed surface that is replaced by transverse striae. In middle age individuals, the auricular surface increases in granularity that is followed by the densification of the demifaces as well as the appearance of micro- and macroporosity. And lastly, as observed in other aging indicators for old age, the auricular surface begins to break down and express general degeneration. Also, there may be lipping and marked irregularities in the retro-auricular area (Lovejoy et al. 1985b).

Lovejoy and colleagues (1985b) conclude that the accuracy rate of this method is similar to those of age estimation methods using the pubic symphysis. Saunders and colleagues (1992) conducted a study performing blind tests of various age estimation methods in which this method performed the best. Santos (1996) also performed a study based on blind test of the Lovejoy and colleagues (1985b) method and found very low accuracy rates for the test sample with the estimated age differing from the chronological age in nearly all stages. And, as noted in much of the literature, the least accurate results occurred with individuals over the age of 45 years who were assessed as younger than the actual age (Murray and Murray 1991; Santos 1996). Santos (1996) concludes that this technique should only be used when supported by additional age indicators.

Even still, Saunders et al. (1992) state that age estimation methods using the auricular surface place a large emphasis on qualitative observations, and future studies are encouraged to create standards with which to improve this method. One possible idea to provide better accuracy when using this method would be to create casts for analysts to use for comparison (Brown 2009).

Murray and Murray (1991) performed a validation study on the Lovejoy et al. (1985b) method. The sample included 189 individuals of known sex, age, and ancestries from the Terry Collection. The authors performed an ANOVA, which indicated that the changes occurring on the auricular surface were independent of sex and, more interestingly, geographic origin of the individual played a role in age estimation. The main source of variation was age and the differences observed due to geographic origin were chalked up to the variation in age profiles for these various origins. The authors concluded that the Lovejoy et al. (1985b) method tended to overage younger individuals and underage older individuals indicating that the variability in auricular surface topography is too great for this method to be utilized as a sole indicator of age, especially on a case-by-case basis.

In 2002, Buckberry and Chamberlain proposed a revised method for estimation of age-at-death using the auricular surface. The authors used the key terms described in the Lovejoy et al. (1985b) method and generated a quantitative composite scoring system that is correlated to seven stages for age assessment. The traits that were independently scored included transverse organization, surface texture, microporosity, macroporosity, and apical changes. The retroauricular area proved to be a poor indicator of age and was not included as a key trait. The scores from the key traits were added to generate the composite score (Buckberry and Chamberlain 2002). This shift to a more independent trait assessment is reminiscent of the

revision McKern and Stewart (1957) performed on the Todd ten-phase method of the pubic symphysis. The authors note that by creating a system that analyses traits independently, this method will not only prove to be more accurate but also an easier method to use by analysts that may not have much experience estimating age from the auricular surface.

Osborne et al. (2004) also conducted a validation study of the Lovejoy et al. (1985b) method. The sample included individuals from the Terry Collection and the Bass Donated and Forensic Collections. The results showed that only 33% of the sample was accurately aged using the original phases. The trend appeared to be that the youngest and oldest individuals in the sample were over-aged, and the middle age individuals were under-aged. Osborne et al. (2004) decided to take the original age ranges, which consisted of 5 years each, and expand them to include the phase below and the phase above so that each phase now would consist of a 15-year age range. This revision, however, only marginally increased the accuracy rate to 59%, a percentage still too low to consider this method reliable.

Osborne et al. (2004) believed the original 5-year age intervals did not accurately represent the true variation observed in the auricular surface. The authors found that age only accounted for 34% of the variation and the best way to capture this variation is to create a scoring system of the individual features of the auricular surface. The authors generated new mean ages and confidence intervals for each of the eight phases originally proposed by Lovejoy et al. (1985b). This resulted in a 6-phase system and, while the accuracy rate increased greatly into the 90th percentile, the confidence intervals now included an average of a 43.5-year span.

Mulhern and Jones (2005) conducted a study testing both the Buckberry-Chamberlain (2002) and the original Lovejoy et al. (1985b) methods to see which proved more accurate. The sample derived from the Terry and Huntington collections housed at the Smithsonian's National

Museum of Natural History in Washington, D.C. It included American black and American white males and females from the 19th and 20th centuries. The results indicate that the methods were applicable to both sexes and ancestries and that the Buckberry-Chamberlain method was easier to apply. Mulhern and Jones concluded that the revised method is more accurate for individuals between the ages of 20-49, and less accurate for individuals age 50-59 years, therefore, cautioning the use of this area as the sole indicator of age.

Similar to Mulhern and Jones (2005), Falys et al. (2006) also tested the Buckberry-Chamberlain method. The results were similar in that the revised version was easier to apply and there were various issues with accurately aging the sample. The authors decided to tackle the issue with precision of aging and took the seven stages proposed by Buckberry and Chamberlain and modified the technique resulting in a three stage system. As with any technique, there are pros and cons to having a minimal number of stages. The pros include a better ability to differentiate between older and younger individuals and the ability to age individuals 60 years and older. The large caveat to this technique is that it does not distinguish middle-aged individuals very well.

Igarashi et al. (2005) created a new method for age estimation using the auricular surface based on a collection of Japanese skeletal remains. The sample consisted of 700 individuals of known age-at-death. This method focused on a binary system, in which specific traits were scored as either being present or absent. Once the traits were assessed, the number of features scored as being present was totaled. These scores were used to generate mean ages and standard deviation. Then composite groups were created and it was evident that too much overlap existed for the technique to be precise enough for accurate age estimation. Igarashi et al. (2005) then proposed a binary scoring system coupled with a multiple regression analysis that fared slightly

better than their first attempted method. And just as Schmitt (2004) points out, most age estimation techniques are not valid to use on an Asian sample since they were developed using samples consisting mostly of European ancestry. This leads researchers to question whether age estimation is ancestry dependent (Murray and Murray 1991; Osborne et al. 2004; Mulhern and Jones 2005). Therefore, validation studies are encouraged to determine the technique's ability to perform accurately on samples that vary from the reference sample used to create the original method.

Issues with Determining Age-at-Death

While pelvic age estimation techniques are universally employed, they are not without their flaws and criticisms (Meindl and Lovejoy 1989; Saunders et al. 1992; Lucy 1996; Meindl and Russell 1998; Jackes 2000; Ross and Konigsberg 2002). The literature review above presents some of the issues encountered when determining age-at-death; other significant issues have been documented (Lucy 1996; Aykroyd et al. 1999; Berg 2008; Konigsberg et al. 2008; Garvin et al. 2012). Some of these include demographic differences such as age, sex, and ancestry. For example, age of younger individuals is less difficult to assess due to the more regularly patterned changes observed throughout skeletal development, while the changes observed in older adults are due to degenerative changes, and therefore, reflecting increased variability (Boldsen et al. 2002).

In addition, extrinsic factors influence the biological assessment of age, which include the external or environmental factors experienced by an individual throughout their entire life, otherwise thought of as an accumulation of one's life-ways. Lucy (1996) argues that one of the main issues with these techniques is simply that it is heavily based on human perception. With the naturally occurring variation observed on the pubic symphysis and humans' difficulty to

accurately describe changes in a three-dimensional surface, utilizing the pubic symphysis as a reliable age estimation technique becomes problematic (Saunders et al. 1992; Lucy 1996). Lucy (1996) also states that this issue is common to most techniques dealing with continuous variables such as age. In addition to issues with inter-observer accuracy, both Konigsberg and colleagues (2008) and Aykroyd and colleagues (1999) explain how much of the error is associated with appropriate reference sample and statistical analyses that may result in bias, age mimicry, and differing error rates.

Use of appropriate reference sample

Techniques for determining age-at-death are based on the observer's ability to accurately assign a numerical stage, or phase, to various morphological changes observed in skeletal age indicators. Ideally, one hopes that the individual being analyzed, or target sample, closely resembles the individuals of the reference sample, the sample from which the age range of the specific technique is based. This, however, is founded on several assumptions. First, the researchers must assume that all individuals within the reference sample, or single population, undergo the same growth and development stages as well as degeneration sequence at the same rate. Then, in order to continue with the analysis, the researcher must assume the individual being analyzed is biologically similar enough to also follow the same rate of change as the reference population (Lucy 1996; Godde and Hens 2012).

While earlier studies found a lack of significant differences among males and females or across different ancestries (Stevenson 1924; Meindl et al. 1985; Zambrano 2005), more recent studies promote the need for population specific standards. Focusing on demographic differences is important because the more similar in age, sex, and ancestry the study sample is to your case, the more accurate an estimation of age will be (Garvin et al. 2012). For instance,

many studies have shown significant differences in rate of aging between populations and sex (Brooks 1955; Gilbert and McKern 1973; Iscan et al. 1985; Katz and Suchey 1986; Iscan et al. 1987; Katz and Suchey 1989; Brooks and Suchey 1990; Iscan 1991; Murray and Murray 1991; Solari and Abramovitch 2002; Arany et al. 2004; Chaillet and Demirjian 2004; Chaillet et al. 2004; Igarashi et al. 2005; Schaefer and Black 2005; Blackenship et al. 2007; Tunc and Koyuturk 2008; Langly-Shirley and Jantz 2010). Often, the issue encountered here is that studies do not exist for every specific combination of age, sex, and ancestry. This is largely due to a lack of skeletal collections from which to develop this specific research.

Moreover, researchers need to be knowledgeable about their case and previously published literature as it has been found that certain methods have proved to perform better for certain age and/or sex groups (Garvin et al. 2012). Berg (2008) found this to be especially true with adult females. Many researchers analyzing the pelvis found differences between sexes and debate whether parity is the cause of this variation (Todd 1921; Stewart 1957; Gilbert and McKern 1973; Brooks and Suchey 1990). And, while much of the research on age estimation has found aging elderly individuals unreliable and not too accurate (McKern and Stewart 1957; Hanihara and Suzuki 1978; Lovejoy et al. 1985; Meindl and Lovejoy 1985; Katz and Suchey 1986; Brooks and Suchey 1990; Santos 1996; Suchey and Katz 1998), Berg has generated a way in which the revised Suchey-Brooks method could produce better r-values than reported for the Suchey-Brooks method on a sample comprised of not only younger female individuals but actually largely on female individuals over 40 years (Berg 2008). Therefore, it is recommended that after an initial analysis of a forensic case, researchers should choose a skeletal age estimation technique that proves more appropriate and accurate than others (Garvin et al. 2012).

As previously mentioned, human variation is caused by various intrinsic and extrinsic factors that may affect the biological age of an individual, which are key elements to include when ensuring the similarity of the reference sample to the target sample (Brown 2009). These factors are the foundation of a hypothesis for the greater variation observed in old age. The belief is that it is due to the accrual of these factors throughout an individual's lifetime (Garvin et al. 2012). This indicates that once an individual reaches a certain age, biological age exhibits too wide a range of variation to allow for the existence of a strong correlation between biological age and chronological age. Extrinsic factors include environmental factors, cultural practices, activity level, overall health, disease, nutrition, presence or absence of trauma, in addition to intrinsic factors such as genetic composition (Bogin 1999; Garvin et al. 2012). Moorrees et al. (1963) observed this phenomenon with dental formation and eruption where a general trend existed in the process but individual variability was too great to produce highly accuracy rates. These factors also contribute to the secular trend observed by Langley-Shirley and Jantz (2010). They looked at fusion rates of the clavicle and found significant differences between modern Americans and Americans born in the early 20th century. Therefore, there is a clear need for techniques that are based on modern individuals.

Berg (2008) points out that one should expect to observe differences between samples due to the intrinsic and extrinsic factors associated with skeletal development and degeneration. Significant differences in growth and development among individuals of different socioeconomic backgrounds can be found due to issues with malnutrition (Cardoso 2008). Regional populations vary not only environmentally but also genetically; therefore researchers should expect some level of morphological variation from sample to sample and additional research is needed to develop population-specific standards (Schmitt et al. 2002). Moreover, the inherent variability

observed at any age may generate an increase in the error rate. For instance, elements displaying features outside of the normal realm of variation or those that follow an abnormal aging process will not be accurately assessed, and therefore, placed into an age range that may not capture the chronological age of the individual. Garvin et al. (2012) recommends controlling for genetic and environmental factors whenever possible.

Hoppa (2000) conducted a study to assess the effects of varying demographic compositions between a reference sample and two known-age target samples: one forensic and one archaeological. Hoppa found that the rate of degeneration in each sample was significantly different, particularly in females over the age of 30 years for the archaeological sample and over the age of 40 years for the forensic sample. This is further supported by the research conducted by Sinha and Gupta (1995) on a sample of males from India, which also showed significantly younger mean ages for many of the phases using both the Todd and McKern-Stewart methods. These studies serve as a cautionary note to illustrate the importance of a proper reference sample when assessing a target sample.

