2015

The height of the pubic tubercle as an indicator of parturition

https://hdl.handle.net/2144/15444

Boston University
BOSTON UNIVERSITY

SCHOOL OF MEDICINE

Thesis

THE HEIGHT OF THE PUBIC TUBERCLE AS AN INDICATOR OF
PARTURITION

by

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B.S. University of Massachusetts, Boston, 2002

Submitted in partial fulfillment of the
requirements for the degree of
Master of Science

2015
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I would like to dedicate this work to my parents, Albert and Jacqueline, my partner Michael and our beautiful daughter, Giuliana.
Acknowledgements

I would like to thank my thesis committee members, Dr. Jonathan Bethard, Ph.D. and Dr. Tara Moore, Ph.D. for pushing me along and for their infinite patience during my long journey to thesis completion.

I would also like to acknowledge, Dr. Christopher B. Ruff, Ph.D., Professor Functional Anatomy and Evolution at Johns Hopkins University. He was kind enough to respond to an email from a student desperate to learn his method of pelvic rearticulation using only three rubber bands. I am incredibly grateful for his instruction and for putting me in touch with his protégé at the University of Tennessee, Knoxville, Dr. Benjamin M. Auerbach, Ph.D. Thanks to Dr. Auerbach for give me a quick hands on tutorial in “rubber-banding” upon my arrival at UTK to conduct my research.

Last, I would like to thank my classmates, friends and family for the support on my long journey and for always encouraging me to finish what I started.
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ABSTRACT

Parity status is a supplemental element of the biological profile in forensic anthropology. The pelvis is thought to exhibit alterations to the bone from pregnancy. Two features of the pelvis have been studied for signs of parturition or past pregnancy. The features have been studied with varying results. They include the pubic bone (Bergfelder and Herrmann, 1980, Cox and Scott, 1992) and the preauricular sulcus (Houghton, 1974, Dee, 1981). Maass and Friedling (2014) also looked at the interosseous groove and the iliac tuberosity.

This study was modeled on Snodgrass and Galloway (2003) that investigated whether or not parity status can be determined by analyzing several areas of the pubic bone for different traits. Snodgrass and Galloway assessed the dorsal surface of the pubic bone for pitting and measured the height of the pubic tubercle. They also rearticulated the pelves of each subject and measured the arcuate angle. For the current study, a sample of 75 females from the William M. Bass Skeletal Collection at the University of Tennessee, Knoxville was examined.
The height of the pubic tubercle and its distance from the symphyseal face was measured bilaterally for each individual. Also, the dorsal surface of each pubic bone was visually assessed for the presence or absence of pitting. Data analysis was then conducted comparing each of these features with parity status. BMI was also calculated for each individual and compared with the three features listed above. There were no correlations found between height of the pubic tubercle, distance of the pubic tubercle, dorsal pitting and parity status. The lack of a correlation between any of the features and parity status make them unusable in forensic applications.
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BMI: Body Mass Index

CT: Computed Tomography/Tomographic

lbs: pounds

UTK: University of Tennessee, Knoxville
Chapter 1: Introduction

When presented with unidentified skeletal remains, forensic anthropologists and bioarchaeologists create what is known as the biological profile. There are four major components of the biological profile. When assessing remains, age at death, sex, race and living stature are the basic criteria used to create identification. There are several secondary components, such as trauma, that are assessed, as well.

A potentially useful secondary component of the biological profile would be parity assessment. Skeletal biologists have long debated whether it is possible to determine whether a woman has borne a child or children from her skeleton. (Mays and Cox 2000, Holt 1978) There are two schools of thought, one believes that parity status can be determined from the skeleton (Putschar, 1931, Houghton, 1975 and Angel, 1969) and the other says it cannot. (Suchey et. al, 1979, Holt, 1978, Snodgrass and Galloway, 2003) The debate continues for the simple fact that skeletal changes can be detected in the pelvic bones. However, no researcher has been able to definitively ascertain what causes these changes.

The purpose of this study was to determine whether parity could be assessed from the bony pelvis, particularly the pubic tubercle. The pubic
tubercle is an appropriate area of the bone to study because it is where the inguinal ligament attaches and in pregnancy, as a woman’s abdomen grows and stretches, so do these ligaments. The stretching of the ligaments leads to remodeling at the sites of attachment.

The current study was modeled after Snodgrass and Galloway’s 2003 study that investigated the usefulness of the height of the pubic tubercle to assess parity. Their study looked specifically at the pubic bone and its utility in determining parity. This was done by measuring the height and distance of the pubic tubercle and also assessing the degree or lack of pitting on the dorsal surface of the pubic bone. Snodgrass and Galloway (2003) also rearticulated the pelves to measure the arcuate angle. They believed that this angle may show changes after a pregnancy. Snodgrass and Galloway found that there is no correlation between the parity status and the height of a woman’s pubic tubercle. However, they did find a relationship between height of the pubic tubercle and other factors such as, the distance of the tubercle from the face of the pubic symphysis. Also, in examining dorsal pitting, they found an association between pitting and the number of children borne. It should also be noted that age and BMI also affected the development of pitting.
Chapter 2: Literature Review

Determining Parturition from the Female Os Coxa

Forensic anthropologists and bioarchaeologists have long debated the question of whether or not parity status can be determined from skeletal remains (Snodgrass and Galloway, 2003). Particularly, they have focused their efforts on the female os coxa. Whether or not markers of parturition can be observed in the female skeleton has long been a point of contention in the field of skeletal biology. Some noted anthropologists believed that it is indeed possible to ascertain whether a woman has borne children from the skeleton alone. Some even believed it was possible to determine how many children a woman had. Other anthropologists do not believe that pregnancy and childbirth leave consistent evidence on the female pelvis.
Determination of Sex from the Pelvis

In order to assess parity, one would need to first determine the sex of the remains. This determination is made to ensure that a male skeleton is not assessed for signs of having borne a child. If the skeleton is determined to be female, then parity assessment can be done. The pelvis has long been believed to be one of the most reliable bones to use for sex determination (Spradley and Jantz 2011).

