FETAL-PELVIC DISPROPORTION AND PELVIC ASYMMETRY AS A POTENTIAL CAUSE FOR HIGH MATERNAL MORTALITY IN ARCHAEOLOGICAL POPULATIONS

by

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ABSTRACT

Females of childbearing age are overrepresented in the population of the Kellis 2 cemetery (100-450 AD) in the Dakhleh Oasis, Egypt (Wheeler 2009). The demographic overrepresentation found here may be the result of complications related to childbirth. Clinical literature demonstrates that fetal size is rarely an explanation for failed labor (Cunningham et al. 2001) and the fetuses buried in the Kellis 2 Cemetery at the Dakhleh Oasis were not larger than average (Tocheri et al. 2005), directing the focus to dimensions of the maternal pelvis for evidence of obstetrical issues, such as abnormally compressed pelvises.

To formulate a test for this hypothesis, a total of 50 adults, 24 of which are female, were examined for this study. The sample consisted of individuals from an archaeological population from the Dakhleh Oasis, Egypt as well as from six populations housed in the American Museum of Natural History (NYC). These include archaeological populations from the sites of El Hesa and Sai Island in the Sudan, also South Africa, Nubia, and India, as well as a medical collection from North America. Pelvic dimension and asymmetry was determined through nine measurements of the pelvis and sacrum.

Kruskal-Wallis tests were used to analyze variance and assess whether the younger females in this group may have been at a higher risk of death during childbirth due to fetal-pelvic disproportion. Mann-Whitney-Wilcoxan nonparametric tests were used to assess differences in asymmetry in young and old groups. A MANOVA test assessed overall variation in the population. Results indicate significant differences between young and old females in pelvic outlet anteroposterior diameter, a measure of midpelvic contraction, as young females had smaller pelvic outlet anteroposterior diameters. There were also significant differences between young and old females in alar-pubis length asymmetry; the young females were more asymmetric. These differences were not found in the male groups. It is suggested that these differences could impact childbirth as a contracted midpelvis, such as that found in the young female group, can cause transverse arrest of the fetal head (Cunningham et al. 2010) and pelvic asymmetry can contribute to obstetrical complications (Campbell et al. 2011).

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CHAPTER 1: INTRODUCTION

Females of childbearing age and fetuses are overrepresented in the population of the Kellis 2 cemetery (Wheeler 2009), perhaps as a complication of childbirth related to abnormally compressed pelvises, a characteristic that is not compatible with viable childbirth. This cemetery has excellent preservation and shows demographic patterns that may be difficult to detect in populations with poorer preservation or sample sizes. The clinical literature shows that fetal size alone is rarely the explanation for failed labor (Cunningham et al. 2001); this leads to a focus on the dimensions of the maternal pelvis instead for osteological evidence of obstetrical issues. A group of individuals from an archaeological population from the Dakhleh Oasis, Egypt and from archaeological populations from the sites of El Hesa and Sai Island in the Sudan, South Africa, Nubia, and India, as well as a medical collection from North America was examined to determine if these groups displayed compressed or asymmetrical pelvises that may have resulted in complications in childbirth as the females in the Kellis 2 cemetery are hypothesized to show.

The purpose of this thesis is to formulate and test a hypothesis for determining whether the young women in this study sample were dying during childbirth. My hypothesis is that young females will exhibit more contracted pelvic dimensions and/or greater pelvic asymmetry than older, potentially multi-parous females and will have significantly different pelvic dimensions than the older women.

Before testing this hypothesis, the mechanics of childbirth and pelvic morphology is discussed. First normal labor is examined, followed by consideration of issues in labor that stem from abnormally shaped or sized pelvises. Special consideration is given to labor issues prevalent in adolescent primigravidae as individuals in archaeological populations often experienced pregnancy and childbirth in adolescence. Issues in both pregnancy and labor are considered here. Attention is then given to the different potential shapes of the human pelvis and the factors that influence pelvic shape. There are four basic pelvic shapes: gynecoid, android, anthropoid, and platypelloid. These shapes are influenced by activity patterns and nutrition in childhood and adolescence before the pelvis has fully ossified, and each has different rates of operatic intervention in labor associated with them. In addition to these four shapes, pelvises may be compressed, or asymmetrical resulting in serious obstetrical implications. Climate also plays an important role in pelvis shape and size. Fetal-pelvic disproportion in both modern clinical literature and archaeological groups is then reviewed, as this may be an important cause of death in archaeological populations. This discussion includes risk factors in mothers as well as different issues that may arise when fetal-pelvic disproportion occurs. Finally, general obstetric issues in modern and archaeological populations are discussed as these, while more difficult to study archaeologically, most likely accounted for many obstetrical deaths in the past.

Consideration then shifts to the materials and methods employed in this analysis. Age and sex composition of the groups studied are examined and methodology is extensively discussed. Results of this analysis are then presented and compared to relevant populations in the discussion and conclusions.

CHAPTER 2: LITERATURE REVIEW

Mechanics of Childbirth

There are many changes to the maternal pelvis and fetal position during labor. The pelvis changes shape due to the hormone relaxin, which makes ligaments more pliable to increase the size of the birth canal (Tague 1994). There are only marginal changes to the inlet circumference due to relaxin, however, the pelvic outlet can increase up to 20-30% in area during this process (Russell 1969). The fetus also changes position several times through the progression of labor. Fetal lie describes the position of the long axis of the fetus to the long axis of the mother and can be transverse, oblique, or longitudinal; more than 99% of labors have a longitudinal lie (Cunningham et al. 2010). Fetal position is most common with the fetal vertex displaying towards the maternal cervix (Arulkumaran 1996). Malpositions include those where the fetus is pointing to the sacrum or sacroiliac joint. Fetal presentation is generally cephalic, with the head presenting, but can be breech, with the feet or buttocks presenting, or transverse, with the shoulder presenting (Cunningham et al. 2010); dysfunctional labor occurs in these presentations more commonly than it does with a cephalic presentation (Arulkumaran 1996). Breech presentation is more common in preterm gestations than full term (Gillogley 1991).