On the other hand, whereas many researchers call for population specific research regardless of the lack of materials (Hoppa 2000), Konigsberg et al. (2008) find the differences between populations to be minor and the real focus should be expanding sample sizes of current research. The authors state that before one may understand inter-population variation, we first need to better understand the aging process in general in an intra-population fashion. This understanding of the way ones age is reflected skeletally will lead to a greater understanding of human variability overall (Brown 2009). Once this is accomplished, one may find that the differences found between populations are trivial or insignificant.

In the same vein, several studies promote the need for general standards that are not specific to ancestry or sex (Katz and Suchey 1986; Nawrocki 1998; Zambrano 2005; Brown 2009). While some research simply did not find any significant differences in ancestry or sex, others believe that since this type of information is unknown in forensic cases, the most widely encompassing sample must be used to generate equations that will be applicable to any demography. Zambrano (2005) tested the equations put forward by Nawrocki (1998) and concluded the general formula performed better than the sex- and population-specific formulae. Another reason for less specific research is because this type of information may not be able to be determined from the skeletal age indicator/s available. For instance, ancestry is not likely to be determined from the pelvis (Katz and Suchey 1989). Moreover, there is so much racial mixture in the United States that even if a skeletal indicator is present from which ancestry may be determined, they may appear ancestrally ambiguous.

Lastly, taphonomy is an extrinsic factor that affects the remains after death and thus the condition of the remains at time of analysis (Konigsberg and Frankenberg 1994). There are many taphonomic processes that render age estimation of certain elements impossible due to damage to the area of interest. For instance, in an archaeological context, Saunders et al. (1992) found the pubic symphysis to be one of the elements frequently damaged to a degree that prohibited any analysis for age estimation from this indicator. This is one of the reasons Lovejoy et al. (1985) focused on the auricular surface, as they believed this feature to have a higher rate of preservation in forensic and archaeological contexts.

Asymmetry of Elements

The issue of asymmetry was introduced in the pubic symphysis section above. Schmitt (2004) warned that elements from different sides of the same individual, if found separately,

could result in the assessment of different age ranges. This issue of asymmetry is also supported by Santos (1996), who came to the same conclusion with both the auricular surface and pubic symphysis. This may be due to biomechanical forces placed on one side of the body or various skeletal elements over others. Therefore, while specific skeletal age indicators may follow a specific timeline, based on the biomechanical forces applied to those markers, the right and left side of a single individual may present different developmental or degenerative stages. While asymmetry is largely associated with extrinsic factors, Garvin et al. (2012) state that biological asymmetry may possibly be enough to produce differing results based on side of the element.

In 2009, Overbury and colleagues addressed the issue of asymmetry regarding age estimation of the pubic symphysis. The authors observed both left and right sides of the pubic symphysis on 140 white males. They found asymmetry to be present on 63% of the sample and, of those exhibiting asymmetry, 75% were assigned varying Suchey-Brooks phases. Overbury et al. (2009) concluded that in cases where conflicting phases are observed, the researcher should use the older of the two phases to more accurately determine the age range of the individual.

Choosing the best practice for age estimation in an asymmetrical individual presents a debate in itself. Overbury et al. (2009) propose the older appearing side, some say the side that was used in the original study for the method being used, but, this may not be known for all methods nor may that side always be present in the test sample. Others believe that averaging the two sides produce the most accurate age assessment (Garvin and Passalacqua 2011).

Statistical Analysis in Age Estimation

Various statistical methods utilized to analyze data have been proven to affect the reliability of the age estimation technique to produce accurate results. For instance, it has been shown that a model constructed from a linear regression analysis generates a bias and tends to

under-age older individuals and over-age younger individuals (Aykroyd et al. 1997; Berg 2008). Aykroyd et al. (1997) promote the use of classical calibration over inverse calibration and note the inherent issues that derive from generating an accurate age assessment from an age indicator. Dapson (1980) recommends age as the dependent variable and the indicator as the independent variable to predict age with the highest degree of accuracy. While this is true for traditional age-at-death estimation, the opposite is what is actually performed in a transition analysis. In transition analysis, the age indicator is dependent on a known age (Garvin et al. 2012). The benefit of running a transition analysis is to determine the age at which one phase becomes another (Milner et al. 2000; Boldsen et al. 2002; Berg 2008; Konigsberg et al. 2008; Godde and Hens 2012; Milner and Boldsen 2012). Transition analysis is ideal for single skeletal age indicators because the currently employed techniques are defined by discrete stages where no specific set of features are repeated (Garvin et al. 2012). Moreover, with the prior distribution assumed to be normal, cumulative probit is the most appropriate analysis for ordered response categories (Agresti 1990).

Boldsen et al. (2002) discuss the utilization of transition analysis in an anthropological context and describe the method and its significance in age estimation from individual forensic cases to larger archaeological samples. The motivation for the generation of this method of analysis derived from the Rostock Manifesto (Godde and Hens 2012). The document noted the need to merge the best mathematical practices with real life scenarios such as limited sample sizes and even a single skeleton. While the original motivation was to increase accuracy for paleodemographic analyses, it was not difficult to understand how this method could advance accuracy of age estimation in the forensic setting as well (Godde and Hens 2012). As is evident in the previously discussed research, Boldsen and colleagues (2002) discuss the problems

inherent to adult age estimation such as observed differences between aging the remains of younger versus older individuals. Another issue the authors tackle is that of age mimicry, where the estimation of age is sensitive and biased due to the age distribution of the reference sample. Transition analysis utilizes an informative prior distribution of ages in the reference sample or an age distribution based on an informative prior that solves the age mimicry problem (Milner et al. 2000; Boldsen et al. 2002; Konigsberg et al. 2008; Godde and Hens 2012; Milner and Boldsen 2012).

Boldsen et al. (2002) assess multiple indicators found on the pubic symphysis, auricular surface, and cranial sutures of skeletons from the Terry Collection. The authors perform analyses for both single and multiple traits. Results show that, as expected, the pubic symphysis performed the best and cranial sutures the worst. The results also showed that differences exist between ancestries (American black versus American white) and sex (males versus females). The authors attribute these differences to either genetic composition or individual variation due to extrinsic factors or ‘lifetime experiences’.

Boldsen et al. (2002) conclude that transition analysis effectively estimated the age at death of older individuals. This method provides the most likely age range of the individual, as well as the error correlated with each age estimate. The authors promote the use of multiple age indicators to obtain the best estimate of age at death. This method provides a way to age the skeleton of older individuals in a more specific manner rather than being lumped into a large terminal group such as 50+ years.

Konigsberg et al. (2008) discuss the issues of age-at-death estimation from analysis of the pubic symphysis due to previously applied *ad hoc* statistical methods, such as the Suchey-Brooks method. This concept was touched on in an earlier publication by Konigsberg and Frankenberg

(1994) where the authors explain the Bayes' Theorem and the differences between posterior and prior probability. They explain that posterior probability is most often used in a forensic setting and it is the likelihood of a particular age conditional on the observed indicator state.

Since age-at-death is not uniform across a population, researchers use the maximum likelihood estimation to estimate the joint probability of ages for a group of skeletons (Konigsberg et al. 2008). This way, there is no bias put into the age estimation based on a priori assumptions. The authors call for a focus on utilizing appropriate prior age-at-death distributions so that a transition analysis may be performed. Konigsberg and colleagues (2008) point out that the *ad hoc* methods, those that result in percentages and age ranges such as the Suchey-Brooks method, do not provide appropriate 'coverage'. Coverage is a term used to indicate the percentage of individuals who fall within, above, and below the given stage. Therefore, a call for additional collection of data on the observable morphological changes is made in order to have the most appropriate prior age-at-death distribution possible.

Konigsberg et al. (2008) investigate the efficacy of the Suchey-Brooks pubic symphysis method for age estimation. The research is comprised of data collected from five (5) different skeletal collections (n = 1766 males). There are several reasons presented as to why the estimation data provided for the 6 phases are less appropriate than those provided using transition analysis. For example, a standard error should be provided for each phase due to the fact that the sample might make it so that the phase is comprised of a small number of individuals. Sampling variance in this manner should be acknowledged and avoided when possible. Another issue is that when the reference sample is used to generate the phase estimates, there is bias and error inherent to a prior distribution of age.

Lastly, several studies present the need for age estimation techniques that are able to assist analysts in paleodemography and archaeology (Lovejoy et al. 1985; Konigsberg and Frankenberg 1994; Hoppa 2000). As noted in much of the literature, the least accurate results occurred with individuals over the age of 45 years who were assessed as younger than the actual age (Murray and Murray 1991; Santos 1996). This is a product of the methods that have large terminal phases such as 50+ years; it is inevitable that individuals well over this age will be under-aged. This trend of bias is observed in methods that employ a linear regression on the data, hence the use of transition analysis in the current project.

Parity

In the early 1900s, research began to be reported on the pelvis regarding sex estimation, which led to the eventual focus on skeletal alteration due to pregnancy and parturition (Ubelaker and De La Paz 2012). Previous researchers propose that greater variability observed in female pelvises is due to parity (Putschar 1976; Suchey et al. 1979; Bergfelder and Herrmann 1980; Tague 1990). Ubelaker and De La Paz (2012) provide a historical review of the past century of literature on the research into skeletal evidence of pregnancy and parturition and the various interpretations forensic anthropologists may employ in their interpretations. This type of research, while invaluable to the proposed research, presents a different approach to the analysis of parity. For instance, Ubelaker and De La Paz (2012:1) list different skeletal indicators such as “the preauricular sulcus, separation of the pubic symphysis, osteitis condensans ilii, osteitis pubis, pubic pitting, bone density loss, and extension of the pubic tubercle.” The current research is not focused on the skeletal indicators of parity, but rather the affect parity has on the rate of degeneration on the bone of age indicators.

In order to understand the role parity plays in these changes, one must understand the physiological changes that occur during pregnancy, parturition, and the postpartum period (Becker et al. 2010). As early as 1976, research stated that females appear ‘older’ than males of the same age due to the bony alterations caused by parity (Putschar 1976). It is known that pelvic morphology reflects age related changes, but what needs to be investigated is whether these changes are compounded by the release of hormones during pregnancy as well as the naturally traumatic event of childbirth (Putschar 1976).

Both the pubic symphysis and auricular surface are subjected to many day-to-day stressors. The pubic symphysis is a midline, nonsynovial joint that resists various degrees of traction, compression and shearing based on activity. For example, standing causes both traction and compression of the joint, sitting causes compression of the joint, and standing/balancing on one leg causes shearing and compression of the joint (Becker et al. 2010; Khorashadi et al. 2011). Research on the strength of these pubic ligaments found that the strongest ligaments are found in males, followed by nulliparous females, and weakest in females in the final trimester. The loosened ligaments of parous females repair and thus regain strength postpartum, but will remain weaker than those observed in nulliparous females (Becker et al. 2010). The sacroiliac joint is potentially subjected to greater forces, as it is directly responsible for the transfer of body weight (Houghton 1974). For this reason, Houghton (1974) proposed this joint would be more greatly affected by parity and parturition than the pubic symphysis with the pre-auricular sulcus being the most indicative marker.

The morphology of the pubic symphysis is affected by pregnancy and parturition due to changes to the interpubic disc. This disc sits between the two pubic symphyses to lessen the effects of forces occurring on the joint. While the widening and separating of the joint has been

attributed to parity, the narrowing of the joint has been attributed to age; both of which may cause the same indicators on bone (Thorp and Fray 1938; Alicioglu et al. 2008). For example, the disc changes in width throughout one's lifetime. Beginning at 3 years of age the width of the disc is approximately 10mm, followed by a decrease to approximately 6 mm around 20 years of age, and finally decreasing to approximately 3mm around 50 years of age. The interpubic disc is thicker in females than males providing a larger area to assist with delivery process. When under certain forces, such as those experienced in parturition, a cleft can develop in the disc. While this cleft can be caused by other confounding factors and observed in both sexes, the cleft observed in parous females is longer and irregular with the possibility of secondary clefts developing in nulliparous females (Becker et al. 2010; Khorashadi et al. 2011).

The healing and closing of clefts differs on an individual level, with some clefts never healing completely. Subsequent pregnancies increase the damage to open clefts as well as cause the development of additional clefts. When a cleft does not heal, the traumatic forces on the joint accumulate postpartum. The pubic symphysis will never return to the way it functioned prior to first pregnancy, with loosened ligaments and trauma to the clefts only adding to the effects of age on the bone. This is problematic due to the fact that the disc, in conjunction with the anterior pubic ligament, is what provides the joint with the most stability. Herein lays the cause of the change in morphology of the pubic symphysis. The looser the ligaments, the more damage to the cartilage that separates and cushions the joint, the more damage will be observed in the form of skeletal changes (Putschar 1976; Becker et al. 2010; Khorashadi et al. 2011).