Hrdlicka (1920) developed handbooks on sex estimation from various morphological features. Krogman (1962), France (1998), and Rogers and Saunders (1994) built upon Hrdlicka’s work with their own ideas on sex determination. Krogman (1962) created a handbook for law enforcement as a guide on how skeletal remains are identified. He included a section on how sexing the remains is accomplished. However, the most important theme in his book is the reminder that human variation should always be considered when skeletal remains are concerned. Rogers and Saunders’ (1994) study looked at each of the ilium, pubis, sacrum and the overall pelvic girdle to determine features that were useful in assessing sex in skeletal remains. Features such as pelvic inlet shape (heart-shaped + male and oval=female) were found to be
reliable indicators of sex. (Ortner, 2003)

The most widely used and accepted method of sex determination is the Phenice method (Phenice, 1969), He examined the ventral arc, concavity of the subpubic region and the medial aspect of the ischiopubic ramus. In females, the ventral arc is present on the anterior aspect of the pubic symphysis. It begins mediosuperiorally and curves ventrally to the ischiopubic ramus. Also in females, the ischiopubic ramus becomes concave just under the symphyseal face of the pubis and is pinched if viewed medially. Males do not have these three pubic traits.

In 2012, Klales et.al looked at the Phenice method of sex assessment. While they did not devise any new traits that could be used to assess sex, they tried to create a more accurate range of expression for each trait. The authors studied how race may affect variation of expression and how experience of an observer affects accuracy of assessment. The purpose of breaking the 3 Phenice characteristics down further was to ensure accuracy and to ensure that nonmetric pelvic sex assessments would meet Daubert standards.
Skeletal Traits Used in Assessing Parturition

If parturition can be discerned, which features of the pelvis are best to use when making this determination? Areas such as the dorsal surface of the pubic bone for pitting, the height of the pubic tubercle, diastasis of the pubic symphysis and grooving of the preauricular area of the ilium have been considered the best areas to review for the hallmarks of parturition.

The preauricular sulcus, an area on the ilium in the greater sciatic notch, was one of the first areas of the female pelvis that was studied for evidence of pregnancy and childbirth. The idea that a groove formed just below the auricular surface of the ilium was proffered by DE Derry at the start of the 20th century (DE Derry, 1909 and 1911). He observed, in the skeletons of ancient Egyptians, that the preauricular sulcus was more pronounced in women and almost nonexistent in men. Noting that this was the attachment site for the ligaments of the sacroiliac ligament, he postulated that the stretching of these ligaments during pregnancy lead to the development of the groove.

Derry’s work built on the original work of researchers such as Zaajer (1893), Lohr (1894), Virchow (1910) and Aeby (1858). These scientists believed that variations observed in the pelvis were most likely attributable to racial
variations. Derry went on to extrapolate that if racial difference causes morphological variations; sex differences may as well. (DE Derry, 1911) These studies laid the groundwork for this author’s the current study in that each postulated that ancestry was responsible for differences in pelvic traits. This led DE Derry and subsequent researchers to extrapolate that sex differences were visible in the pelvis, as well. One major sex difference is the fact that women can and do give birth. If sex differences are expressed in the pelvis, could parturition be one difference that leaves its mark?

Anatomist TW Todd (1921) was one of the first to propose that pregnancy and childbirth did not leave its mark upon the skeleton. Having assembled the skeleton collection, which bears his name (along with CA Hamann); his primary interest was to study pelves to assess age-related changes to the pubic symphysis. A negative aspect of using the bones of the women in the Hamann-Todd collection at the Museum of Natural History (Cleveland, Ohio) is that their provenance was very uncertain. The individuals were often lacking comprehensive demographic information. Thus, Todd felt that determining parity status from female skeletal remains in the collection was near impossible. He cited the lack of accurate demographic information accompanying each
skeleton as the likely reason. This led him to surmise in the same paper (Todd, 1921: 40) that, “I do not believe that pregnancy and child-birth leave any permanent stamp upon the skeleton”. Although, the leap seems to be an untested jump, he may have very well been on the right track.

Anthropologist T. Dale Stewart (1957), whose did extensive work with age assessment using the pubic bones, weighed in with his opinion on dorsal pitting. Dorsal pitting refers to the pits that are sometimes present on the dorsal surface of the pubic symphyses. These pits were once thought to correlate to parity status in women. However, pitting can occur when an individual suffers some form of injury or trauma to the area. It is thought to occur when the ligaments that attach to the dorsal surface become stretched or detached from the bone. He stated that pitting was the result of pregnancy. He also believed, as did many others, that relaxation and stretching of ligaments leaves evidence on the pubic symphysis. What was novel about Stewart’s thinking was that he felt prenatal care or lack thereof affected how damaged the pubic bones became during pregnancy. Many years later, Stewart tempered his remarks with a caveat that changes to the pubic symphysis were primarily age-related, but that some
alterations observed may be attributable to pregnancy and parturition (Stewart, 1957).