The first fetal movement in the labor process is the descent (Cunningham et al. 2010), and can vary between nulliparas and multiparas. In nulliparous women, fetal engagement with the pelvis may occur before labor begins and descent follows during the second labor stage, while in multiparous women descent begins with engagement. Fetal descent accelerates at the terminal portion of maternal cervical dilation as the cervix retracts around the presenting part of the fetus (Cohen 1999). In normal cephalic labor, the fetus rotates as it descends to the pubic symphysis. The fetal head then extends from its flexed position as it reaches the pelvic floor (Cunningham et al. 2010). The perineum and vaginal opening is distended and the occiput head slowly emerges. The fetus then rotates again so that one shoulder is anterior to, and the other posterior to, the pubic symphysis. The anterior shoulder is then delivered followed by the posterior shoulder. After the shoulders are clear the remainder of the fetal body soon follows (Figure 1).

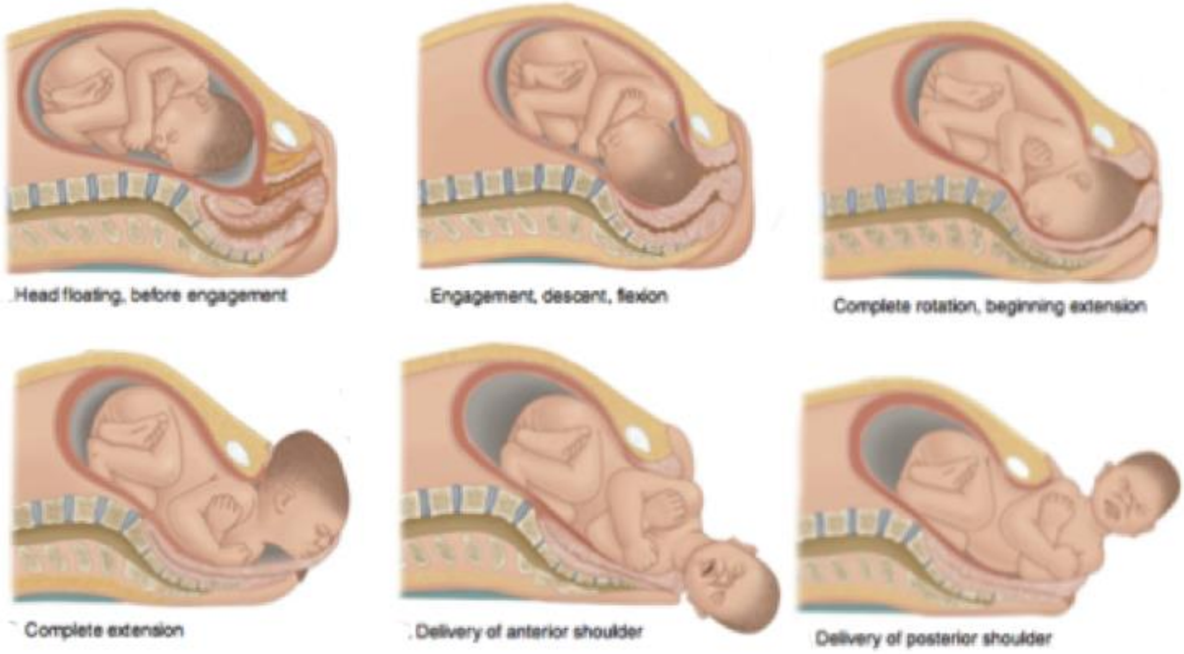

Figure 1: Stages of the normal birth process (adapted from Cunningham et al. 2010).

Normal labor in the mother begins with uterine contractions that cause dilation and effacement of the cervix (Cunningham et al. 2010). There are three stages of labor; the first stage begins with the beginning of labor and ends with complete cervical dilation; the second stage begins with complete cervical dilation and ends with the delivery of the infant; and the third stage begins at the delivery of the infant and ends with the delivery of the placenta. The first stage includes latent and active phases of labor. The latent phase of labor begins with the preparatory division, which includes changes in connective tissue but no cervical dilation. This is when the mother begins to have regular contractions. The active phase of labor begins the dilatational division in which cervical dilation is quite rapid. The second stage of labor begins with complete cervical dilation and ends with infant delivery (Cunningham et al. 2010, Arulkmaran 1996). While variable, on average this stage lasts 50 minutes in nulliparous women and 20 minutes in multiparous women; modern medicine advocates instrumental delivery after one hour as fetal distress can occur if this stage is extended (Arulkmaran 1996). The descent of the occiput is described above. The pelvic division of labor follows the dilatational division with continued but slowing cervical dilation and movement of the fetus through the stages outlined above: first engagement with the pelvis, flexion, descent, internal rotation as the fetus descends to the pubic symphysis, extension and finally external rotation as the head then shoulders are delivered (Cunningham et al. 2010). The perineal phase of this stage of labor causes the sensation of bearing down as the presenting part of the fetus applies pressure on the rectum (Arulkmaran 1996). The third stage of labor involves the delivery of the placenta. Some clinicians include a fourth stage of labor that encompasses the hour following delivery in which postpartum hemorrhage is most likely to occur.