The hormones released during pregnancy such as relaxin, progesterone, and oestrogen derive from both ovarian and placental changes. Normally, the pubic symphysis withstands minor movements up to 1mm. Pregnancy hormones, however, allow the joint to stretch at least

an additional 2-3mm in preparation for childbirth. Not only are they responsible for the loosening of the pelvic ligaments, but they also play a role in bony changes such as resorption and remodeling. These changes occur at sites of ligament attachment such as the dorsal aspect of the pubic symphysis where the posterior pubic ligament attaches and the preauricular sulcus where the inferior sacro-iliac ligament attaches. With the thickening and stretching of ligaments plus the added strain of activities during pregnancy, osteoclastic resorption begins which results in depressions and pitting. Active remodeling follows degradation and these two processes result in bony changes at attachment sites (Derry 1911; Abramson et al. 1934; Angel 1969; Houghton 1974; Putschar 1976; Holt 1978; Kowalk et al. 1996; Becker et al. 2010; Khorashadi et al. 2011).

The frequency of these bony alterations has been found to change in association with childbearing years. The highest frequencies are observed in parous females around the age of 30 years and decline to lower frequencies around the age of 70 years (Kelley 1979). Snodgrass and Galloway (2003) state that the nature of bony alterations such as pitting becomes observed in older ages because of hormones associated with menopause and postmenopausal changes. These also play a role in bone loss, which affects pelvic stability. Furthermore, Snodgrass and Galloway (2003) state that dorsal pitting had a higher correlation to BMI rather than parity in parous females over the age of 50 years.

Khorashadi and colleagues (2011) present a case study on symphysis pubis diastasis, a term used to describe the separation of the joint to a width greater than 10mm. Other research also mentions the possibility of separation of the joint during childbirth, resulting in postpartum complications (Boland 1933a; Boland 1933b). The authors found that it is most often attributed to the strain put on the joint during childbirth after the loosening of the ligaments during pregnancy. It can either be due to too quick of a delivery process or a very prolonged delivery

process. Other events that may cause diastasis of the joint are the use of forceps during delivery as well as by trauma in rare instances. This case study in particular involved the separation of the joint to a width of 34mm, with no changes observed in the sacroiliac joint. The female in the study required a pelvis brace in order to bring her joint back into normal position. Once a female experiences diastasis of the joint, however, there is a recurrence rate of 68%-85% in subsequent pregnancies.

Scars of parturition are listed as one of the indicators of parity, and are caused by osteitis pubis. Osteitis pubis is the term given to the various inflammatory disorders experienced on the pubic symphysis documented as more common in men (Ashworth et al. 1976). Osteitis pubis is observed in male athletes and even from trauma incurred after medical treatment of the bladder, prostate, and urinary tract infections. This condition is caused by repetitive minor trauma to the area and is also seen in women from walking during pregnancy and the stretching of ligaments during pregnancy (Wilstse and Frantz 1956; Harris 1974; Harris and Murray 1974; Ashworth et al. 1976). Galloway (1995), Jurmain (1999), Ubelaker (1999), and White (2000) each noted obesity as a confounding factor adding stress to the pubic symphysis and Anderson (1988) adds occupations stressors that cause repetitive trauma to the pelvis such as repetitive squatting.

Stewart (1957) points out more of a cultural implication of the variation in parity indicators observed on the pubis. Stewart takes into account that the differences in obstetrical care differ drastically between historical and modern populations. Galloway (1995) adds to this thought by pointing out that the frequency of Cesarean section has increased drastically in modern times, thus lessening the stress put on the ligaments during delivery. The higher frequency of childbirth, the younger age of first parturition, and the lack of quality prenatal care

would more than likely increase the effect of the trauma on the pubis (Schemmer et al. 1995; Stewart 1957; Ashworth et al. 1976).

Bone loss has been attributed to the loss of micronutrients, such as calcium and iron, both during and post pregnancy through lactation (Mensforth and Lovejoy 1985; Kent et al. 1990). Goldsmith and Johnston (1975) found that a significant correlation exists between an increase in bone mineralization and oral contraceptives taken shortly after lactation. Knowing that oral contraceptives are more prevalent in industrialized societies than in nonindustrialized societies, another issue is presented to consider along with the higher quality in obstetrical care. One factor that has been investigated is the effect of environmental differences as well as differences of affluence. Ashworth et al. (1976) conducted a study assessing the age of the remains of two groups of pre-Columbian Peruvian mummies in which one group lived in poverty while the other had an abundance of resources. The results allowed the authors to conclude that the scarring observed on the pubic symphysis is not correlated to a lifestyle of poverty associated with poor nutrition as both populations exhibited similar frequencies of scarring in females.

The above studies illustrate the variety of issues presented with assessing age-at-death of the skeleton of parous females. While, Hoppa (2000) found no significant differences between females with low birth numbers and high birth numbers in the archaeological sample, the sample sizes were small and they were not compared to nulliparous females. The current study aims to address these issues and determine whether parity affects pelvic age indicators enough to cause an inaccurate age assessment.

CHAPTER III

MATERIALS & METHODS

Research Design

Due to the physiological changes that occur during pregnancy, parturition, and the postpartum period, there is reason to believe that these events may increase the rate at which the age indicators of the pelvis degenerate. This hypothesis has yet to be formally tested on a modern skeletal collection. The purpose of this study, therefore, is to assess the effects of parturition on age indicators of the pubic symphysis and auricular surface to determine whether it influences the morphology of the pelvis enough to effect the physiological age of the individual.

The pubic symphysis and auricular surface need to be systematically assessed to determine whether any differences in the rate of degeneration exist between the three groups: males, nulliparous females, and parous females. More specifically, an investigation into the influence of parity on degenerative changes in the pubic symphysis and auricular surface will be conducted by using the scoring systems provided in the following age estimation methods: Todd (1920; 1921), Suchey-Brooks (Katz and Suchey 1989; Brooks and Suchey 1990), Lovejoy and colleagues (Lovejoy et al. 1985; Meindl and Lovejoy 1989), and Buckberry and Chamberlain (2002). The data collected using these scoring systems were first statistically analyzed for intra-observer bias study to confirm the validity of the data, and then variation in degeneration change across groups was evaluated using transition analysis and likelihood ratio tests to determine the statistical significance of any differences observed between the groups. This chapter provides a description of the sample, the age estimation scoring methods for the indicators of interest, and the statistical analyses performed to discover whether parity causes differences in rate of

degeneration of pelvic age indicators between the parous females, nulliparous females, and male groups.

Materials

Data were observed on the pubic symphysis and auricular surface of 434 individuals from the William M. Bass Donated Skeletal Collection housed at The University of Tennessee, Knoxville. This is a collection of modern skeletal remains with information available such as recorded/known age at death, ancestry, and sex (Table 1). Since it is dependent on body donations, the demographic structure of the WMB Collection is highly influenced by the region in which it is located: eastern Tennessee. The majority of the collection is comprised of American White individuals, mostly males, over 50 years of age. While younger age groups are underrepresented in the sample, one of the goals of this research is to target the older age groups to better address the ‘truncated’ categories of age estimation.

Table 1. Sex, age-at-death distribution, and ancestry of the test sample.

Sample	n	Age Range	Average Age	Ancestry *			
				W	B	AI	H
Males	234	23 – 96 yrs	61.15 yrs	212	20	0	2
Nulliparous Females	43	39 – 101 yrs	65.49 yrs	43	0	0	0
Parous Females	157	29 – 95 yrs	65.71 yrs	151	1	3	2
Total	434	23 – 101 yrs	63.23 yrs	406	21	3	4
* W – American White, B – American Black, AI – American Indian, H - Hispanic							

Prior to data collection, an inventory list of the collection was provided that included medical history information such as the sex, age at death, ancestry, and number of children for each individual. This list was used to ensure that data would be collected on a large enough sample of parous and nulliparous females. In addition, a male sample of comparative size was assessed to use as a control for these age assessment techniques. For example, if a significant

difference was observed in the rate that the two groups of females progressed through the stages defined by each aging system, the male sample would serve as a control to make sure variation was related to sex differences alone. Using the predetermined list of individuals, the identifying information on the boxes, except for the case number, was covered to ensure unbiased observations. This way, the individuals that were pre-selected for the study through the use of the inventory list were identified only by the case number and the age of the individual was unknown when assessing the age indicators.

Data Collection

Visual assessment began with the earliest donated individuals and continued until the most recent addition to the collection was analyzed, at which point data collection ended. All pelvic age indicators for each individual were observed at one time. This differs from a truly blind study that would look at the pubic symphysis at one point in time and the auricular surface at another. The pubic symphysis and auricular surface from both the left and right sides of the pelvis were visually assessed and observations were recorded on a data sheet (Appendix A).

First, the features of the pubic symphysis were noted and matched with the best fitting stage in both the Suchey-Brooks (Suchey and Katz 1986; Brooks and Suchey 1990) and Todd (Todd 1921) pubic symphysis scoring systems. Then, the features of the auricular surface were noted and matched with the best fitting stage in the system presented by Lovejoy et al. (1985) and Meindl and Lovejoy (1989), as well as individually scored resulting in a composite score following the method proposed by Buckberry and Chamberlain (2002). Once visual assessment was complete, the box was returned and the next box was pulled for analysis. The identifying information on the boxes remained covered until the end of each day, at which point only the identifying information on cases for which data collection was complete were revealed.

Any os coxa with signs of pathology, trauma, and/or postmortem damage that may interfere with an accurate assessment of the age indicator was not used. The other elements remained in the box and out of sight so as to not influence the assessment of the pelvic age indicators. No osteometric equipment was required for this study. A magnifying glass was used for better detail and description of surfaces. Pictures of the symphyseal face and auricular surface were taken in order to document each assessment.

Ultimately, the demographic structure of the collection, availability of medical histories, and condition of the remains determined the composition of this sample. The sample consists of 200 females and 234 males (Figure 5). The female sample includes 157 parous individuals (have given birth), and 43 nulliparous individuals (have not given birth) (Figure 6). The number of times each parous female gave birth was gleaned from associated medical histories.

Figure 5. Sample distribution separated by sex. Age ranges include all individuals within that decade.

Figure 6. Female sample age distribution separated into nulliparous and parous groups. Age ranges include all individuals within that decade.

Due to the composition of the WMB Collection, the majority of the current sample is classified as American White. With such a small representation of other ancestries, this information was not taken into consideration for the following analyses. In support of this decision, Katz and Suchey (1989) point out that so much racial mixture exists in the U.S. that the use of general phases encompassing a variety of ancestries is most appropriate. Many additional studies have shown that difference between populations may be minor compared to variation observed within populations and call for increased sample sizes to better capture this occurrence (Katz and Suchey 1989; Nawrocki 1998; Zambrano 2005; Konigsberg et al. 2008; Brown 2009).

Methods Used to Score Age Indicators

The Todd (1920; 1921) method is comprised of a ten-phase system for assessing the pubic symphysis. Each phase is defined by the degree of degenerative change that is reflected in a morphological description with an associated age range. Age ranges begin at 18 years of age

and increase in 2-5 year increments until 50 years of age (Table 2). The early phases describe post-adolescent morphology when the pubic symphysis expresses billowing. Then, the phases describe the changes that occur across middle-aged adults, which are characterized by delimitation of the upper and lower extremities and the formation of a rim on the symphyseal face. The final phase encompasses all individuals 50 years and older when features express increased degeneration. This final phase is defined by the breaking down of the symphyseal rim, erosion of the symphyseal face, and lipping along the margins (Todd 1920).

Table 2. Description of the Todd (1920: 301-313) scoring system.

Phase	Age Range (in years)	Pubic Symphysis Morphology
1	18 – 19	Rugged symphyseal face, horizontal billowing, no definition of margins.
2	20 – 21	Billowing surface begins to fill on dorsal limit with dorsal margin beginning to be delimited, ossific nodules may begin to fuse with upper symphyseal face, no definition of margins.
3	22 – 24	Progressive obliteration of billowed surface, increased definition of dorsal margin and plateau, beginning of ventral beveling, no definition of margins.
4	25 – 26	Complete formation of dorsal margin and plateau, increase in ventral beveling, beginning of delimitation of lower extremity.
5	27 – 30	Increased definition of lower extremity, beginning delimitation of upper extremity.
6	30 – 35	Development and likely completion of ventral rampart, increased definition of extremities, no lipping of margins.
7	35 – 39	Surface changes from fine grained to dense bone, no formation of symphyseal rim.
8	39 – 44	Surface becomes smooth due to inactivity, oval outline of face but no rim, no lipping.
9	45 – 50	Symphyseal rim begins to develop, lipping may be present on dorsal and ventral margins.
10	50 +	Erosion of face, possible osteophytic growths, breaking down of ventral margin, disfigurement increases with age.