A contemporary of Stewart’s, J. Lawrence Angel was a proponent who furthered Stewart’s theory. He believed that dorsal pitting and the number of pits present are indicative of past parturition and the number of children borne by the woman. He cited the previous work of Putschar (1931) and Stewart (1957) as a basis for his theory. (Angel, 1969)

Nils Gustaf Gejvall, a Swedish zoologist and osteologist was asked to give an assessment of a skeleton known as the “Fisherman of Barum” in Stockholm, Sweden. This skeleton dated to the Mesolithic era and the sex of the skeleton had been debated since its discovery in 1939 by Elias Dahr (Swedish zoologist). With regard to sexing the individual, Gejvall consulted noted anthropologist J. Lawrence Angel for help. Angel stated with certainty that the “Fisherman” was actually a female and that the pitting present on the dorsal surface of her pubic bone showed that she had borne 10-12 children. Originally thought to be male, Angel’s assessment was controversial. (Gejvall, 1970)

Around the same time as the “Fisherman from Barum” assessment, two Ascadi and Nemeskeri (1970), Hungarian paleodemographers, hypothesized that
the female pelvis underwent alterations at the micro-anatomical level. They developed a five-phase system of classifying these changes, which ranged from 1-2 pregnancies to over 9. They used Putschar (1931) and Stewart’s (1957) studies as a basis for their classification system. This was considered groundbreaking theory in the field of paleodemography. The theory was so astounding because no one had ever thought to create a classification system that focused on micro changes in the bone. Now, however, their work is considered a stretch of the science that was available at the time. (Ascadi and Nemeskeri, 1970)

As stated previously, J. Lawrence Angel believed that pregnancy and childbirth did indeed leave their mark upon the female pelvis. In 1971, Angel expanded his research and observed that the pubic tubercle forms an “unusual spike” and the pubic bone becomes roughened due to childbirth. He attributed these alterations to the “tearing and stretching” of ligaments that occur while a woman is pregnant and later, during childbirth. (Angel, 1971)

Gilbert and McKern (1973) conducted a study about aging of the female pubis. In their paper, they touched upon parturition and its influence on the morphology of the pubic bone. Like Stewart, they felt that it was not possible to
quantify the number of pregnancies from the female pelvis, but they did subscribe to the theory that pregnancy and childbirth did alter the bone.

Shortly after Gilbert and McKern, Houghton (1974, 1975) also examined the question of determining parity from the female bony pelvis. He expanded upon the theory that the preauricular sulcus was an artifact of pregnancy. Houghton stated that the preauricular sulcus appeared in two distinct forms. These two forms were the groove of ligament (GL) or the groove of pregnancy (GP). He suggested that like on the dorsal surface of the pubic bone, pregnancy would leave a groove that consisted of a series of pits in the preauricular area of the ilium. He postulated that the GP was an exclusively female trait because only women bore children. The GL, which could be found in nulliparous women and men, was thought to be a more straight line attributed to causes other than parturition.

Putschar (1976) presented a completely opposing view from Todd’s 1931 study. Putschar stated in a paper on the topic of parturition and its effect on the pubic symphysis that it is quite possible that childbirth creates visible alterations in the bony pelves of females. He stated the shearing of cartilage during childbirth and the effects of ovarian and pregnancy hormones cause bone
remodeling and resorption at the symphysis that can be visually assessed. In his examination of the pelvis he noted normal human variation focusing on the pubic symphysis. The traits he studied were the median cleft, the retropubic eminence and the osteocartilaginous border of the symphyseal face. He believed that some of the variations may have been generated by pregnancy and childbirth. Lest the males be left out, he also postulated that weight gain in men had similar effects on the pubic bone. Putschar also believed parturition changes were expressed in bone resorption and remodeling on a more microscopic level. He theorized that the stretching on the pelvic ligaments and shearing of the cartilage during pregnancy and childbirth were responsible for the variations. The extension of the pubic tubercle was something he believed could be an indicator of past pregnancy. (Putschar, 1976)

CA Holt (1978) conducted research that seemed to dispel the belief that dorsal pitting is indicative of past pregnancy. He studied 68 female pelves from the Hamann-Todd collection. Each individual had adequate medical documentation of birth history. He found that a significant percentage of women (38%) who had never given birth had severe pitting. Conversely, about 13% of the women who had borne children had very little or no alteration of the pubic
bone. Holt recognized a potential correlation between scarring of the bone and a history of pathology, trauma, occupation or obesity in those women who had scarring and no children.

Further clarification of whether or not dorsal pitting was indicative of past pregnancies in the female pelvis came from Judy Suchey and her team (Suchey et al., 1979). The team conducted a study on 486 female pubic bones of known parity. A slight correlation was discovered between dorsal pitting and the number of full-term pregnancies. As with previous studies, some nulliparous women showed moderate to severe dorsal pitting and some women who had borne children had no pitting. Suchey et al. believed that pitting was, in some cases, an age-related phenomenon.

Expanding on Holt’s (1978) earlier work, MA Kelley (1979) conducted research that used three traits instead of focusing on one. Again the Hamann-Todd collection was used. He assesses the pelves of 198 females looking at dorsal pitting of the pubic symphysis, the interosseous groove at the posterior of the auricular surface and the preauricular sulcus. When the three traits were assessed in combination, the highest correlation with parity occurred. Kelley added a qualification that the bone remodeling of age can obliterate these traits.
and hamper accurate parity assessment. Like most research on the topic, this study only furthered the idea that parity is sometimes expressed in the bony pelvis and sometimes it is not. (Kelley, 1979)

Bergfelder and Hermann (1980) conducted research on changes in the pubis and whether or not these changes can be definitively attributed to parity status. They looked at 49 sets of female pubic bones. The sample had documented information on births and miscarriages. Bergfelder and Hermann ultimately concluded that there was no correlation between the number of births and the extension of the pubic tubercle and protrusion of the rim of the pubic symphysis. They did, in fact, conclude that dorsal pitting seemed to increase in relation to the number of births and that the pubic tubercle became more “slim and conical” in women who have had multiple children. Bergfelder and Hermann did include the caveat that some of these same alterations were noted in childless women and were absent in women who have had children. An interesting condition that they noted was that overall pelvic structure and age were contributing factors.