Issues in the first stages of labor can include a prolonged latent phase of labor (Cunningham et al. 2010). A prolonged latent phase is one that is longer than 14 hours in multiparous women or 20 hours in nulliparous women (Cohen 1999). Prolonged labor is associated with postpartum hemorrhage, uterine rupture, and maternal infection and is a significant cause of death in childbirth (Arulkmaran 1996). It may also end with obstructed labor. If labor is dysfunctional and is allowed to continue for a prolonged time, it becomes less likely that the dysfunction can be corrected (Dudley 2008). In the active phase of labor, labor can be protracted or arrested (Cunningham et al. 2010). Protraction occurs when cervical dilation or fetal descent progresses but is slower than normal while arrest of dilation occurs at two hours with no cervical dilation change and arrest of descent occurs at one hour with no fetal descent change; arrest of dilation is usually caused by ineffective uterine contractions (Dudley 2008). Both protraction and arrest of descent can be caused by fetal-pelvic disproportion and fetal malposition (Cohen 1999). Protraction disorders are caused by cephalopelvic disproportion in 30% of cases and that arrest disorders are caused by it in 45% of cases (Cunningham et al. 2010). Fetal malposition and excessive sedation can also contribute to both disorders and different complications can arise from them. Problems in the second stage of labor often stem from fetal malposition (Arulkmaran 1996). Difficult instrumental delivery and shoulder dystocia can occur after a prolonged first then second stage.

Age Related Issues in Labor

There are many obstetrical implications of pregnancy and delivery in adolescent women. While delivery may be successful, risk of many complications is increased. These risks are highest in the youngest girls and decrease as individuals approach 20 years of age. Risk of low birth weight, prematurity, and small size for their gestational age is increased in adolescents (Fraser et al. 1995). Even when sociodemographic factors such as prenatal care level, marital status, and education level were controlled for, teenagers, even those 18 and 19 years old, had significantly increased risk for these issues compared to 20-24 year old mothers.

In Lewis and Nash's (1967) study of pregnancy in 103 women under the age of 16, 96% of women were able to deliver vaginally. In total, 20% of women were pre-eclamptic and one woman had eclampsia. These rates were also found in Utian's (1967) study of 100 women in the same age group of women (under the age of 16) in Cape Town in which 21% of these women were found to be pre-eclamptic in contrast to the control group of 22 year olds, of which 12% were pre-eclamptic. Lewis and Nash (1967) state that pregnancy and labor in the group of women under 16 typically proceed without difficulty. In contrast, Utian (1967) found a tendency of the group of women under 16 years to begin labor before full term; 13% of this group began labor at 36 weeks in contrast with 6% of the control group. Prematurity rates in the study group were also at 10% in contrast to 3% in the control group. Overall, 36% of the group under 16 developed pregnancy toxemias while only 17% of the control group did. Also, the study group was more likely to develop the more severe forms of pre-eclampsia. Goldberg and Craig (1983) also found that pregnancy induced hypertension, in which they grouped pre-eclampsia, and was the most common problem in women under 16 years; this occurred in 62.5% of 128 women in their study. This may have been exacerbated by the poor antenatal attendance of the women in this study. In total, 11.7% of this group had premature labor, 12.5% were anemic, and 4.7% had antepartum hemorrhages. However, only 11 cesarean sections were performed and only two were due to fetal-pelvic disproportion.

Higher rates of complications in pregnancy were also found in adolescents under the age of 16 years in Upper Egypt (Rasheed et al. 2010). In contrast to Fraser et al. (1995), in women older than the age of 16 the risk of obstetric and neonatal complications was found to be comparable to that in women between 20-30 years of age. Rasheed et al.'s (2010) study analyzed 2153 primigravidae under 19 years of age as well as 3162 primigravidae between 20-30 years of age at the Sohag University Hospital, Sohag, Egypt. While rates of low birth weight and postpartum hemorrhage were comparable between the study and control groups here, there was significantly increased risk of several other complications in the adolescent age group, including ectopic pregnancy, pre-eclampsia, preterm labor, and cesarean delivery. All of these were highest in mothers under 15 years of age and reached the adult rates at approximately 16 years of age. Rates of cephalopelvic disproportion severe enough to result in cesarean delivery were much higher in the adolescent age group; this was the indication for cesarean delivery in 26% of adolescents versus 9% of the older group. In the group of adolescents here, pregnancy occurred within marriages and was planned in 94% of instances; psychological instability of the young mothers causing issues in pregnancy was therefore as likely as was biological immaturity of the cervix and uterus.

Similar results were found by Clark (1971) in analyzing clinical data over 11 years from 1104 adolescents from Freedmen's Hospital and a home for pregnant girls in Washington, D.C. The average age for these women was 16 years; the individuals ranged in age from 10-16 though less than 4% of individuals were less than 14 years of age. Overall, 16% of patients developed toxemia; this rate was five times greater than that found in older patients. In patients without prenatal care this incidence rose to 23% of women. Additionally, 14% of adolescent patients delivered prematurely. Only nine patients had cephalopelvic disproportion, these disproportions were fairly evenly divided between contraction of the pelvic inlet and the midpelvis. Cesarean delivery was only used in 1.3% of adolescents in this study.