The Suchey – Brooks method is a six-phase system derived from the original ten phases from the Todd method (Katz and Suchey 1986, 1989; Brooks and Suchey 1990). The modification involved combining phases I-III, IV-V, and VII-VIII and leaving phases VI, IX, and X as they were originally written. Sex specific age ranges are provided for each of the phases. The authors provide a table including the mean age, standard deviation, and 95% age range for each phase for males and females (Table 3).

Table 3. Description of the Suchey-Brooks (Suchey et al. 1988: 3-4) scoring system.

Phase	Female			Male			Pubic Symphysis Morphology
	mean	S.D.	95% range	mean	S.D.	95% range	
1	19.4	2.6	15 – 24	18.5	2.1	15 – 23	Billowed surface, lack of delimitation of extremities, ventral beveling may begin.
2	25.0	4.9	19 – 40	23.4	3.6	19 – 34	Billowed surface, begin delimitation of upper and lower extremities, begin development of ventral rampart.
3	30.7	8.1	21 – 53	28.7	6.5	21 – 46	Lower extremity defined, ventral rampart near or at completion, increased definition of upper extremity, dorsal plateau complete, no lipping.
4	38.2	10.9	26 – 70	35.2	9.4	23 – 57	Surface is fine grained, oval out line complete but may have ventral hiatus, complete definition of upper extremity, complete separation of pubic tubercle from face, rim present, slight lipping possible.
5	48.1	14.6	25 – 83	45.6	10.4	27 – 66	Complete rim, slight depression of surface within the rim, moderate lipping, no erosion of rim although breakdown possible.
6	60.0	12.4	42 – 87	61.2	12.2	34 – 86	Erosion of rim present, depression of face, pitting and porosity present on face, disfigurement and irregularity increases with age.

Lovejoy et al. (1985b) analyzed the morphological changes of the auricular surface associated with advancing age and generated eight phases. Phases I through VII are associated with 5-year age increments and phase VIII is for individuals 60 years and older (Table 4). The prominent age related features of the auricular surface for young individuals are a billowed surface that is replaced by transverse striae (Lovejoy et al. 1985b). In middle age individuals, the auricular surface increases in granularity that is followed by the densification of the demifaces as well as the appearance of micro- and macroporosity. And lastly, as observed in other aging indicators for older ages, the auricular surface begins to break down and express general degeneration. Also, there may be lipping and marked irregularities in the retro-auricular area.

Table 4. Description of the Lovejoy (Lovejoy et al. 1985: 21-26) scoring method.

Phase	Age Range (in years)	Auricular Surface Morphology
1	22 – 24	Youthful appearance, billowed surface, fine granularity.
2	25 – 29	Youthful in appearance, billowing begins to transition to striae, granulation becomes more coarse.
3	30 – 34	Loss of billowing with replacement by striae, coarse granulation, microporosity possible.
4	35 – 39	Uniform coarse granularity, striae may still be present, slight microporosity, minimal changes at apex, no macroporosity.
5	40 – 44	Transition from coarse granularity to densification of surface, slight to moderate activity in the retroauricular area, slight changes at the apex, macroporosity may be present.
6	45 – 49	Complete densification of surface, microporosity lost to densification, little to no macroporosity, slight to moderate apical changes, moderate retroauricular activity.
7	50 – 59	Dense surface becomes irregular, marked periauricular activity, irregularity and lipping at margins, macroporosity present, apical changes present, marked retroauricular activity.
8	60 +	Breakdown of subchondral bone with lipping around the margins, marked periauricular activity, increased irregularity typical of degenerative joint change, macroporosity present, marked apical changes, osteophytic growths in retroauricular area.

The Buckberry-Chamberlain (2002) method used the key terms of the Lovejoy et al. (1985) method and generated a quantitative composite scoring system that is associated to seven stages. The traits that are independently scored included transverse organization, surface texture, microporosity, macroporosity, and apical changes. The scores from the key traits are added to generate the composite score. The authors provide a table with each of the composite scores and the corresponding mean age, standard deviation, and 95% age range (Table 5).

Transverse organization is based on the amount present beginning with (1) 90% or more of the surface, (2) 50 – 89% of the surface, (3) 25 – 49% of the surface, (4) less than 25%, and ending with (5) no transverse organization present. The surface texture is scored beginning with (1) 90% or more of the surface is finely granular, (2) 50 – 89% of the surface is finely granular with areas of coarsely granular bone, (3) 50% of the bone is coarsely granular with no densification, (4) less than 50% of the surface is dense bone, and ending with (5) 50% or more of the surface is dense bone. Microporosity and macroporosity is scored on amount present beginning with (1) absent, (2) present on one demiface, and ending with (3) present on both demifaces. Apical changes is scored based on the amount of change present beginning with (1) the apex being sharp and distinct, (2) some lipping is present but shape remains distinct, and ending with (3) irregularity of the apex (Buckberry and Chamberlain 2002: 233-234).

Table 5. Description of the Buckberry-Chamberlain (2002) scoring system.

Composite Score	Phase	Mean	S.D.	Age Range (in years)
5 – 6	1	17.33	1.53	16 – 19
7 – 8	2	29.33	6.71	21 – 38
9 – 10	3	37.86	13.08	16 – 65
11 – 12	4	51.41	14.47	29 – 81
13 – 14	5	59.94	12.95	29 – 88
15 – 16	6	66.71	11.88	39 - 91
17 – 19	7	72.25	12.73	53 – 92

Methods

The data collected using these scoring systems were then statistically analyzed with an intra-observer accuracy study to confirm the validity of the data, then through the use of transition analysis and likelihood ratio tests, which will determine the significance of differences observed between the groups. These tests will help to address the hypothesis of this study, with the null hypothesis stating that there will be no differences in the rate of degeneration of the pubic symphysis and/or auricular surface between the three groups: males, nulliparous females, and parous females, and the alternative hypothesis stating that the pubic symphysis and/or auricular surface degenerate at different rates among the three groups, males, nulliparous females, and parous females.

Intra-observer Accuracy Study

First, the test-retest method was evaluated to determine the intra-observer error rate. Twenty pelvises (~5% of total sample) observed on the first and second days were observed again on the second and third days. Only pelvises for which observations of the pubic symphysis and auricular surface could be made were included in the retest sample. The intra-observer error rate evaluates how consistent the researcher is in scoring the age indicator. The correlation coefficient for these variables is used to quantify the strength and nature of the relationship between the two assessments. The correlation coefficient measures the strength of linear association between two variables on a scale from -1.0 to 1.0. Variables with a perfect positive relationship are indicated by a correlation coefficient of 1.0, variables with a perfect negative relationship are indicated by a correlation coefficient of -1.0, and a correlation coefficient of 0 indicates no linear association (Bryant and Yarnold 1995; Madrigal 1998). The null hypothesis is that there will be no correlation between the variables. The alternative hypothesis is that there

will be a linear association between the two variables. Ideally, support will be found in favor of the alternative hypothesis ensuring accuracy in the observer's ability to reliably assess the age indicators on both the pubic symphysis and auricular surface. If the results fail to support the alternative hypothesis, the observer did not show proficiency with these age scoring methods and the project would not continue.

Spearman's rho correlation coefficient was calculated in SPSS 20.0. A Spearman's rho correlation analysis was carried out to assess the statistical significance of the correlation between the two data sets at the 0.01 and 0.05 significance level. A Spearman's rho correlation analysis is a non-parametric test, meaning that assumptions are not made about the distribution of the variables (Madrigal 1998).

Transition Analysis

Algee – Hewitt (2012) discusses the addition of transition analysis to the anthropological toolkit. Transition analysis is one of the most recent advances in anthropological statistics and the popularity of this method is steadily increasing within the field (Boldsen et al. 2002; Milner and Buikstra 2006; Konigsberg et al. 2008; Gavin et al. 2012; Godde and Hens 2012). Several studies have tested transition analysis and found the analysis is easily replicable with very low error rates obtained between estimated age and age-at-death (Buikstra et al. 2006; Wilson and Algee-Hewitt 2009). One of the reasons this method has been adopted so easily is due to its ease of application utilizing the free, user-friendly statistical programs such as R, ADBOU, and NPHASES. ADBOU allows researchers to input data from a single skeleton and choose the most appropriate reference sample depending on whether the individual is from an archaeological context or a forensic context (Boldsen et al. 2002; Garvin et al. 2012). NPHASES is a program that takes data from single skeletal traits and calculates mean age at

transition, utilizing the Todd and McKern-Stewart methods (Wilson and Algee-Hewitt 2009; Konigsberg 2013).

The term ‘transition analysis’ was chosen for this method of analysis because the intercept and slope established in the generalized linear model is transformed into the “mean and standard deviation for a logistic distribution of the age at transition from stage 0 to stage 1” (Boldsen et al. 2002: 82). In other words, the intercept is the age at which an individual transitions from one stage to the next, and the slope is the rate of transition. Transition analysis is based on the assumption that age indicators progress forward through phases without skipping ahead phases or backtracking, in other words, “an individual can only move from state i to $i + 1$, never in the opposite direction, and never directly from i to $i + 2$ or higher” (Boldsen et al. 2002: 82). Therefore, what is being assessed is the probability that a skeleton is in one phase over another. When the age indicators can be observed on a sample of known-aged individuals, the following general linear model is assumed:

$$\Pr(y_j = 1 \mid a_j) = \Lambda(\alpha + \beta a_j),$$

where y_j is the skeletal trait in the j -th individual, a_j is the age at death of the j -th skeleton in the reference sample, α and β are parameters to be estimated from the reference sample, and $\Lambda(\cdot)$ represents an inverse link function. Boldsen and colleagues (2002) use the logit link $\exp(\cdot)/(1 + \exp(\cdot))$. The link function is used to ‘link the cumulative distribution function of the response to the explanatory variables’ (Agresti 1990: 331). The parameters estimated are the mean and standard deviation. The mean is α/β and the standard deviation is $3^{-1/2} \pi/\beta$ (Boldsen et al. 2002: 82). This calculation of standard deviation, however, is for a logistic distribution. The current study calculates standard deviation on the log-normal scale using the formula $1/\beta$. As stated

above, the mean value is exponentiated to calculate the median transition ages, or $\exp(-\alpha/\beta)$.

The likelihood function for estimating these parameters is:

$$L(\alpha, \beta) = \frac{\prod_{j=1}^n \exp[(\alpha + \beta a_j)y_j]}{\prod_{j=1}^n [1 + \exp(\alpha + \beta a_j)]}$$

The maximum likelihood estimates of α and β can be calculated using free statistical packages in R (Boldsen et al. 2002: 82).

For methods that include more than two stages, such as those observed in the current study, a cumulative logit, or proportional odds, model can be applied as a binomial function to individuals who have made a certain transition and those who have not:

$$\Pr(y_j \geq i \mid a_j) = \Lambda(\alpha_i + \beta a_j).$$

where i denotes a particular stage. This model differs from the previous is that the slope, or standard deviation, remains constant over all transitions (Boldsen et al. 2002: 83). Boldsen and colleagues recognize the inherent issue with a constant standard deviation due to the fact that standard deviations generally increase with each subsequent stage. What this model does provide, however, is an accurate estimation of the mean age-at-transition from each stage to the next with the previous phase being younger than the next in each case.

A transition analysis, also known as a cumulative probit analysis, was conducted on the data in order to establish the age-at-transition distributions between the stages of each age indicator scoring system for each group following the approach described in Konigsberg et al. (2008). For each analysis, the male group was tested against the nulliparous female group as

well as the parous female group, and the nulliparous female group was compared to the parous female group. This parametric model was fit to the data using the package VGAM in “R” (R Core Team 2013) utilizing the script developed and provided by L.W. Konigsberg (Konigsberg et al. 2008; Konigsberg 2014). The cumulative probit analysis was carried out on the log scale to correct for the negative ages-at-transition that may occur on the original scale. The mean age-at-transition for each method was converted back to the original scale of years by calculating the exponential value of the mean, or $\exp(-\alpha/\beta)$, which provides the median transition ages. The standard deviation was calculated by taking the inverse of the slope.

For the individuals where age indicators from both sides could be assessed, a random sequence was generated through the website Random.org to determine which side was included in the analysis (Random.org 2014). The random sequence was generated using the ‘Coin Flipper’ program. The coin was the 2004 American Voting Coin that depicts the relief of John Kerry on one side and George W. Bush on the other. John Kerry faces the left and George W. Bush faces the right, which was directly translated to the data from the left or right side. This will correct for any bias that may be generated by the technique of consistently choosing the older phase displayed by the element or averaging the two sides.