Dee (1980) conducted a radiologic study using a sample that consisted of the pelves of 100 men and 200 women. Assessment of the preauricular sulcus
was done to determine whether or not it was an exclusively female trait.

In about 2/3 of the male skeletons there was evidence of a slight groove, but it did not appear to be similar to the groove observed in the female pelvis.

Dunlap (1981) also examined the preauricular sulcus and whether its presence was indicative of childbirth. He demonstrated that the presence of the sulcus was always a female trait, but that its absence did not necessarily indicate that the skeleton was a male. He also correlated earlier research that stated that the number of pregnancies could not be determined by changes in the bone. His study corroborated the theory that women with a history of past pregnancies often showed no bony changes at all and women with no reported parity history often have robust changes in the pelvis. Dunlap appears to be one of the first researchers to explore the possibility of unreported pregnancies playing a role in this discrepancy. Although Dunlap believed that pregnancy history might account for the formation of the preauricular sulcus in women, he stated that anomalies in the lumbosacral area or in the sciatic notch might also be the reason for bony changes. He attributed this to the pelvic instability that such anomalies were likely to cause.
A study by Owsley and Bradtmiller (1983) postulated that dorsal pitting; the preauricular sulcus and Schmorl’s nodes could be considered suggestive evidence of parity status. Schmorl’s nodes are herniations in the cartilage of the intervertebral disc which can protrude into the vertebral body and even into adjacent vertebra. These nodes can be asymptomatic or cause great pain and discomfort.

The team assessed these three features when collecting demographic information from archaeological samples. Schmorl’s nodes had the weakest relationship to past pregnancy. However, Owsley and Bradtmiller (1983) believed that because conditions that lead to the nodes, such as trauma and osteoarthritis were absent; pregnancy was a very likely cause. They proffered that the stress of pregnancy on the ligaments and joints of the pelvis may cause the nodes to form.

Cox and Scott (1992) studied the Christ Church, Spitalfields skeletal series. These remains were buried between the early 1700’s-mid 1800’s. The original number of skeletons was 968. Cox and Scott looked at 94 of the 138 known females in the series. These 94 were chosen because each had known historical and demographic data ascribed to it. Four main variables were assessed by the
observers. These were sacral scarring, preauricular sulcus, dorsal pitting and extension of the pubic tubercle. Cox and Scott discovered that there is a negative correlation between presence/depth of the preauricular sulcus or dorsal pitting and parity status. A positive correlation was found, though, between sacral scarring and extension of the pubic tubercle and parity status.

Igarashi (1992) studied whether parturition could be ascertained from the ossa coxae of Japanese women. A basic study using 20 skeletons of which, 16 had borne children and 4 had not. The presence of the preauricular sulcus was assessed using 3 designations, marked, moderate or absent. The conclusion reached by Igarashi was that the pregnancy itself was responsible for leaving its mark on the bone and not the act of parturition. Most likely, the mechanism was the stretching of the ligaments, which influenced the morphology of the bone.

Snodgrass and Galloway (2003) is the one of the most recent studies that looked primarily at parity assessment. In 2003, they examined the pelvises of 148 women. The parity status of these women was known. Their findings found the extension of the pubic tubercle cannot be used to accurately assess parity status because it shows no correlation. However, the distance from the tubercle to the symphyseal face and dorsal pitting were more useful in assessing parturition and
showed stronger correlation. They cautioned that these methods were not accurate and definitive enough to be used in a forensic setting. Snodgrass and Galloway stipulated that the results could very well be attributed to the individual’s body mass. Like others before them, they felt that body mass more strongly impacted the bone morphology than just pregnancy alone. (Snodgrass and Galloway, 2003)

Robert Tague (1988) explored the idea that estrogen plays a role in the resorption of the bone at the pubic symphysis and the auricular surface. He posited that estrogen spurred osteoclastic activity at the sites of ligamentous insertion in the dorsal pubic area and the preauricular area of the ilium. He visually assessed the innominates of three distinct samples; Black human nulliparous females, three populations of archaeological Amerindian samples and African pongids (both chimps and gorillas). After assigning sex and age-at-death for each individual, the degree of resorption was assessed visually. The pubic symphysis and the auricular area were considered separately and independent of each other for each set of innominates. Tague concluded that osteoclastic activity was evident in the symphyseal area more often in women who have borne children. This was expressed as dorsal pitting.
However, it was not significantly be correlated to resorption in the auricular area. Tague postulates that resorption in the pubic area may serve an obstetric advantage by inhibiting synostosis of the symphyseal joint in women of reproductive age.

BC Andersen postulated in her 1986 Ph.D. dissertation that pelvic scarring, in the form of pitting of the dorsal surface of the pubic bone, occurs in nulliparous and parous women. She determined it was not a reliable indicator of parturition. Andersen took this a step further and postulated that pelvic instability is a more likely cause of pelvic scarring. She pointed to factors that may influence the scarring, such as obesity and trauma.