Overall, adolescents were able to successfully deliver infants at similar rates as older women but were at much higher risk of several serious pregnancy complications. Pre-eclampsia, hypertension, and toxemia were especially prevalent in younger age groups (Lewis & Nash 1967, Utian 1967, Goldberg & Craig 1983, Rasheed et al. 2010, Clark 1971), as was premature delivery (Utian 1967, Fraser et al. 1995, Rasheed et al. 2010), low birth weight (Fraser et al. 2010), and cephalopelvic disproportion (Rasheed et al. 2010).

Pelvic Morphology

There are several potential shapes of the female pelvis (Cunningham et al. 2010). These shapes are greatly influenced by climate, nutrition, and activity patterns in childhood and adolescence before the pelvis has reached skeletal maturity (Abitol 1996, Greulich and Thoms 1938, Nuger 2008). Three general patterns of the female pelvis are here discussed: normal pelvises, contracted pelvises, and asymmetrical pelvises.

Normal Pelvises

Many factors contribute to the determination of shape in the female pelvis (Abitol 1996). Physical activity during adolescence and age at the acquisition of erect posture in particular play a large role in shaping the growing pelvis. While male pelvises are almost always purely android in form, the female pelvis shows much more variability. Pelvic shapes include gynecoid pelvises that are circular, android pelvises that are triangular, anthropoid pelvises that are ovoid anteroposteriorly, and platypelloid pelvises that are ovoid transversely (Figure 2, Cunningham et al. 2010). Android, anthropoid, and platypelloid pelvises can cause suboptimal birth canal shapes (Arulkumaran 1996). Pure gynecoid pelvises only accounted for 38% of pelvises in Abitol’s (1996) study of radiographs of 611 pregnant women. The remaining pelvises were divided between android pelvises (24%), anthropoid pelvises (25%), and platypelloid pelvises (4%) with the remainder unclassified. While the normal human pelvis is midway between anthropoid and platypelloid shapes, these shapes may be the result of differences in time of acquisition of erect posture in childhood. Other factors in the formation of pelvic shape in humans include obstetric requirements, hormones, and environmental and cultural features.

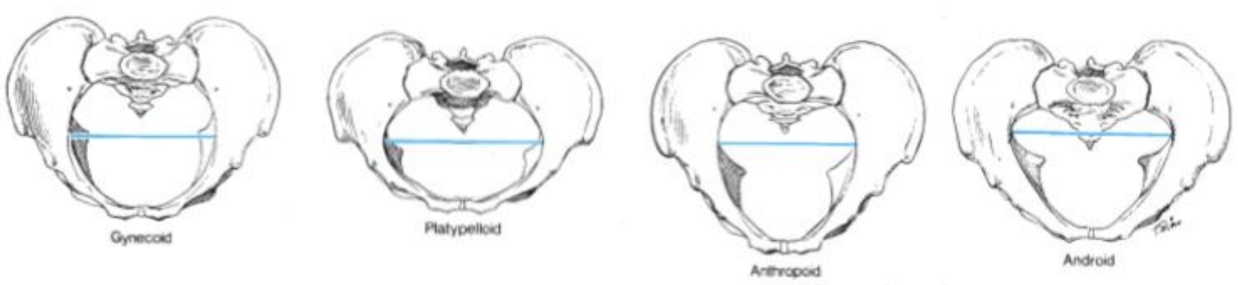

Figure 2: Different pelvic shapes (adapted from Cunningham et al. 2010).

Abitol (1996) found that vigorous physical activity was associated with android pelvises as 84% of females with android pelvic shapes reported moderate to intense physical activity in adolescence before the pelvis is completely ossified, while the majority of individuals with other pelvis forms did not report strenuous activity. In total, 2/3 of the individuals who had reported vigorous activity in adolescence had android pelvises. Age when the individual first stood up unaided was also associated with different pelvic shapes; this was studied in 154 individuals with written records of age when they first stood unaided. The average age for acquiring an upright posture was 14 months, which was associated with both gynecoid and android pelvises. Anthropoid pelvises were associated with late acquisition of upright posture, while platypelloid pelvises were associated with early and very early standing. Platypelloid pelvises are also associated with pelvic deformity due to rickets (Thoms 1947).

Greulich and Thoms (1938) studied case records for 600 white primimarous women at the New Haven Hospital. They classified pelvis shape by the relationship of pelvic inlet transverse diameter and anteroposterior diameter. They found the least amount of operative intervention while giving birth among those individuals with anthropoid pelvises, as only 16.3% of women with anthropoid pelvises required such intervention. Operative intervention here included cesarean section, version extraction, outlet forceps, and midplane forceps delivery. Those women with gynecoid pelvises had the second lowest level of operatic intervention with 18% necessitating intervention, followed by women with android pelvises with 19.5% requiring intervention. Android pelvic shapes can cause deep transverse arrest of the fetus as they become smaller inferiorly (Dudley 2008). Android pelvises are particularly problematic if the fetus is in certain malpositions, as it can cause poor descent. Women with platypelloid pelvises had the highest rates of requiring intervention in this study, with 30.7% of these women needing intervention (Greulich & Thoms 1938). This pelvic shape can cause transverse arrest of the fetus (Dudley 2008). Greulich and Thoms refer to these pelvic shapes as dolichopellic, mesatipellic, brachypellic, and platypellic respectively. Greulich and Thoms (1938) found that among the different groups they studied, the group of student nurses was both from a more privileged economic background and was more likely to have anthropoid or gynecoid pelvic shapes than individuals from less privileged backgrounds were. Therefore, adequate early nutrition and attainment of normal body size made it more likely that these women would have anthropoid or gynecoid pelvises, the pelvic shapes that were more suitable for successful childbirth.