Parameter estimates are provided on the entire sample of males, nulliparous females, and parous females, however, due to the composition of each group, only the transitions that all groups share in common will be compared for each age indicator scoring system. This resulted in only the final three stages being compared thus generating two transition distributions for each method of analysis and the three groups. For the pubic symphysis age estimation methods, stages 8, 9, and 10 were investigated for the Todd method and stages 4, 5, and 6 for the Suchey – Brooks method. For the auricular surface age estimation methods, stages 6, 7, and 8 were

investigated for the Lovejoy method and stages 5, 6, and 7 for the Buckberry – Chamberlain method. The purpose of this comparison is to observe whether the age-at-transition distributions differs between sexes and/or the two groups of females, with the focus being on whether the parous group illustrates difference in rate of degeneration, or transition to subsequent observable stages, when compared to the male and nulliparous groups.

Lastly, two figures summarizing and illustrating the findings were generated. The first of the figure set illustrates the estimated age-at-transition distributions in the form of a density plot. The second figure is an estimated probability plot demonstrating the probability of an individual of a certain age to be assigned a particular phases for each group. The probabilities are based on the known ages of each individual and the associated phase assigned during assessment. The age-at-transition for both figures is in the straight scale of years and in the first figure, the median age-at-transitions are provided in the upper right hand corner of each chart. These figures were referenced to determine whether phases should be collapsed into one phase for the analysis. Significant overlap of median ages-at-transition indicates no difference in the way the groups are distributed for those certain phases. The resulting interpretation for this scenario would be to collapse the overlapping phases into a single phase, as there is no difference to warrant separation. If a lack of significant overlap exists in the transitional curves, no modification in phases is necessary (Berg 2008).

Likelihood Ratio Test

The maximum likelihood results from the transition analysis were then compared using a likelihood ratio test between the male group and the nulliparous female group as well as the parous female group, and the nulliparous female group and the parous female group. The likelihood ratio test compared the goodness of fit of two models, the full and reduced. The

parameters included in the full model include age, phase, and group. The parameters included in the reduced model include age and phase. The full model is representative of the alternative hypothesis (H_A) and the reduced model is representative of the null hypothesis (H_0). The null hypothesis is that no difference exists between the groups. The alternative hypothesis is that differences do exist between the groups. If a statistically significant difference is found between the two models, the results will be in favor of the alternative hypothesis. Since the full model, H_A , includes the additional variable ‘group’, a statistically significant difference between the two models confirms the difference is group-based.

This test compares the log likelihoods of the two models to determine whether significant differences exist between the groups using a chi-square statistic (Ramsey and Schafer 2002).

The test statistic is:

$$\Lambda = 2(l_A - l_0)$$

where Λ denotes the difference in log likelihood values between the two models; l_A represents the alternative model and l_0 represents the null model. The degrees of freedom are equal to the additional number of parameters included in H_A . The parameters for the full model, H_A , include four (4) intercepts (Age, Phase, Group A, Group B), and one slope for the model, totaling five (5) parameters. The parameters for the reduced model, H_0 , include two (2) intercepts (Age, Phase), and one slope for the model totaling three (3) parameters. Therefore, the degrees of freedom for the likelihood ratio tests are equal to two (2) for each test. The difference, Λ , is then compared to a chi-square with the specified degrees of freedom. If the chi-square statistic reveals statistically significant differences between the two models, H_0 is rejected in favor of H_A (Weiss 2005: 144). This test was run in R using the *lrtest* function (R Core Team 2013).

Analysis of Incorrectly Assessed Individuals

If statistically significant differences are found between the male, nulliparous female, and parous female groups in the above analyses, an investigation will be made into the implications this may have for age estimation. This analysis is designed to assess the possible effects of significant differences in mean age-at-transition across groups with no intent to serve as a validation study. For each age estimation method, the age range associated with the phase selected for each individual will be compared to known age. An accurate assessment is determined when the age range of the phase encompasses the actual age of the individual. If an inaccurate assessment was made, an error rate will be calculated and the direction of bias will be noted (over-aged or under-aged). The error rate is calculated by dividing the number of incorrectly assessed individuals by the sample total for each group. If the likelihood ratio test reveals significant differences between groups, this count will demonstrate whether a difference in pattern of inaccuracy and bias exists. More specifically, the phase selected for the individuals who were inaccurately assessed were evaluated to determine whether there was a pattern of bias unique to the parous group and, if so, whether the inaccurate assessment is enough to cause an inaccurate assessment of the chronological age of the individual.

The next chapter will report on the above analyses to determine whether any differences in rate of degeneration for each age indicator and scoring system exist between the three groups, males, nulliparous females, and parous females. The transition analysis will provide median age-at-transition for each of the groups for the differing scoring methods, and the likelihood ratio tests will determine whether the differing median age-at-transitions are statistically significant. The count of inaccurate assessments will provide insight into whether patterns of inaccuracy and bias exist between the groups. More specifically, the results of the accuracy assessment will

determine whether a significant difference exists in the rate of degeneration between parous females and nulliparous females and whether this difference is an increase in rate of transition, which is one of the hypotheses of this study.

CHAPTER IV

RESULTS

Intra-observer Accuracy Study

The Spearman's rho correlation analysis revealed a nearly perfect positive linear relationship. The variables for the pubic symphysis observations collected using the Todd method had a correlation coefficient of 1.00 for the left side and 0.916 for the right side, which were significant at the 0.01 confidence level. The variables for the pubic symphysis observations collected using the Suchey-Brooks method had a correlation coefficient of 1.00 for the left side and 0.839 for the right side, which were significant at the 0.01 confidence level. The variables for the auricular surface observations collected using the Lovejoy method had a correlation coefficient of 0.927 for the left side and 0.966 for the right side, which were significant at the 0.01 confidence level. The variables for the auricular surface observations collected using the Buckberry-Chamberlain method had a correlation coefficient of 0.948 for the left side and 0.863 for the right side, which were significant at the 0.01 confidence level.

Other significant correlations observed during this test include the strong positive relationships between the right and left sides of each method, which are all significant at the 0.01 confidence level. The correlation coefficient for the association between the left and right sides of the pubic symphysis employing the Todd method for the original data set was 0.745 and 0.82 for the re-test data set. The Suchey-Brooks method had a correlation coefficient of 0.997 for the original data set and 0.818 for the re-test data set. The correlation coefficient for the association between the left and right sides of the auricular surface employing the Lovejoy method was 0.867 for the original data set and 0.934 for the re-test data set. The Buckberry-Chamberlain

method had a correlation coefficient of 0.824 for the original data set and 0.912 for the retest data set.

These results are in support of the null hypothesis as no significant differences were found between the variables. This ensures the consistency in the observer's ability to reliably assess the age indicators on both the pubic symphysis and auricular surface, thus confirming the accuracy of the observations. While no significant differences were found between the left and right sides of each element, the data set for this research includes a randomly chosen side for each individual.

Transition Analysis

Transition analysis was conducted on the data in order to establish the median transition ages between the stages of each age indicator scoring system for each group: males, nulliparous females, and parous females. The purpose of this comparison is to observe whether the median age-at-transition differs between groups. Focus was placed on whether the parous female group demonstrates a significant difference in rate of degeneration, or transition to subsequent observable stages, when compared to the male and nulliparous female groups.

The results of the transition analysis for each age indicator scoring system and group are provided below. Following each set of results is a table and two figures summarizing and illustrating the findings. Each table lists the transition phase (Parameter), the number of individuals included in that subsample (n), the mean transition age on the log scale, and the standard deviation. The mean age-at-transition was converted into the straight scale of years by exponentiating the estimate and can be located in the far right column of each table. The first of the figure set illustrates the estimated age-at-transition distributions in the form of a density plot. The second figure is an estimated probability plot demonstrating the three phases for each group

based on the known ages of each individual and the associated phase assigned during assessment. The age-at-transition for both figures is in the straight scale of years and in the first of the set, the median age-at-transitions are provided in the upper right hand corner of each chart. The transitional curves in the figures for each of the indicator scoring systems exhibit separation of median ages-at-transition with no significant overlap. This indicates no modification is necessary such as collapsing of phases. These results are supported by the results of the likelihood ratio test below.

For the Todd scoring system, all groups had scores for stages 8, 9, and 10 and these are the only stages reported on here. The median age-at-transition for stages 8 to 9 for the male group occurred at 43.7 years, the nulliparous female group at 44.9 years, and the parous female group at 34.7 years of age. The median age-at-transition for stages 9 to 10 for the male group occurred at 50 years, the nulliparous female group at 54.5 years, and the parous female group at 44.8 years of age (Table 6, Figures 7-8).

The data collected for the Todd scoring systems showed the parous female group transitioning from stage 8 to 9 approximately 9 years earlier than the males and 10 years earlier than the nulliparous female group. For the transition from stage 9 to 10, the parous female group transitioned approximately 6 years earlier than the male group and 10 years earlier than the nulliparous female group. The male group transitioned from stage 8 to 9 approximately 1 year earlier than the nulliparous female group and from stage 9 to 10 approximately 4.5 years earlier (Table 6, Figures 7-8).

Table 6. Transition analysis parameters for each group for the Todd scoring system. Shaded rows indicate parameters used in study.

Sample	Parameter	<i>n</i>	Mean Age-at-Transition (log scale)	Median Age-at-Transition (years)
Males	5/6	9	3.377184	29.28818
	6/7	12	3.485824	32.64932
	7/8	22	3.621241	37.38395
	8/9	38	3.777135	43.69069
	9/10	203	3.911942	49.99595
	Standard deviation	234	0.1001303	
Nulliparous Females	7/8	4	3.621018	37.37561
	8/9	10	3.804611	44.90778
	9/10	39	3.998162	54.49788
	Standard deviation	43	0.1328225	
Parous Females	8/9	16	3.54765	34.7316
	9/10	153	3.801599	44.7727
	Standard deviation	157	0.1726581

Figure 7. Estimated age-at-transition distribution for each group for the Todd scoring system.

Figure 8. Estimated probability of each group being in stages 8, 9, and 10 for the Todd scoring system. Probabilities based on known ages of individuals in sample and assigned phase during assessment.

For the Suchey-Brooks scoring system, all groups had scores for stages 4, 5, and 6 and these are the only stages reported on here. The median age-at-transition for stages 4 to 5 for the males occurred at 44.17 years, the nulliparous females at 46.22 years, and the parous females at 31.99 years of age. The median age-at-transition for stages 5 to 6 for the males occurred at 53.14 years, for the nulliparous females at 54.14 years, and for the parous females at 45.07 years of age (Table 7, Figures 9-10).

The data collected for the Suchey-Brooks scoring systems showed the parous female group transitioning from stage 4 to 5 approximately 12 years earlier than the males and 15 years earlier than the nulliparous female group. For the transition from stage 5 to 6, the parous female group transitioned approximately 8 years earlier than the male group and 9 years earlier than the nulliparous female group. The male group transitioned from stage 4 to 5 approximately 2 years earlier than the nulliparous female group and from stage 5 to 6 approximately 1 year earlier (Table 7, Figures 9-10).

Table 7. Transition analysis parameters for each group for the Suchey-Brooks scoring system. Shaded rows indicate parameters used in study.

Sample	Parameter	<i>n</i>	Mean Age-at-Transition (log scale)	Median Age-at-Transition (years)
Males	2/3	17	3.299417	27.09683
	3/4	31	3.604271	36.75488
	4/5	56	3.787949	44.1657
	5/6	199	3.973023	53.14493
	Standard deviation	234	0.1136874	
Nulliparous Females	4/5	11	3.833496	46.22385
	5/6	38	3.991481	54.13502
	Standard deviation	43	0.1333309	
Parous Females	4/5	19	3.46547	31.99151
	5/6	154	3.808144	45.06673
	Standard deviation	157	0.1962913

Figure 9. Estimated age-at-transition distribution for each group for the Suchey-Brooks scoring system.

Figure 10. Estimated probability of each group being in stages 4, 5, and 6 for the Suchey-Brooks scoring system. Probabilities based on known ages of individuals in sample and assigned phase during assessment.

For the Lovejoy scoring system, all groups had scores for stages 6, 7, and 8 and these are the only stages reported on here. The median age-at-transition for stages 6 to 7 for the male group occurred at 46.89 years, for the nulliparous female group at 48.28 years and for the parous female group at 41.38 years of age. The median age-at-transition for stages 7 to 8 for the male group occurred at 58.38 years, for the nulliparous female group at 59.00 years, and for the parous female group at 56.65 years (Table 8, Figures 11-12).

The data collected for the Lovejoy scoring systems showed the parous female group transitioning from stage 6 to 7 approximately 5 years earlier than the males and 7 years earlier than the nulliparous female group. For the transition from stage 7 to 8, the parous female group transitioned approximately 2 years earlier than the male group and 3 years earlier than the nulliparous female group. The male group transitioned from stage 6 to 7 approximately 2 years earlier than the nulliparous female group and from stage 7 to 8 less than 1 year earlier (Table 8, Figures 11-12).