Komar and Buikstra (2008) briefly touch on the issue of parity assessment. They reviewed the most relevant studies on the subject of dorsal pitting, preauricular sulci and extension of the pubic tubercle with regard to each as indicators of parity. They cite the conclusions from Suchey et al. (1979) that dorsal pitting cannot accurately assess the number of full term pregnancies a woman has had in her lifetime. Suchey and her team did conclude that severe pitting on the dorsal surface of the pubic bone more than likely correlates with a female who has experienced a late-to-full term pregnancy. Komar and Buikstra
go on to mention Cox and Scott (1992) who concluded that the presence of the preauricular sulcus or dorsal pitting was not indicative of past pregnancy. They did believe, though, these features resulted from biomechanical stressors imposed upon the skeleton during life. They were the first to notice that extension of the pubic tubercle in the 18th century sample from Spitalfields in England correlates significantly with both past parturition and the number of births.

Komar and Buikstra also touched on the study that was model for the current study, Snodgrass and Galloway (2003). They note that Snodgrass and Galloway concluded, in their study of pubic tubercle height, that extension of the tubercle was more related to pelvic morphology and not really with parity status. A slight correlation between parturition and dorsal pitting was noted in younger females in the study.

Age-related changes to the pubic bone may account for there being no obvious correlation in the older females in the study. Komar and Buikstra are careful to note the caveat by Snodgrass and Galloway that the accuracy of the correlation of dorsal pitting and pregnancy is not accurate enough to be forensically significant.
Ubelaker and De La Paz (2012) published a historical review of all of the studies that have investigated parity assessment and the female skeleton. They summarized the topic over the last 120 years by features such as, dorsal pitting, extension of the pubic tubercle, the preauricular sulcus, trauma and pathology to the pubic area, bone mineralization and overall biomechanics. In summary, Ubelaker and De La Paz (2012) concluded that there is no feature that can be considered a reliable indicator of past pregnancy in female skeletal remains.

In 2014, P. Maass and LJ Friedling conducted an extensive study to determine whether the scars left on a woman’s bony pelvis could be attributed to factors other than pregnancy. The sample for their study came from collections at the University of Cape Town and University of Stellenbosch, both in South Africa. The study population was made up entirely of South African skeletons. The sample contained both males and females. 312 skeletons were assessed for scarring on the dorsal pubic surface, pubic tubercle, preauricular sulcus, interosseous groove and the iliac tuberosity. Along with pelvic measurements, femoral measurements were taken. The above listed features were compared with regard to age and sex. The main focus of the analysis was an assessment of the influence of body size and pelvic size on scarring. Their findings were as
follows: scars were found in both sexes, but were seen more often and with more severity in females. The overall results of the complex set of analyses conducted by Maass and Friedling suggest that weight bearing and stability of the pelvis was most likely a better explanation of pelvic scarring than parturition was in this study. (Maass and Friedling, 2014)

As was stated earlier in this section, the question of parity assessment from the pelvis has long been investigated in the field of forensic anthropology. However, there is still a gap in the research thus far because no one study has definitively determined a reliable skeletal feature that is more often than not indicative of a female that has borne children. The purpose of the current study is to definitively determine whether or not extension of the pubic tubercle is a reliable indicator of parity status. This study is also designed to investigate the reliability of dorsal pitting as a gauge of parturition. Both of these features will be assessed alone and in conjunction with each other.
Chapter 3: Materials and Methods

Study Sample

The study sample consisted of 75 female ossa coxae drawn from the William M. Bass Donated Skeletal Collection at the University of Tennessee. The demographic information collected consisted of the woman’s age-at-death, living weight, living stature and parity status. There was no other identifying information provided. Each sample was labeled with an identifying number that followed the UTK format, “Year of death + the number of the order in which the skeleton was acquired in the particular year”, (i.e., 06-97).

The skeletons analyzed were collected between the years 1999-2008. The youngest individual was 44 years of age at death and the oldest was 93. The mean age was 64.8 years old for this sample. The standard deviation was 12.90. Due to the limited number of non-European-American individuals in the Bass Collection, there are only three individuals of different ancestry represented in this study. There is one East Asian, one Black and one American Indian in the sample. Both parous and nulliparous females were analyzed. For purposes of this study, all ancestries were pooled together. Ancestry was not a key component of the study except for the purposes of having a study that
represented a greater portion of the general population.
Skeletal Measurements

In this study three measurements were taken on each set of pubic bones. The measurement criteria were similar to those of Snodgrass and Galloway (2003).

1. Height of the pubic tubercle: this measurement was taken with digital sliding calipers (to the nearest 0.01 mm). This measurement is defined as the maximum height of the tubercle as it protrudes from the pubic bone. The measurement was taken from the ventral side of the pubic bone.

2. Distance of the pubic tubercle to the symphyseal face: The distance was measured with sliding digital calipers to the nearest 0.01 mm. The measurement is defined as the distance from the most anterior point of the pubic tubercle to the most anterior boundary on the symphyseal face.

3. Dorsal pitting: This criterion was not an actual measurement, but rather a morphological assessment. The dorsal surface of each pubic bone was visually assessed for the presence or absence of pits. Present was noted with a 1 and absent a 0.
All pelves were rearticulated using the “C Ruff Method” and then photographed. (CB Ruff 2005) This method was created by Dr. Christopher B. Ruff of Johns Hopkins University (personal communication) and uses three rubber bands to rearticulate the pelvis, as it would be in life (Figure 1). Each pelvis was photographed from four angles, anterior, posterior, superior and with the symphyseal faces facing forward (Figure 4). The pelves were rearticulated with the intention of measuring the arcuate angle of each one. However, during the rearticulation process, it was determined that each pelvis was too mobile and that the accuracy of the measurement could not be ensured. So the arcuate angles of the pelves were not measured or calculated. Thus, they are not included in this study.