Climatic adaptations can also affect pelvic dimensions (Nuger 2008). Nuger found a significant relationship between latitude and transverse pelvic inlet, midplane, and outlet diameter; larger pelvic dimensions were found in higher latitudes and colder climates while smaller pelvic dimensions were found in lower latitudes and hotter climates. While female transverse pelvic inlet diameter is significantly correlated with latitude, male transverse pelvic inlet diameter is not significantly correlated with any measure of climate. This relationship is significant when controlling for body size. In Nuger's (2008) study, anteroposterior dimensions were not as consistently correlated with climate or latitude. Bergmann's Rule shows that broader body breadth is selected for in colder climates while thinner body breadth is selected for in warmer climates. This causes selection pressures on the female pelvis as larger individuals are more likely to have larger infants and conversely, smaller individuals will be more likely to give birth to smaller infants (Nuger 2008). There are also climate pressures on the infants as larger infants are more likely to survive in colder climates as they have better thermoregulation while smaller infants are more likely to thrive in hotter climates as they will cause less thermoregulatory stress to their mother (Nuger 2008). The larger infants in colder climates would therefore select for larger pelvic size while smaller infants in hotter climates would not exert this pressure.

Another aspect of pelvic morphology is the changes that occur in the pelvis with parturition. Kelley (1979) analyzed the relationship between dorsal pubic pitting, pre-auricular grooves, grooves at the interosseous ligament insertion site, lipping at the dorsal pubic margin, and sacral pitting in a sample of 198 females from the Hamann-Todd osteological collection. The latter two features were not included in the final analysis as sacral pitting was quite rare in the sample population and dorsal pubic margin lipping reflected degenerative arthritis and occurred in nulliparous and multiparous women arbitrarily. Of the remaining three traits, dorsal pitting is absent in 77% of nulliparous women and 56% of multiparous women, a preauricular groove is absent in 54% of nulliparous women and 21% multiparous women, and an interosseous groove is absent in 67% of nulliparous women and 36% of multiparous women. Conversely, dorsal pitting is present in 23% of nulliparous women and 44% of multiparous women, a preauricular groove is present in 45% of nulliparous women and 79% multiparous women, and an interosseous groove is absent in 33% of nulliparous women and 64% of multiparous women. While these traits are not conclusive as to parity status on their own, the combination of all three traits may indicate parity status, although ambiguity may still persist. Other authors have found that osteological changes in the pelvis are more likely to be age related than reliable indicators of parity (Suchey et al. 1979). Additionally, any signs of parturition become obliterated in elderly females (Kelley 1979).

Compressed Pelvises

Several authors have found age related size differences in female pelvises. In Tague's (1994) study of pelvic size and age at death in prehistoric Native American populations, significant differences were found in the linea terminalis length between the young (18-24) and old (25 and older) female groups. There was no difference in the male groups. Tague (1994) postulated that this difference could either occur due to differential survivorship based on pelvic size or due to continued pelvic growth into adulthood in females. Tague ultimately concluded that the differences found were more likely a result of continued growth in female pelvises into adulthood as longitudinal studies of radiographs of males and females between 8 and 18 years of age showed significant growth in females in late adolescence but not in males (Moerman 1981, Coleman 1969).

However, these conclusions may not always be accurate for modern skeletal samples. In Fuller's (1998) attempt to recreate Tague's (1994) results, no significant differences were found in the pelvises of the young and old females measured. The measurements were from African-American and European-Americans from the Hamann-Todd collection and African-Americans from the Terry Collection. While Fuller measured pubic length with chords instead of Tague's linea terminalis arc, it was found that that the chords are approximately equivalent to Tague's measurements. One possible explanation for the differences between Tague's (1994) prehistoric Native American group and Fuller's (1998) modern African-American and European-American groups is the difference in age at menarche between them (Fuller 1998). Moerman (1982) found that pelvic capacity was very influenced by age at menarche and that an important amount of growth in the pelvis occurs during the first year after menarche. Greulich and Thoms (1944) and Clark (1971) found that once remodeling during puberty is over, the pelvic inlet only grows a small amount; menarche follows the puberty growth spurt closely (Fuller 1998). Therefore if the prehistoric Native American groups that Tague (1994) studied had an age at menarche during late adolescence then the pelvic bone growth would continue longer than in the modern groups Fuller (1998) studied that have an earlier age at menarche (Fuller 1998).

Pelvic size is also very affected by nutritional status. Small pelvises in one archaeological Nubian population are likely a result of reduction in overall body size due to meager resources (Sibley et al. 1992). Sibley et al. analyzed 36 females from a well-preserved medieval cemetery in Kulubnarti in Sudanese Nubia. There is considerable evidence for nutritional or physiological stress in this group as there were high rates of enamel hypoplasia and porotic hyperostosis, exceptionally high infant mortality, and reduced stature. The females studied ranged between 19-44 years of age. Anteroposterior and transverse diameters of the pelvic inlet, midpelvis, and outlet were taken, as were the oblique diameter of the pelvic inlet and the posterior-sagittal diameter of the midpelvis. These pelvic measurements were compared to modern American obstetric standards to assess potential issues in labor. The Nubian pelvises were smaller overall than American pelvises and up to one half of them would be considered contracted in at least one plane. The most common areas of contraction include the inlet transverse diameter (67% contracted) and midpelvic posterior sagittal diameter (84% contracted). Additionally, 33% of the females had moderate inlet contracture; successful delivery with these dimensions is considered borderline. When compared with Tague's (1986) Native American pelvic measurements, the Nubian individuals had smaller, more contracted pelvises, which are significantly smaller than the Native American pelvises in most dimensions. Fetal-pelvic disproportion in this group is difficult to estimate however, as proportionally smaller infants may reduce stress here.