Table 8. Transition analysis parameters for each group for the Lovejoy scoring system. Shaded rows indicate parameters used in study.

Sample	Parameter	<i>n</i>	Mean Age-at-Transition (log scale)	Median Age-at-Transition (years)
Males	2/3	8	3.161905	23.61554
	3/4	12	3.406488	30.15914
	4/5	14	3.526306	33.99815
	5/6	31	3.652504	38.57113
	6/7	79	3.847781	46.88891
	7/8	189	4.067035	58.38361
	Standard deviation	234	0.1487212	
Nulliparous Females	5/6	6	3.723854	41.42373
	6/7	16	3.877112	48.28455
	7/8	37	4.077579	59.00247
	Standard deviation	43	0.02451045	
Parous Females	4/5	3	3.278421	26.53385
	5/6	10	3.4732	32.23975
	6/7	47	3.722835	41.38156
	7/8	144	4.036961	56.65392
	Standard deviation	155	0.1810669

Figure 11. Estimated age-at-transition distribution for each group for the Lovejoy scoring system.

Figure 12. Estimated probability of each group being in stages 6, 7, and 8 for the Lovejoy scoring system. Probabilities based on known ages of individuals in sample and assigned phase during assessment.

For the Buckberry-Chamberlain scoring system, all groups had scores for stages 5, 6, and 7 and these are the only stages reported on here. The median age-at-transition for stages 5 to 6 for the males occurred at 39.81 years, for the nulliparous females at age 29.12 years, and the parous females at 38.32 years of age. The median age-at-transition for stages 6 to 7 for the males occurred at 58.36 years, for the nulliparous females at 58.98 years, and for the parous females at 59.45 years of age (Table 9, Figures 13-14).

The data collected for the Buckberry-Chamberlian scoring systems showed the parous female group transitioning from stage 5 to 6 approximately 1 year earlier than the males and 9 years later than the nulliparous female group. For the transition from stage 6 to 7, the parous female group transitioned approximately 1 year later than the male group and less than 1 year later than the nulliparous female group. The male group transitioned from stage 5 to 6 approximately 10 years later than the nulliparous female group and from stage 6 to 7 less than 1 year earlier (Table 9, Figures 13-14).

Table 9. Transition analysis parameters for each group for the Buckberry-Chamberlain scoring system. Shaded rows indicate parameters used in study.

Sample	Parameter	<i>n</i>	Mean Age-at-Transition (log scale)	Median Age-at-Transition (years)
Males	2/3	3	2.959941	19.29683
	3/4	8	3.158575	23.53702
	4/5	30	3.385012	29.51836
	5/6	99	3.684344	39.81897
	6/7	200	4.066681	58.36293
	Standard deviation	233	0.2551305	
Nulliparous Females	5/6	18	3.336761	28.12787
	6/7	40	4.077249	58.98296
	Standard deviation	42	0.433579	
Parous Females	4/5	15	3.314893	27.51944
	5/6	61	3.646065	38.32358
	6/7	140	4.085123	59.44926
	Standard deviation	155	0.3136589

Figure 13. Estimated age-at-transition distribution for each group for the Buckberry-Chamberlain scoring system.

Figure 14. Estimated probability of each group being in stages 5, 6, and 7 for the Buckberry-Chamberlain scoring system. Probabilities based on known ages of individuals in sample and assigned phase during assessment.

Likelihood Ratio Test

The likelihood ratio test compared the goodness of fit of two models, the full (H_A) and reduced (H_0). The full model includes group as a parameter and the reduced model does not. With only one model taking the additional parameter 'group' into account, a statistically significant difference between the two models will confirm the difference is group-based. The degrees of freedom are equal to the additional number of parameters included in H_A . The parameters for the full model, H_A , include four (4) intercepts (Age, Phase, Group A, Group B), and one slope for the model, totaling five (5) parameters. The parameters for the reduced model, H_0 , include two (2) intercepts (Age, Phase), and one slope for the model totaling three (3) parameters. Therefore, the degrees of freedom for the likelihood ratio tests are equal to two (2) for each test. The null hypothesis is that no difference exists between the groups. The alternative hypothesis is that differences do exist between the groups. The expectation of the likelihood ratio test is that significant differences will exist between the parous female group and the male and nulliparous female groups. A summary of the likelihood ratio test results can be found below in Table 10.

For the Todd scoring system, significant differences exist between the male and nulliparous female groups ($p < 0.01$), the male and parous female groups ($p < 0.001$), and between the nulliparous and parous female groups ($p < 0.001$). These results show that there is a statistically significant sex-based difference in the rate at which each group transitions between stages.

For the Suchey-Brooks scoring system, significant differences exist between the male and parous female groups ($p < 0.001$), and between the nulliparous and parous female groups ($p < 0.01$). These results show a statistically significant difference in the rate at which the parous

female group transitions between stages when compared to the male group and nulliparous female group. Significant differences were not found between the male and nulliparous female groups ($p > 0.05$).

For the Lovejoy scoring system, significant differences exist between the male and parous female groups ($p < 0.001$), and between the nulliparous and parous female groups ($p < 0.01$). These results show a statistically significant difference in the rate at which the parous female group transitions between stages when compared to the male group and nulliparous female group. Significant differences were not found between the male and nulliparous female groups ($p > 0.33$).

No significant differences were found between any of the groups for the Buckberry-Chamberlain scoring system. The p-values corresponding to each test are as follows: male group and nulliparous female group ($p > 0.10$), male group and parous female group ($p > 0.15$), nulliparous female group and parous female group ($p > 0.51$).

Table 10. Likelihood ratio test results for each comparison by age indicator scoring system.

Method	df	X ²	Pr(>X ²)	p-value *
Todd				
Males & Nulliparous Females	2	7.9946	0.01837	p < 0.01
Males & Parous Females	2	29.645	3.652e-07	p < 0.001
Nulliparous Females & Parous Females	2	16.767	0.0002286	p < 0.001
Suchey – Brooks				
Males & Nulliparous Females	2	1.1385	.0556	p > 0.05
Males & Parous Females	2	41.889	8.015e-10	p < 0.001
Nulliparous Females & Parous Females	2	12.707	0.001741	p < 0.01
Lovejoy				
Males & Nulliparous Females	2	2.1607	0.3395	p > 0.33
Males & Parous Females	2	15.643	0.000401	p < 0.001
Nulliparous Females & Parous Females	2	11.145	0.0038	p < 0.01
Buckberry – Chamberlain				
Males & Nulliparous Females	2	4.5687	0.1018	p > 0.01
Males & Parous Females	2	3.76	0.1526	p > 0.01
Nulliparous Females & Parous Females	2	1.3253	0.5155	p > 0.05

* p-values in bold are considered statistically significant.

Analysis of Incorrectly Assessed Individuals

Since statistically significant differences were found between the male, nulliparous female, and parous female groups in the above analyses, an investigation was made into the implications this may have for age estimation. This analysis is designed to assess the possible effects of differences in median age-at-transition across groups.

A count was performed of the individuals who were correctly assessed versus those who were not for each age estimation method. For each age estimation method, the age range associated with the phase selected for each individual will be compared to known age. An accurate assessment is determined when the age range of the phase encompasses the actual age of the individual. The error rate and direction of bias were noted for the male group, the nulliparous female group, and the parous female group. For the Todd method, 28 of the males and 23 of the females were incorrectly assessed, resulting in an error rate of 11.96% for the males and 11.50% for the females. For the male group, eleven were under-aged (4.7%) and seventeen were over-aged (7.3%). For the nulliparous female group, four were under-aged (9.3%) and zero was over-aged. For the parous female group, three were under-aged (1.9%) and sixteen were over-aged (10.2%) (Table 11).

Table 11. Age ranges and direction of bias of incorrectly assessed individuals for the Todd scoring system (- = under-aged / + = over-aged).

Age	Males	Nulliparous Females	Parous Females
20s	++++		+
30s	+++++--		+++
40s	+++++---	--	+++++ + + + + + + + + + +
50s	-----	-	-
60s			--
70s		-	
80s			
90s			
% Under-aged	4.7	9.3	1.9
% Over-aged	7.3	0	10.2

For the Suchey-Brooks method, one of the males was under-aged and none of the females were incorrectly assessed, resulting in an error rate of ~ 0% for the males and 0% for the females.

For the Lovejoy method, 45 of the males and 29 of the females were incorrectly assessed, resulting in an error rate of 19.23% for the males and 14.64% for the females. For the male group, ten were under-aged (4.3%) and thirty-five were over-aged (15%). For the nulliparous female group, zero was under-aged and four were over-aged (9.3%). For the parous female group, six were under-aged (3.8%) and eighteen were over-aged (11.5%) (Table 12).

Table 12. Age ranges and direction of bias of incorrectly assessed individuals for the Lovejoy scoring system (- = under-aged / + = over-aged).

Age	Males	Nulliparous Females	Parous Females
20s	+		+
30s	+	+	+
40s	+	+	+
50s	+	+	+
60s	+		-
70s	-		-
80s			
90s			
% Under-aged	4.27	0	3.8
% Over-aged	15	9.3	11.5

For the Buckberry-Chamberlain method, 9 of the males and 6 of the females were incorrectly assessed, resulting in an error rate of 3.86% for the males and 2.53% for the females. For the male group, zero was under-aged and nine were over-aged (3.8%). For the nulliparous female group, zero was under-aged and one was over-aged (2.3%). For the parous female group, zero was under-aged and five were over-aged (3.2%) (Table 13).

Table 13. Age ranges and direction of bias of incorrectly assessed individuals for the Buckberry-Chamberlain scoring system (- = under-aged / + = over-aged).

Age	Males	Nulliparous Females	Parous Females
20s	++		
30s	+		+
40s	+		++
50s	++++	+	++
60s			
70s			
80s			
90s			
% Under-aged	0	0	0
% Over-aged	3.8	2.3	3.2

The present research confirms there is a difference in the rate of degeneration between the three groups with a relatively low intra-observer error rate. While each group transitioned through the phases in a similar manner, the rate and thus ages, at which the groups traveled through the phases, occurred in a dissimilar manner. In general, the male group and the nulliparous female group transition around the same age, while the parous females transition at an earlier age. This difference, however, is more pronounced in age indicator scoring systems of the pubic symphysis. The results from the analysis of the age indicator scoring systems of the auricular surface do not show any significant differences for the Buckberry and Chamberlain scoring system, but significant differences do exist between the parous females and the other two groups for the Lovejoy scoring system. Ultimately, a decision was made to focus on the changes occurring on the pubic symphysis as it appears to be more greatly affected by parity than the age indicators of the auricular surface.

The comparison between the male group and female groups illustrate a widely recognized trend found in age estimation, which is that younger individuals tend to be over-aged and older individuals tend to be under-aged. This study demonstrates that the pattern of bias indicates that

a higher frequency of parous females was over-aged than nulliparous females and a higher frequency of nulliparous females were under-aged than parous females. The following chapter will discuss the implications of these findings in the broader context of application with a focus on the fields of forensic anthropology and paleodemography.

CHAPTER V

DISCUSSION

The present research confirms there is a difference in the rate of degeneration between the three groups with a relatively low intra-observer error rate. While each group transitioned through the phases in a similar manner, the rate and thus ages, at which the groups traveled through the phases, occurred in a dissimilar manner. In general, the male group and the nulliparous female group transition around the same age, while the parous females transition at an earlier age. This trend in parous and nulliparous female aging may not have been recognized in previous studies due to the lumping of all females in a sample. When age estimation research is conducted on a female sample, the parous females bias the overall sample in a manner that generates an increase in rate of degeneration, assuming the majority of females in the sample experienced pregnancy and parturition. Therefore, when standards are created for both sexes, the females tend to follow a different trend than the males, observed as advancing through stages at a generally faster pace than males of similar ages.

This difference, however, is more pronounced in the pubic symphysis. The results from the analysis of the auricular surface do not show any significant differences using the Buckberry and Chamberlain scoring system, but significant differences do exist between the parous females and the other two groups using the Lovejoy scoring system. Ultimately, a decision was made to focus on the changes occurring on the pubic symphysis as it appears to be more greatly affected by parity than the age indicators of the auricular surface.

Transition Analysis & Likelihood Ratio Test

The transition analysis reveals two important findings. First, parous females appear to transition to subsequent phases at an earlier age than males and nulliparous females. Second, parity seems to have a greater effect on the age indicators on the pubic symphysis than those on auricular surface.

The data collected using the Todd and Suchey-Brooks scoring systems showed the parous females transitioning between the latest three phases approximately 9-10 years and 8-14 years earlier than the males and nulliparous females, respectively. These differences in median age-at-transition are significant ($p < 0.001$). This indicates that parity should be taken into consideration when assessing age from the pubic symphysis using these methods.