Also, Body Mass Index was calculated for each of the individuals in the sample using the living stature and the living weight. The formula used for this calculation was “Formula: weight (lbs) / [height (in)]² x 703”.

Chapter 4: Results

After all the measurements and photographs were taken, statistical analysis was conducted using the R software program. Parity status was compared with the height and distance of the left and right pubic tubercles. Also, Body Mass Index was calculated for each individual and was compared to the height and distance of the left and right pubic tubercles. Last, dorsal pitting was assessed on a present or absent scale and a correlation was calculated to the number of children an individual had, the woman’s age-at-death and her BMI.
Data Analysis

Descriptive statistics for the sample used in this study are presented in Table 1. The sample consisted of 75 ossa coxae. The age range is between 44 years old and 93 years old. The mean age is 64.8 years old. There is a considerable variation in the heights and weights of the women in the study sample. Living statures ranged from 56.3 inches to 72.01 inches with a mean height of 63.82 inches. Living weights ranged from 80 pounds to 386 pounds with a mean of 160.9 pounds. (Table 1)

Data analysis showed that there may be a slight correlation between age and height (p= 0.055). Though, this is not definitive. Based on the statistical analysis, the overall hypothesis of this study was not proven. The data gleaned from this sample showed that there is no correlation between pubic tubercle height/distance and parity status. Further analysis also showed there is no relationship between BMI and pubic tubercle height and distance.
Table 1 - Descriptive Statistics for Study Sample Measurements

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>76</td>
<td>64.803</td>
<td>12.895</td>
<td>44</td>
<td>93</td>
</tr>
<tr>
<td>Height</td>
<td>76</td>
<td>162.087</td>
<td>7.616</td>
<td>143.000</td>
<td>182.880</td>
</tr>
<tr>
<td>Weight</td>
<td>76</td>
<td>160.862</td>
<td>58.513</td>
<td>80.000</td>
<td>386.000</td>
</tr>
<tr>
<td>Children</td>
<td>76</td>
<td>2.079</td>
<td>1.824</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>L tubercle height</td>
<td>74</td>
<td>4.646</td>
<td>1.928</td>
<td>0.000</td>
<td>9.680</td>
</tr>
<tr>
<td>R tubercle height</td>
<td>74</td>
<td>5.895</td>
<td>5.242</td>
<td>0.000</td>
<td>34.200</td>
</tr>
<tr>
<td>L tubercle distance</td>
<td>75</td>
<td>24.526</td>
<td>6.629</td>
<td>0.000</td>
<td>36.370</td>
</tr>
<tr>
<td>R tubercle distance</td>
<td>75</td>
<td>25.530</td>
<td>4.468</td>
<td>13.050</td>
<td>36.460</td>
</tr>
</tbody>
</table>
When correlations were run between parity status of the females in the sample and the height of the pubic tubercle; there was no correlation shown between the two variables. The correlation of parity status (children/no children) and the height of the left pubic tubercle was $r = 0.179$ with a $p$ value of 0.125. This confirmed the lack of a relationship between whether or not a woman has given birth and the height of the left pubic tubercle ($p > 0.1$). Further analysis was done comparing the distance of the left pubic tubercle from the symphyseal face. There was also no relationship shown ($r=0.161$, $p = 0.163$).

Similar results were achieved in the analysis of the height of the right pubic tubercle and whether or not a woman had given birth ($r=0.002$, $p= 0.98$). These numbers show that there was no significant relationship. Right pubic tubercle distance (from the symphyseal face) and parity status also did not correlate ($r= 0.125$, $p= 0.281$).

Further correlations were run on the number of children a woman had versus the height and distance of the pubic tubercles respectively. Again, there were no significant relationships found. The height of the left pubic tubercle compared with the number of children a woman had given birth to had an $R$-
value of 0.203 and a p value of 0.081. The left tubercle distance had an R-value of 0.036 and a p value of 0.757. The right tubercle had a height of R-value= 0.037 and a p value =0.751. The right tubercle distance had an R-value of 0.007 with a p value of 0.947. These calculations only served to further confirm the lack of a relationship between the number of children a women had with the height and distance of the pubic tubercle. (Table 4)
BMI vs. Pubic Tubercle Height and Distance

The entire theory of this study was built around the hypothesis that the stretching of the inguinal ligaments during pregnancy would spur remodeling and growth of the bony attachments. BMI was calculated and compared with height/distance of the pubic tubercle. The idea being that being overweight would cause the same stretching and remodeling phenomenon as pregnancy.

No relationship was found between Body Mass Index and the height and distance of the left and right pubic tubercle in this study sample. Ranked BMI groups in this study sample (underweight, normal weight, overweight, and obese) were compared to pubic tubercle height and distance bilaterally. No correlation was shown. When polyserial correlation calculations were run between the ranked BMI groups and pubic tubercle height and distance an interesting relationship was suggested. The analysis was suggestive of a relationship between left tubercle distance and ranked BMI groupings “out in the world”. (Table 2)
### Table 2- BMI P values

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>BMI</th>
<th>L tubercle height</th>
<th>R tubercle height</th>
<th>L tubercle distance</th>
<th>R tubercle distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>NA</td>
<td>0.534463</td>
<td>0.266423</td>
<td>0.150167</td>
<td>0.027181</td>
<td>0.287271</td>
</tr>
<tr>
<td>BMI</td>
<td>NA</td>
<td>0.101129</td>
<td>0.85175</td>
<td>0.265048</td>
<td>0.060338</td>
<td></td>
</tr>
<tr>
<td>L tubercle Height</td>
<td>NA</td>
<td>0.532254</td>
<td>0.000617</td>
<td>0.067529</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R tubercle height</td>
<td>NA</td>
<td>8.37E-07</td>
<td>0.067529</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L tubercle distance</td>
<td>NA</td>
<td>9.88E-08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
*Dorsal Pitting and Parity Status*

Three correlations were conducted investigating the relationship between dorsal pitting and parity stats: dorsal pitting and age, dorsal pitting and BMI and dorsal pitting and number of children. No correlation was found between any of the three areas and parity status.