Asymmetric Pelvises

Asymmetry in pelvic dimensions is one factor that may cause difficulties in childbirth. Pelvic asymmetry can also cause leg length asymmetry (Badii et al. 2003). Badii et al.'s (2003) study of symmetry in iliac crest height found that asymmetry of greater than 5mm only occurred in 5.3% of the 323 pelvises evaluated; the authors measured distance between the iliac crest and acetabulum from CT scans and used every pelvic and abdominal CT scan taken in two months in one institution. Campbell et al. (2011) found that significant amounts of asymmetry were present in several pelvic dimensions in young females but not in old females. Campbell et al.'s study involved 45 young females (18-24 years), 51 old females (25+ years), 16 young males (18-

24 years), and 48 old males (25+ years) from four archaeological Native American populations from New Mexico and Alaska. Measurements evaluated included greater sciatic notch width, iliac blade length, alar-pubis length, and sacral-ischial spine length. The young female group had significant amounts of asymmetry in greater sciatic notch width, alar-pubis length, and sacral-ischial spine length while old females did not have significant asymmetry in any dimension. Campbell et al. (2011) concluded that these differences suggest that the young female group may have suffered from greater stress levels during childhood and adolescence, which may contribute to both pelvic asymmetry and mortality; pelvic shape is affected by vitamin D deficiency, childhood nutritional status, and activity patterns in childhood and adolescence (Abitol 1996, Greulich and Thoms 1938). The differences may also suggest that the greater amount of pelvic asymmetry may have contributed to death in childbirth.

The human pelvis is extremely sexually dimorphic and growth patterns in males and females are accordingly very different. In females, pubic length, ischium height, biiliac diameter, inlet transverse diameter, and midplane transverse diameter have significant growth continuing after stature growth ceased (Moerman 1981). Females show greater growth in ischium length, sacrum breadth, and outlet transverse diameter than males do, although these dimensions continue to grow after stature growth ceases in both sexes. Growth is greater in females than in males at all points on the pelvis between 9 and 18 years of age (Coleman 1969). The pubis border also has different completion times as the inferior border of the pubis is generally complete by 18 years of age in females and males while the superior border may continue to grow in females between 20 and 30 years of age (Tague 1994).

Fetal-pelvic disproportion

Fetal-pelvic disproportion is one postulated cause of maternal mortality in the population represented in the Kellis 2 cemetery at the Dakhleh Oasis. Although cephalopelvic disproportion is usually rectified with cesarean section in modern cases, this was not a viable option for much of human history.

Modern

Fetal-pelvic disproportion can arise from contraction of the pelvic inlet, midpelvis, or pelvic outlet or any combination of these (Cunningham et al. 2010). A contracted pelvic inlet can cause abnormal fetal presentation, as the fetus is unable to descend into the pelvic cavity before labor begins as it does in normal labor. While cephalic presentations are still the most common, the fetal head may rest in the iliac fossa or float freely over the pelvic inlet. This allows the fetus to assume other, more dangerous, positions with little encouragement; the incidence of face or shoulder presentations is three times as high and umbilical cord prolapse occurs five times as frequently. Breech presentation coupled with cephalopelvic disproportion is especially dangerous as there is a risk that the fetal head will become entrapped (Hofmeyr 1991). Contracted midpelvises are more common than contracted pelvic inlets or outlets and can cause transverse arrest of the head of the fetus (Cunningham et al. 2010). This can be resolved with midforceps operation or cesarean delivery. Pelvic outlet contraction is generally associated with midpelvic contraction and is rare on its own. It does not generally lead to dystocia but can cause perineal tearing. The size of the fetus by itself rarely causes fetal-pelvic disproportion or failed labor; the fetus is of average size in most cases of fetal-pelvic disproportion. The most frequent cause of cesarean delivery in the United States is dystocia in some form (Cunningham et al. 2010).

Selin et al.'s (2008) study of dystocic labor in Sweden found that primiparity and cephalopelvic disproportion were both risk factors for dystocic labor. Even when maternal age, pre-pregnant body mass, and gestational age are controlled for, women who underwent emergency cesarean delivery due to protracted labor had narrower pelvic outlets than those who deliver vaginally (Stålberg et al. 2006).

Steer (2006) postulates that preterm birth is an adaptation to fetal-pelvic disproportion in African women. A 13-year study in London found that infants born to African women were born between 24-31 week gestation 2.5 times more often than white infants (Steer 2006). These premature African infants had lower gestation specific perinatal mortality than European infants. This occurred because the African infants were less likely to have jaundice and respiratory problems than their European counterparts; African infants that were not premature had higher gestation specific mortality than European infants of the same age. African women had the highest cesarean section rates in the study, a further indication that their full-term infants were difficult for these women to deliver.

Historical

One potential example of historic fetal-pelvic disproportion comes from an Anglo-Saxon cemetery at Worthy Park. This female was buried with an infant between her legs; the infant's head was proximal to her knees while its legs and feet were in her pelvis (Hawkes & Wells 1975). The female's pelvis had a slightly android shape and smaller pelvic brim anteroposterior diameter than typical; this dimension was 90 mm although measurement points were not reported. The pelvis also features a narrow sub-pubic angle and somewhat deep vertical depth; from the pelvic brim to the ischial tuberosity was 97 mm. Overall the dimensions of this pelvis would present some obstruction to passage. Additionally, the infant found in the burial was significantly larger than the average infant size found in the similar Owslebury cemetery; the body size inferred from bone length indicates that this infant weighed between 4000-4500 g. The cause of death of this female and infant may be due to the combination of a slightly constricted pelvis, and a larger than average infant. However, the unusual position of the infant suggests several other potential explanations such as a delivery that was arrested due to an umbilical cord that was either too short or wrapped around the infant's neck or a coffin birth.