In addition, the males differed significantly from the nulliparous females using the Todd scoring system. One explanation for this is the greater number of phases than the Suchey-Brooks scoring system for example. With more stages, there is greater opportunity to differ whereas with the collapsed Suchey-Brooks system, there are fewer stages and therefore fewer opportunities to differ. For the Lovejoy method, the parous females transitioned between the latest three phases approximately 5-7 years and 1.5-2.5 years earlier than the males and nulliparous females, respectively. These differences in median age-at-transition were also found to be statistically significant ($p < 0.001$ between males and parous females and $p < 0.01$ between the two female groups). While these findings are statistically significant, this is a much smaller amount of variation when compared to the differences observed on the pubic symphysis.

Other studies provide results for median age-at-transition for the Suchey-Brooks scoring system. Konigsberg et al. (2008) provide results on an American sample of males from various collections such as the Los Angeles Coroner's Office, the Terry Collection, and US Korean War

Dead, and Kimmerle et al. (2008) provide results on a male Balkan sample. For the transition from phases 4 to 5, the median age-at-transition for the current study is 44.17 years for the males, 45.1 years for the Konigsberg et al. (2008) study, and 44.33 years for the Kimmerle et al. (2008) study. For the transition from phases 5 to 6, the median age-at-transition for the current study is 53.14 years, 71.7 years for the Konigsberg et al. (2008) study, and 66.18 years for the Kimmerle et al. (2008) study. The median ages-at-transition are quite similar for the transition from phases 4 to 5. The variation observed in the median ages-at-transition for the transition from phases 5 to 6 can be attributed to the sample, as none of them are appropriate references for the others.

Berg (2008) provides median ages-at-transition for a female Balkan sample using his redefined and modified Suchey-Brooks phases. Berg (2008) reports a median age-at-transition of 35.2 years from phases 4 to 5, 50.3 years from phases 5 to 6, and 65.9 years from phases 6 to 7. The current study reports a median age-at-transition of 46.22 years from phases 4 to 5, and 54.13 years from phases 5 to 6 for nulliparous females and 31.99 years and 45.07 years, respectively, for parous females. Clearly, the two studies are not comparable as they were not scored using the same scoring system nor were they performed on an appropriate reference sample, although it is still interesting to note the differences between the studies.

Berg (2008) used graphical depictions of transitional curves similar to the probability plots seen in Figures 4, 6, 8, and 10. These were referenced to determine whether phases should be collapsed into one phase for the analysis. As was observed in Berg's study, separation of median ages-at-transition was apparent with no significant overlap was between the median ages-at-transition depicted in the probability plots. Therefore, no modification such as collapsing of phases is necessary. Berg (2008) also noted that the number of years between median age-at-transition increased with the advancement of phases. The current study followed the same

general pattern. For example, for the Todd scoring system, approximately three years separated the median ages-at-transition from phases 5/6 to 6/7, five years from phases 6/7 to 7/8, six years from phases 7/8 to 8/9, and six years from phases 8/9 to 9/10. These increasing age differences are to be expected as the variation within each phase increases with the accumulation of extrinsic factors that come with age (Berg 2008).

Implications for Age Estimation

Differences in pubic symphyseal morphology between the male and female samples were to be expected. A lengthy history of prior research notes the variation in females when assessing age from the pelvis (Todd 1921; Gilbert and McKern 1973; Suchey et al. 1979; Meindl and Lovejoy 1989; Hoppa 2000; Berg 2008; Kimmerle et al. 2008). While parity is a widely accepted reason for such variation, other factors play a role such as bone loss and the subsequent condition of osteoporosis. Not only does this event begin approximately 5 years earlier in females than males (35 years of age as opposed to 40 years), but the rate at which bone loss occurs can be over two times faster as well (Berg 2008). These confounding factors will be discussed in greater detail below. What is important to note here is that Berg (2008) recognized and investigated the difference in morphological changes occurring on the pubic symphysis in females, especially females in the older cohorts. He found that by adopting an additional phase for the Suchey-Brooks method and employing transition analysis, a dramatic increase in accuracy rates can be seen in age estimation of a female sample into older age.

On the other hand, Hoppa (2000) states that females actually look younger than males in middle to older ages and did not observe a greater variation in the female sample. The contradictory findings were attributed to the differences in the aging processes of the reference samples used in the study. Hoppa (2000) also tested the effects of parity using the Spitalfields

collection that had known parity data. No significant differences were found, however, what was tested was whether a difference exists between low- and high-birth females, not between parous and nulliparous females. These findings appear to be quite the anomaly when compared to the abundance of evidence to the contrary, including the results of the current study.

The comparison between the males and females illustrated a common trend found in age estimation, which is that younger individuals tend to be over-aged and older individuals tend to be under-aged. The tables above demonstrate that females tended to be over-aged up until the time they were in their 50s (Tables 12, 13, and 14). The majority of females who were under-aged were 50+ years old. The male trend for over-aging follows that of the females, however, males that were under-aged tended to be much younger, even as young as their 30s. Milner and Boldsen (2012) found that the Lovejoy scoring systems consistently underestimates age at death beginning around 40 years of age. This issue has been attributed to the basis of the original age estimation methods and the use of linear regression. With the exception of the Lovejoy method, the error rate between the male and female groups was quite similar. One of the benefits of using transition analysis is to avoid the issue of age mimicry, or bias due to the composition of the reference sample (Godde and Hens 2012; Milner and Boldsen 2012).

As the goal of this project was not to quantify the performance of each aging method, a count of inaccurate assessments was conducted and an error rate was calculated. The count of the number of nulliparous versus parous individuals who were incorrectly assessed only somewhat followed the hypothesis that a difference in pattern of bias exists with a pattern of overestimation found to be unique to the parous group. Out of the female individuals incorrectly assessed, the expectation was that the nulliparous individuals would either be aged correctly or under-aged and the parous individuals would be over-aged. While there was a general trend that

follows this assumption, six nulliparous females were over-aged and nine parous females were under-aged. More specifically, for the Todd method, 9.3% of the nulliparous females were under-aged and 0% was over-aged compared to 1.9% and 10.2%, respectively, for the parous females. For the Lovejoy method, 0% of the nulliparous females were under-aged and 9.3% were over-aged compared to 3.8% and 11.5%, respectively, for the parous females. For the Buckberry-Chamberlain method, 0% of the nulliparous females were under-aged and 2.3% were over-aged compared to 0% and 3.2%, respectively, for the parous females. While the pattern of bias may not have consistently followed the expected pattern, it was evident that the majority of incorrectly assessed females were parous.

If focus were to be placed solely on the pubic symphysis scoring systems, a pattern of under-estimation for nulliparous females and over-estimation for parous females does exist for the Todd method. The age ranges associated with the phases of the Suchey-Brooks method, however, are too encompassing to warrant incorrect assessment of age. Moreover, there is little difference in overall error rates when a comparison is made between the male sample and female samples. This suggests that revisions to the methods used in this study may not be necessary in regards to accurately assessing the age of remains of women who have had children. Another option would be to conclude that if a parity indicator is present, it might be best to determine age of the individual from the auricular surface, rather than the pubic symphysis.

Figure 15 demonstrates the differences in pubic symphysis morphology observed in nulliparous and parous females of similar ages. The top row includes nulliparous females ages 46, 46, and 47 years, respectively. The bottom row includes parous females ages 47, 47, and 45 years, respectively. The left and center column include elements from the left side and the right column includes elements from the right side. The parous individuals in this figure were over-

aged using the Todd scoring system. There are features of the symphyseal face of parous females that stand out as a commonality among these elements. Each of the parous females expresses pitting and increased disfiguration. The nulliparous females retain a dense appearance. While Kimmerle et al. (2008) did not separate the female sample based on parity, they did note that differences were observed between male and female pubic symphysis morphology in presence and amount of porosity, lipping, and bone density.

Figure 15. Photographic exemplars of pubic symphyses of similarly aged nulliparous and parous females: Top row is of nulliparous females aged 46, 46, and 47 years, respectively; Bottom row is of parous females aged 47, 47 and 45 years, respectively. The left and center columns are pubic symphyses from the left side and the right column contains pubic symphyses from the right side.

The skeletal alterations caused by parity have been thoroughly investigated in previous literature. What has not been found is a strong correlation between parity indicators and the number of children. Moreover, there has not been a single indicator that is solely indicative of pregnancy and/or parturition (Kelley 1979; Suchey et al. 1979; Snodgrass and Galloway 2003). Furthermore, these bony alterations can be seen in both nulliparous females and males. Suchey and colleagues (1979) present a possible reason for the parturition scars on nulliparous females. The authors propose the possibility that some females may not be entirely truthful when presenting or acknowledging parity information for various personal reasons.

The main issue is the multitude of confounding factors that may impact the degree to which the pelvis is affected (Ubelaker and De la Paz 2012). Kelley (1979: 545) lists several factors such as, “interaction of hormone levels, maternal birth canal diameter, fetal head circumference, amount of physical activity during pregnancy, number of pregnancies, obstetrical care, and age at time of death.” Ubelaker and De la Paz (2012) expand on this list by including both pregnancy and non-pregnancy related factors such as:

“various manifestations of the preauricular sulcus, osteitis condensans ilii, pubic pitting, trabecular bone loss and sclerosis, pelvic exostoses and erosions, and extension of the pubic tubercle (4).”

as well as:

“urinary tract infection, repeated minor trauma, surgery, general joint laxity and pelvic instability, lumbosacral anomalies, variation in sciatic notch angle, occupation-related activities, obesity, habitual posture including squatting, congenital anomalies, metabolic and degenerative conditions, and general pelvic and body size (5).”

Moreover, the frequency of these bony alterations has been found to change in association with childbearing years. The highest frequencies are observed in parous females around the age of 30 years and decline to lower frequencies around the age of 70 years (Kelley

1979). Snodgrass and Galloway (2003) state that the nature of bony alterations such as pitting becomes observed in older ages because of hormones associated with menopause and postmenopausal changes. These also play a role in bone loss, which affects pelvic stability. Furthermore, Snodgrass and Galloway (2003) state that dorsal pitting had a higher correlation to body mass index rather than parity in parous females over the age of 50 years.

While one may be able to conclude that paleodemographers should consider parity when determining age from female pelvis, variation is too great between females in historical and prehistorical populations versus a recent sample from the United States to reference this study. Milner and Boldsen (2012) state that the fundamental objectives of those working in the archaeological sector versus those in the forensic sector warrant distinction when dealing with specific methodologies. The authors promote the use of transition analysis in both sectors, but stress the importance of uniformity/contemporaneity of target and reference samples. Godde and Hens (2012) support the need for appropriate reference samples as they found that two populations transitioned through the aging process in a similar manner, but at a dissimilar pace. Milner and Boldsen (2012) found the most effective method of age estimation is actually a combination of experienced practitioner and the use of transition analysis, where the practitioner can take into consideration multiple indicators from various elements of an individual.

Stewart (1957) points out more of a cultural implication of the variation in parity indicators observed on the pubis. Stewart takes into account that the differences in obstetrical care differ drastically between historical and modern populations. Galloway (1995) adds to this thought by pointing out that the frequency of cesarean section has increased drastically in modern times, thus lessening the stress put on the ligaments during delivery. Other forms of variation include everything from age at first parturition, activity level during pregnancy,

medical/obstetrical care before, during, and after birth, birth rates and practices, to methods of birth control. Therefore, future research would be needed on additional populations in order to determine how parity affects pelvic age indicators across various times and locations (Stewart 1957; Ashworth et al. 1976; Schemmer et al. 1995; Ubelaker and De la Paz 2012).

As stated above, bone loss has been attributed to the loss of micronutrients, such as calcium and iron, both during and post pregnancy through lactation (Mensforth and Lovejoy 1985; Kent et al. 1990). Goldsmith and Johnston (1975) found that a significant correlation exists between an increase in bone mineralization and oral contraceptives taken shortly after lactation. Knowing that oral contraceptives are more prevalent in industrialized societies than in nonindustrialized societies, another issue is presented to consider along with the higher quality in obstetrical care. One factor that has been investigated is the effect of environmental differences as well as differences of affluence. Ashworth et al. (1976) conducted a study assessing the age of the remains of two groups of pre-Columbian Peruvian mummies with one group lived in poverty while the other had an abundance of resources. The results allowed the authors to conclude that the scarring observed on the pubic symphysis is not correlated to a lifestyle of poverty associated with poor nutrition as both populations exhibited similar frequencies of scarring in females. This study, however, does not explain what differences might be observed between those populations and a modern sample from the United States, therefore, again, heading caution to research on historic and pre-historic populations based on the findings of the current study.