However, logistic regressions with dorsal pitting as the dependent variable and the number of child a woman bore as the independent factor revealed some interesting relationships. Having 3 children increased the logistic odds of dorsal pitting by 2.3 percent. Having 4 or more children marginally increased the logistic odds of dorsal pitting by 1.4 percent. This finding is suggestive of the fact that additional data may show that 4+ children will also significantly increase the logistic odds of dorsal pitting. Additional data would come from a bigger study sample.

Although this is not a robust model due to the small numbers, a relationship between the numbers of children a woman has given birth to and dorsal pitting may be suggested. (Table 3)
<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>Dorsal Pitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Child</td>
<td>1.273</td>
</tr>
<tr>
<td></td>
<td>(0.862)</td>
</tr>
<tr>
<td>Two Children</td>
<td>1.204</td>
</tr>
<tr>
<td></td>
<td>(0.780)</td>
</tr>
<tr>
<td>Three Children</td>
<td>2.303**</td>
</tr>
<tr>
<td></td>
<td>(0.880)</td>
</tr>
<tr>
<td>Four or More</td>
<td>1.455</td>
</tr>
<tr>
<td></td>
<td>(0.842)</td>
</tr>
<tr>
<td>Constant</td>
<td>-1.609*</td>
</tr>
<tr>
<td></td>
<td>(0.632)</td>
</tr>
</tbody>
</table>

Observations: 75
Log Likelihood: -46.331
Akaike Inf. Crit.: 102.662

Note: p<0.1; *p<0.05; **p<0.01
Table 4 - Correlation matrix of women with/without children

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Had kids</th>
<th>Height</th>
<th>Weight</th>
<th>L tubercle height</th>
<th>R tubercle height</th>
<th>L tubercle distance</th>
<th>R tubercle distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>1</td>
<td>-0.00375</td>
<td>-0.22078</td>
<td>-0.11816</td>
<td>0.130862</td>
<td>-0.16894</td>
<td>0.25511</td>
<td>0.124487</td>
</tr>
<tr>
<td>Had kids</td>
<td>1</td>
<td>-0.07662</td>
<td>-0.20445</td>
<td>0.179754</td>
<td>0.002676</td>
<td>0.16327</td>
<td>0.125886</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>1</td>
<td>0.33126</td>
<td>0.123411</td>
<td>0.017047</td>
<td>-0.07662</td>
<td>0.021533</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>0.217353</td>
<td>-0.01386</td>
<td>0.107075</td>
<td>0.108015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L tubercle height</td>
<td>1</td>
<td>0.074812</td>
<td>0.388873</td>
<td>0.220929</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R tubercle height</td>
<td></td>
<td>1</td>
<td>-0.53963</td>
<td>0.213693</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L tubercle distance</td>
<td></td>
<td></td>
<td>1</td>
<td>0.572457</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R tubercle distance</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1- Rearticulated pelvis using the "C. Ruff" method.
Figure 2- Dorsal pitting in a 57 year-old woman with no children. Her living weight was 230 lbs.
Figure 3- Lack of dorsal pitting in a 65 year-old woman with 3 children. Her living weight was 110 lbs.
Figure 4 - Dorsal pitting in a woman who was 60 years old and had 3 children. Her living weight was 171 lbs.
Chapter 5: Discussion

Although it is not a vital component of the biological profile, parity status would serve to enhance the profile and possible aid in identification. Parity status estimation from dry bone would be a helpful and an interesting addition to the biological profile. The goal of this study was to ascertain whether or not parturition can be discerned from skeletal remains, specifically a woman’s pubic bone.

The height of the pubic tubercle did not show any correlation to parity status. Neither did the distance of the tubercle from the symphyseal face of the pubis. These results are similar to those obtained by Snodgrass and Galloway (2003) on whose study this research was loosely modeled.

Also, dorsal pitting did not show any correlation to parity status in this sample. Pitting also did not correlate with age or BMI either. However, when logistic regressions were done between the number of children a woman had and dorsal pitting, there was a marginal increase in the logistic odds of the two being related. This is suggestive of relationship between the two variables. A larger study sample may reveal a more definitive relationship between a higher number of times a woman has given birth and the presence of dorsal pitting in
the pubic bone.