A similar example was presented by Cruz & Cohia (2010). A female skeleton was found with a full-term infant in the pelvic area in a Portuguese cemetery dating to the 18th century. The female skeleton was buried in the Christian tradition with head to the west, feet to the east, and in a supine position. The infant bones were mainly in the pelvic channel, between the lumbar region and onto the pelvis. The female was between 25-30 years of age and had poor dental health. The infant's length places it in the 95th percentile of modern growth charts. In contrast, the mother had an estimated stature of 145.7±5.92 cm. Unlike Hawkes and Wells' (1975) burial, this infant was probably buried while still in utero. Cruz and Cohia (2010) state that the large size of the infant, coupled with the relatively small size of the mother, probably caused death during labor due to fetal-pelvic disproportion.

General obstetric problems

Modern

There are also many obstetric issues that can arise that are not due to skeletal size or shape and are not reflected in the skeleton. Noncephalic presentation in vaginal deliveries, when not accompanied by medical intervention, results in higher mortality and morbidity in mothers and infants than cephalic presentations do as a result of the mechanics of delivery (Sekulic 2000). Cephalic presentations occur when the fetal head is the presenting part and occur in 96.8% of labors (Cunningham et al. 2010). Noncephalic positions include breech presentations with the feet or buttocks presenting in 2.7 % of labors and transverse presentations with the shoulder presenting in 0.3% of labors. Noncephalic presenting fetuses can be impossible to deliver vaginally (Sekulic 2000). The fetus' cephalic presentation is largely gravity driven; the pregnant female posture favors this fetal position. Before the 24th week of gestation, the fetus will shift position more than it does afterwards. The percentage of fetuses in a cephalic position increases steadily between the 24th and 35th weeks of gestation and cephalic position is very stable after the 35th week of gestation. However, several conditions can cause other presentations of the fetus, including a gestational age of less than 35 weeks and some diseases of the fetus, such as those in some muscle, peripheral nervous system, spinal cord and brainstem, and osseous-articular system diseases. Other causes include the inability of the fetus to turn or move, causing noncephalic presentation (Sekulic 2000).

Another obstetric risk is maternal obesity (Djelantik et al. 2011, Cunningham et al. 2010). Djelantik et al.'s study of 7871 women in Amsterdam showed that women who were obese before becoming pregnant were more likely to have infants large for their gestational age, preterm infants born between 32-37 weeks gestation, and extreme pre-term infants born before 32 weeks gestation than women who were not obese. All of these outcomes place the infants at higher risk of perinatal morbidity and mortality. Obesity is also associated with subfecundity and increased risk of preeclampsia, cesarean section, emergency cesarean section, and gestational diabetes (Cunningham et al. 2010).

One especially severe obstetric risk to both mother and infant is shoulder dystocia. Here one or both of the infant's shoulders fail to deliver without intervention. There are different levels of shoulder dystocia ranging from difficulty in delivery to operatic intervention (Cuningham et al. 2010). Most commonly shoulder dystocia occurs when the fetus's posterior shoulder enters the maternal pelvis before the anterior shoulder has passed the pubic symphysis (Sriemevan et al. 2000). If the fetus is large or the pelvis is contracted, both shoulders can be trapped at the pelvic inlet (Cohen 1999). Shoulder dystocia is very unpredictable, but the most important risk factor here is macrosomia (abnormally large infant size) (Hofmeyr 1991, Sriemevan et al. 2000); maternal obesity, diabetes, and advanced maternal age all increase risk of macrosomia. This does not factor in all cases though, as 50-60% of infants who experience shoulder dystocia weighed less than 4kg (Sriemevan et al. 2000). Other factors that are associated with shoulder dystocia include multiparity, maternal obesity, abnormalities in the active phase of labor, and short maternal height (Mazouni et al. 2006, Gemer et al. 1999). Complications in infants from shoulder dystocia may stem from decreasing umbilical artery pH after fetal head delivery; shoulder dystocia causes 7.5% of cases of seizures in the first 72 hours after birth (Sriemevan et al. 2000). Other infant injuries include brachial plexus injuries such as Erb's or Klumpke's palsy due to extreme traction while attempting to deliver the fetal anterior shoulder, as well as fractures of both the humerus and clavicle (Sriemevan et al. 2000, Gemer et al. 1999). Maternal complications can include cervicovaginal lacerations, postpartum hemorrhage, and postpartum pelvic infection.

Historical

Maternal and infant death is typically difficult to determine from the archaeological record, especially when not attributable to skeletal causes such as constricted pelvises. Differential burial practices for infants and adults may make finding true mortality patterns problematic. Death due to childbirth can be impossible to determine except in the cases in which a female and infant are buried together, although even here their relationship may not be actually that of mother and child and death could be due to many different causes (Malgosa et al. 2004). Death due to childbirth may possibly be confirmed if a female is found with a full-term infant and a distorted pelvis (Wells 1975). Cases where a pregnant woman with fetus not fully delivered have been found, though these are rare (Hawkes & Wells 1975, Cruz & Cohia 2010).