Role of Parity on Physiological & Morphological Changes of the Pelvis

The results of the current study are further supported by the understanding of what occurs physiologically and morphologically to the pelvis during pregnancy, parturition, and postpartum.

Putschar (1976) was one of the original researchers to propose that females appear 'older' than males of the same age due to the bony alterations caused by parity. As was presented in the literature review section of this project, there is no shortage of research to support this statement in both the anthropological and medical fields of investigation.

The pelvis is a weight-bearing structure that is subjected to many day-to-day stressors that provides reliable age indicators for generation of the biological profile. The current research shows that males and nulliparous females follow a similar trend in aging using the pelvic age indicators, while parous females appear to advance through the phases of a scoring system at a more rapid rate than the males and nulliparous females. This can be explained by the physiological changes experienced by parous females such as the release of ligament-loosening hormones to various levels of trauma experienced during parturition and postpartum events.

The hormones released during pregnancy, such as relaxin and oestrogen, derive from both ovarian and placental changes. Normally, the pubic symphysis withstands minor movements up to 1mm. These hormones, however, allow the joint to stretch at least an additional 2-3mm in preparation for childbirth. Not only are the hormones responsible for the loosening of the pelvic ligaments, but they also play a role in bony changes such as resorption and remodeling. These changes occur at sites of ligament attachment such as the dorsal aspect of the pubic symphysis where the posterior pubic ligament attaches and the preauricular sulcus where the inferior sacroiliac ligament attaches. With the thickening and stretching of ligaments plus the added strain of activities during pregnancy, osteoclastic resorption begins which results in depressions and pitting. Active remodeling follows degradation and these two processes result in bony changes at attachment sites (Angel 1969; Houghton 1974; Putschar 1976; Holt 1978; Becker et al. 2010; Khorashadi et al. 2011).

Houghton (1974) proposed that the sacroiliac joint would be more greatly affected by parity than the pubic symphysis as it is directly responsible for the transfer of body weight. In the current study, however, a lack of significant differences were observed as far as the age indicators of the auricular surface is concerned. While Houghton (1974) states that the pre-auricular sulcus is the most indicative marker for parity, this area of the bone does not affect the morphology of the auricular surface, which is used to determine age. One of the factors to consider here is that the sacroiliac ligaments are short and broad and supported by many other pelvis ligaments whereas the pubic ligaments are short and narrow (Figures 16-18). This allows for greater instability with the loosening of ligaments during pregnancy. Furthermore, research on the pubic ligaments shows that they are strongest in males followed by nulliparous females and weakest in females in the final trimester. While the ligaments of parous females repair and thus regain strength postpartum, the ligaments remain weaker than those observed in nulliparous females (Becker et al. 2010).

Figure 16. Illustration of the superior and inferior pubic ligaments (Gray, 1918).

Figure 17. Illustration of the anterior view of the pelvic ligaments (Gray, 1918).

Figure 18. Illustration of the posterior view of the pelvic ligaments (Gray, 1918).

One of the reasons the pubic symphysis of parous females incurs an increase in the changing of morphology is due to damage to the interpubic disc. This disc changes in width, and thus amount of cushion on the joint, as a function of age. This is why this area is a reliable indicator of age in both sexes. The interpubic disc is thicker in females than males providing a larger area to assist with delivery process. When under certain forces, such as those experienced during pregnancy and parturition, a cleft can develop in the disc. While this cleft can be caused by other confounding factors and observed in both sexes, the cleft observed in parous females is longer and irregular with the possibility of secondary clefts developing in multiparous females (Becker et al. 2010; Khorashadi et al. 2011).

The healing and closing of clefts differs on an individual level, with some clefts never healing completely. Moreover, with subsequent pregnancies, the damage to open clefts increases as well as the development of additional clefts. When a cleft does not heal, the traumatic forces on the joint accumulate after birth. The pubic symphysis will never return to the way it functioned prior to first pregnancy, with loosened ligaments and trauma to the disc only adding to the affects of age on the bone. This is problematic due to the fact that the disc, in conjunction with the anterior pubic ligament, is what provides the joint with the most stability. Moreover, parous females experience an increase in bone loss attributed to the loss of micronutrients, such as calcium and iron, both during and post pregnancy through lactation (Mensforth and Lovejoy 1985; Kent et al. 1990). Herein lies the cause of the change in the morphology of the pubic symphysis. The looser the ligaments, the more damage to the cartilage that separates and cushions the joint, the less healthy bone exists due to the leeching of micronutrients, the more damage will be observed in the form of skeletal changes (Putschar 1976; Becker et al. 2010; Khorashadi et al. 2011).

Khorashadi and colleagues (2011) present a case study on symphysis pubis diastasis, a term used to describe the separation of the joint to a width greater than 10mm. The authors found that it is most often attributed to the strain put on the joint during childbirth after the loosening of the ligaments during pregnancy. It can either be due to too quick of a delivery process or a very prolonged delivery process. Other events that may cause diastasis of the joint are the use of forceps during delivery as well as by trauma in rare instances such as car crashes (Becker et al. 2010). This case study in particular involved the separation of the joint to a width of 34mm, with no changes observed in the sacroiliac joint. The female in the study required a pelvic brace in order to bring her joint back into normal position. Another study reports a 50mm diastasis of the pubic symphysis after an urgent vacuum-assisted delivery, again, with no effect on the sacroiliac joint. This individual was placed on pain medication and had limited mobility but did not require a brace or medical intervention. At the 6-month follow up, this gap was reduced to 10mm (Figure 19) (Chang and Markman 2002). Once a female experiences diastasis of the joint, however, there is a recurrence rate of 68%-85% in subsequent pregnancies (Khorashadi et al. 2011). This study demonstrates how one may experience advanced trauma to the pubic symphysis without affecting the sacroiliac joint, and thus the auricular surface.

Figure 19. Radiograph illustrating a 50mm diastasis of the pubic symphysis (A) and a 6-month follow-up radiograph where the gap is reduced to 10mm (B) (Chang and Markman 2002).

Future areas of research

Future considerations for this research should include a more in-depth analysis of parity. For example, does the number of children affect the rate of degeneration? Does the age at first parturition affect the rate of degeneration? Is there a difference in rate of degeneration between those having natural versus cesarean section births? Is there a difference in rate of degeneration for parous females of differing ancestries due to bone density differences? While these questions may be answered through the information provided by the deceased or next of kin, there are many more questions revolving around the confounding factors listed above that may not be possible to answer such as pelvic outlet diameter and fetal head circumference.

Another issue to consider moving forward is whether these questions would prove helpful in the forensic context with the objective of identification. Many of these questions cannot be answered through the markers on the bones themselves. What may be helpful, however, is to work backwards from a missing persons case. For example, if one is searching for a 30 year old American White female and mother of five, one may be able to then deduce what effects this would have had on the pelvis and thus expand the age range on the older side of the spectrum for potential matches. Another way to look at this example would be if the biological profile states the individual is likely a 45 year old American White female with the possibility of at least one child, one can expand the possibility of missing persons to include females who are actually younger than the age expressed by the skeletal remains. Another option would be to conclude that if a parity indicator is present, it might be best to determine age of the individual from the auricular surface, rather than the pubic symphysis.

CHAPTER VI

CONCLUSION

A large part of forensic anthropology is providing a positive identification of the individual from recovered remains. Inaccurate age estimation of a skeleton can result in the remains being misidentified or unidentified. Due to the understanding what occurs physiologically and morphologically during pregnancy, parturition, and postpartum, a hypothesis was postulated that these events might increase the rate at which the areas of interest of the pelvis degenerate. For instance, the looser the ligaments, the more damage to the cartilage that separates and cushions the joints, the less healthy bone exists due to the leeching of micronutrients in females, the more damage will be observed in the form of skeletal changes (Putschar 1976; Becker et al. 2010; Khorashadi et al. 2011). This hypothesis had yet to be formally tested on a recent skeletal collection. The purpose of this study, therefore, was to assess the effects of parturition on age indicators of the pubic symphysis and auricular surface to determine whether it influences the physiological age of the individual enough to cause an inaccurate estimate of the chronological age.

The pubic symphysis and auricular surface were analyzed to determine whether any differences in rate of degeneration exist between the three groups: males, nulliparous females, and parous females. More specifically, an investigation into the influence of parity on degenerative changes in the pubic symphysis and auricular surface were conducted using the scoring systems provided in the following age estimation methods: Todd (1920,1921), Suchey-Brooks (Katz and Suchey 1989; Brooks and Suchey 1990), Lovejoy and colleagues (Lovejoy et al. 1985b; Meindl and Lovejoy 1989), and Buckberry and Chamberlain (2002). The data collected using these scoring systems were statistically analyzed with an intra-observer accuracy

study to confirm the validity of the data, then through the use of transition analysis and likelihood ratio tests, which determined the significance of differences observed between the groups. Since the above analyses showed significant differences between groups, a count was performed on the individuals who were inaccurately assessed to determine whether there was a pattern of overestimation unique to the parous group and, if so, whether the over-estimation is enough to cause an inaccurate assessment of the chronological age of the individual.

The present research confirms there is a difference in the rate of degeneration between the three groups: males, nulliparous females, and parous females, with a relatively low intra-observer error rate. In general, the male group and the nulliparous female group transition around the same age, while the parous females transition at an earlier age. This difference, however, is more pronounced in age indicator scoring systems of the pubic symphysis. The results from the analysis of the age indicator scoring systems of the auricular surface do not show any significant differences using the Buckberry-Chamberlain scoring system, but significant differences do exist between the parous females and the other two groups using the Lovejoy scoring system. Ultimately, a decision was made to focus on the changes occurring on the pubic symphysis as it appears to be more greatly affected by parity than the age indicators of the auricular surface.

The data collected using the Todd and Suchey-Brooks scoring systems showed the parous females transitioning to subsequent phases approximately 9-10 years and 8-14 years earlier than the males and nulliparous females, respectively. These differences in median age-at-transition are highly significant ($p < 0.001$). In addition, the males differed significantly from the nulliparous females using the Todd scoring system. For the Lovejoy method, the parous females transitioned to subsequent phases approximately 5-7 years and 1.5-2.5 years earlier than the

males and nulliparous females, respectively. These differences in median age-at-transition were also found to be statistically significant ($p < 0.001$ between males and parous females and $p < 0.01$ between the two female groups).

The count of the number of nulliparous versus parous individuals who were incorrectly assessed only somewhat followed the hypothesis that a difference in pattern of bias exists with a pattern of overestimation found to be unique to the parous group. Out of the female individuals incorrectly assessed, the expectation was that the nulliparous individuals would either be aged correctly or under-aged and the parous individuals would be over-aged. Although there was a general trend that follows this assumption, six nulliparous females were over-aged and nine parous females were under-aged. While the pattern of bias may not have consistently followed the expected pattern, it was evident that the majority of incorrectly assessed females were parous.

If focus were to be placed solely on the pubic symphysis scoring systems, a pattern of under-estimation for nulliparous females and over-estimation for parous females does exist for the Todd method. The age ranges associated with the phases of the Suchey-Brooks method, however, are too encompassing to warrant incorrect assessment of age. Moreover, there is little difference in overall error rates when a comparison is made between the male sample and female samples. This suggests that revisions to the methods used in this study may not be necessary in regards to accurately assessing the age of remains of women who have had children. Another option would be to conclude that if a parity indicator is present, it may be most appropriate to determine age of the individual from the auricular surface, rather than the pubic symphysis.

The present results are significant in that they represent a noteworthy find within the realm of forensic anthropology and similar professional fields that may utilize this information on modern cases from the United States today. The current project is addresses several issues by

employing transition analysis to 1) utilize an appropriate age-at-death distribution for the reference sample, 2) combat the issues inherent in linear regression analyses including biased age estimations and lumping older individuals into terminal categories such as 50 years plus, and 3) generate appropriate age-at-transitions for females who have had children, given their rate of degeneration of pelvic age indicators increase due to such a naturally traumatic event. This project indicates that parturition has a greater effect on the pubic symphysis than the auricular surface when determining age at death. This may lead to future estimations or correction factors that allow age estimation to be done more reliably.

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APPENDIX A

Case#: _____

Observer Initials: _____

Date: _____

Pubic Symphysis

Todd Phase – L – _____ R – _____

Suchey-Brooks Phase – L – _____ R – _____

Berg Phase (if different) – L – _____ R – _____

Notes -

Auricular Surface

Lovejoy et al. 1985 & Meindl and Lovejoy 1989 Phase – L – _____ R – _____

Buckberry & Chamberlain

Transverse Organization – L – _____ R – _____

Surface Texture – L – _____ R – _____

Microporosity – L – _____ R – _____

Macroporosity – L – _____ R – _____

Apical Changes – L – _____ R – _____

Composite Score – L – _____ R – _____

Notes -