There may be several reasons why this study did not find a relationship between parity status and height and/or distance of the pubic tubercle. First, the sample size may have been just too small to reveal a significant relationship. A larger sample may reveal evidence of parity status in the pubic bone. Second, there may be a relationship between parity status and a combination of pelvic traits that may need to be assessed together. This may yield more definitive results, such as was done in the study by Maass and Friedling, (2014)

Maass and Friedling (2014) conducted a study of 312 individuals from the skeletal collection at the University of Cape Town and University of Stellenbosch in South Africa. Males and females were included, but only individuals that were 20 years of age or older were included in the sample. Five pelvic features were studied. These were the dorsal surface of the pubic bone, the pubic tubercle, the preauricular sulcus the interosseous groove and the ischial tuberosity. Pelvic and femoral measurements were taken and body and pelvic size were taken into account. Scarring was found in the pelves of both sexes. Maass and Friedling suggested that weight bearing and stability of the pelvis was most likely a better explanation of pelvic scarring than parturition was in this study.
Third, the advanced age of most of the individuals in the sample may have impacted the results. The remodeling of bone as an individual ages may alter the bone in such a way as to “hide the evidence” of parturition. (Ortner, 2003) There were only a few younger female skeletons in the William M. Bass Skeletal Collection for analysis. Thus, in addition to a larger sample size, one may need to work with a collection with younger skeletons. (Bouvier and Uberlaker, 1977)

Fourth, the errors in observations and measurements may have been made by the investigator in the current study. Whenever there are measurements and observations made in a scientific study, there is a risk of intra-rater error. (Fish, 1978, Meindl et al., 1985). Future studies should include an analysis of intra-rater reliability.

Biological variation exists in all human skeletons and this is considered “normal” to anthropologists. Therefore, the height and distance of a woman’s pubic tubercle may be attributable to nothing more than her individual structure and development. Thus, the measurements and observations recorded may not be related to parturition. (El-Najjar and McWilliams, 1978)
Chapter 6: Conclusion

Although parity status is not a vital element of the biological profile, it would be a very useful addition to a skeletal identification. So far, there has not been a study that definitively assesses that a woman has had a child solely by examination of her skeleton.

The current study examined the pubic bone on a gross anatomical level. A quantitative and morphological assessment was done and bore no conclusive results. Parity status could not be determined by measuring the height and distance of pubic tubercle or by discerning dorsal pitting of the pubic bone. When BMI was compared to these same three characteristics no significant relationship was shown.

However, examining multiple pelvic indicators together in a multivariate analysis may reveal a link between parturition and changes in the female pelvis. Further, microscopic analysis of the bony pelvis may also provide more valuable information and be a more useful assessment in the future.

Another factor that may affect the results of this study is maceration. Maceration is defined as the softening of tissue by soaking in a liquid or the softening of tissue after death by autolysis.
There are many methods of maceration, most using chemicals and/or heat. Methods of maceration include such things as, mechanical flesh removal, microwave or boiling. The most common method is a heat bath with a mild detergent. It is possible that any procedure to remove flesh from the bone, whether with heat or chemicals may obliterate changes in the bone or create artifacts in the bone that weren’t there originally. Thus, changes in the bony structures and in the bony artifacts that may have been left by pregnancy and childbirth may become obliterated. (Steadman et. al, 2006)

Aging may also play a role in masking the detection of parturition in the female skeleton. Assessing morphological changes to the pubic symphysis is considered to be one of the most reliable areas from which to assess age-at-death. (Buikstra and Ubelaker, 1994) If a woman was pregnant decades earlier, would age-related changes to the pubic bone obliterate evidence of past parturition?

As Todd (1921) states in his description of the tenth and last phase of his pubic scoring system, the symphyseal face displays a reduction in density (rarefaction) and irregular ossification. He also stated that disfigurement of the bone increases with age. It only stands to reason that normal age-related changes to the bones of the pelvis would have an effect on parity detection. The lack of
evidence for a correlation between pubic tubercle height and parity status, both in this study and others, may have a very simple cause. All of the studies to date have approached the problem on a macroscopic level. The bone traits that are observed and measured are all done with the naked eye. Is there a way to assess parturition by looking at the bone on a microscopic level? Just as tree rings show evidence that a tree has survived periods of distress, the bones of the pubic symphysis may show evidence of past stress at the microscopic level.

However, it may just be that childbirth does not leave a permanent mark in the bone and cannot ever be ascertained with certainty from the bony record. Parturition may be one of the major events in a woman’s life that leaves no discernable evidence upon her skeleton.
Chapter 7: Future Directions

Future studies should investigate the effect of parturition on bone at a microscopic level. For example, in 1988, Tague quantified bone resorption on the dorsal aspect of the pubis and the preauricular area with respect to sexing the pelvis. His study showed that only a small portion of female pelves exhibited more severe bone resorption at the dorsal pubis than the males. Thus, making bone resorption a weak feature to use for sex assessment. However, further study of the bony pelvis investigating specifically the evidence of “scars of parturition” on a histological level may eventually show a link.

Another avenue of analysis is computed tomography (CT) scans of the pelvis in living subjects. This would allow for a much larger sample size and it would also allow a researcher to view the bony pelvis of a woman pre-pregnancy and immediately after birth. It would allow for before and after comparisons of the pelvic region from the same individual. This type of comparison may show changes in the bone directly attributable to pregnancy and the act of giving birth.

Additionally, comparison of pelvic CT scans of males and nulliparous and parous females may reveal changes in the bone that cannot be observed in dry bone. The inability to observe changes in dry bone may be due to age-related
alterations in the bone. These alterations likely obliterate evidence of parturition gradually over a woman’s lifespan. Using CT technology would help alleviate this problem.

A study in 2013, (Villa et al., 2013) looked at the use of pelvic CT technology to assess age-at-death. Specifically, they wanted to know whether age-at-death could be assessed from changes to the pubic bone and the auricular surface in recently dead individuals. This study would be a great model for a future study that assesses parturition from CT scan.
References


Vita

Tracy Aurigemma was born in 1969 and raised in Revere, Massachusetts. She is the mother of an 8-year old daughter, Giuliana Michael. Following high school, Tracy attended Salem State University in Salem, Massachusetts where she earned a Bachelor of Arts in Exercise Science. In 2002, she earned a second Bachelor’s degree at the University of Massachusetts, Boston in Biological Anthropology.

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