Arriaza et al. (1988) discuss several maternal mortality causes in an Andean population from pre-Columbian Chile between 1300 BCE-1400 AD. Due to the exceptional preservation found here, many potential causes of death can be found that would not be evident in skeletonized individuals. Arriaza et al. (1988) examined 187 female mummies, 18 of which were determined to have died from complications from childbirth. The authors estimate that one quarter of women died in childbirth between 2000 BCE and 600 AD while later rates of maternal mortality dropped below 7% of women; this apparent difference may be due to small sample size or more skilled midwives in later time periods. Of the women studied, three died before completing delivery. One individual had a fetus in breech presentation with the feet presenting.

Most of the remaining women likely died soon after childbirth in the puerperial period. Causes here may have included eclampsia, unhygienic conditions, infections, and hemorrhage.

Another broad study of maternal mortality in a population was conducted on 330 adult female burials from medieval Stockholm (Högberg et al. 1987). A total of 1072 individuals in a Swedish cemetery on the island of Helgeandsholmen near an almshouse and hospital were studied. Although females here showed excess mortality in the reproductive years compared to their male counterparts, only three deaths could be proven to be as a result of childbirth, one of which was due to pelvic contraction. This was determined through osteological examination of the pelvis. Two individuals had fetuses still in utero while the third individual's fetus may have been stillborn and was buried with her.

Malgosa et al. (2004) present a case of a young female buried with a full-term fetus still in utero. This burial was found under a house in the prehistoric (1500-1000 BCE) village of El Cerro de las Viñas de Coy, in southeast Spain. This burial was well preserved without important movement of the bones. This is important as the fetus in this burial was positioned in a transverse/oblique lie in the pelvic girdle of the female with the right arm outside the mother's uterus. This transverse position is very rare but impossible to deliver vaginally (Cunningham et al. 2010, Sekulic 2000). The infant's position shows that labor here was dystocic and that the fetus was either lying obliquely or transversely instead of in a cephalic presentation (Malgosa et al. 2004). In modern medicine, Caesarean section is the only course to deliver the infant and preserve the mother's life. However, in this case it is probable that the mother's death was due to sepsis and exhaustion.

Another example of death in childbirth due to an unusual medical condition is presented by Sjøvold et al. (1974). A young woman and fetus, both with exostosis multiplex, were found in a churchyard in Gotland, Scandinavia; the burial was from the thirteenth century. Exostosis multiplex can be hereditary. Exostoses are typically bilateral and grow diagonally to the long bone axis. The woman had reduced pelvic dimensions and an exostosis on the ilium as well as on the clavicles, ribs, vertebrae, ulnae, and radii while the full-term fetus had exostoses on the tibiae. Most importantly, the female had exostoses extending into the pelvic cavity, which decreased pelvic size and may have changed the uterus position. Death therefore may have been caused by fetal-pelvic disproportion. Chondrosarcoma may also occur as result of continued exostosis growth after epiphyseal closure; if this occurred it might have caused death due to cancer metastasis, however there are no indications that this was the case.

CHAPTER 3: MATERIALS AND METHODS

Materials

The sample used for this research consisted of individuals from an archaeological population from the Dakhleh Oasis, Egypt and seven populations housed in the American Museum of Natural History (NYC). These include archaeological populations from the sites of El Hesa and Sai Island in the Sudan, South Africa, the Democratic Republic of Congo, and India, as well as an historical medical collection from North America. In total, the sample contains 52 adults, 24 of which are female. In the group of females, 10 are young and 14 are old individuals (Table 1). Young females were defined as those 29 years old and younger. Two pelvises were subsequently removed from the analysis: one old female from India, as this individual had an antemortem pelvic fracture, and one old male from the Democratic Republic of Congo, as this individual was a pygmy. The level of preservation was sufficient for all other individuals to take the necessary measurements to test this hypothesis.

Individual pelvises were selected based on availability at the American Museum of Natural History and at the Dakhleh Oasis. The three pelvises from the Dakhleh Oasis were the only pelvises accessible to be measured. At the American Museum of Natural History, pelvises were selected based on their condition and whether their preservation was sufficient to take all or most of the necessary measurements.

Sex was estimated based on pelvic morphology following the criteria in Standards (Buikstra & Ubelaker 1994) and verified with curatorial records. These criteria included the ventral arc, subpubic concavity, and ischiopubic ramus ridge presence, greater sciatic notch width, and preauricular sulcus presence (Buikstra & Ubelaker 1994, Byers 2007). Age was estimated based on degenerative changes to the pubic symphysis and auricular surface (Buikstra & Ubelaker 1994, Lovejoy et al. 1985). Degenerative changes to the face of the pubic symphysis are some of the most reliable criteria to estimate age at death (Buikstra & Ubelaker 1994). No juveniles were included in this analysis. The age categories used were young adult (29 or younger) and old adult (30 or over). The medical collection from North America provided exact ages for each individual but age was still verified from skeletal remains

Table 1: Geographic and age distributions of individuals

Population	Context	Young Female	Old Female	Young Male	Old Male
Deir Abu Metta, Dakhleh Oasis, Egypt	Archaeological	0	1	0	2
El Hesa, Egypt	Archaeological	7	1	4	3
Sai Island, Nubia	Archaeological	1	2	3	3
Nubian Egypt	Archaeological	0	0	2	1
South Africa	Archaeological	0	0	0	3
Democratic Republic of Congo	Archaeological	0	0	0	1
India	Archaeological & Historical	0	2	3	2
North America	Historical	2	8	0	1
TOTAL		10	14	12	16

The Dakhleh Oasis is located in the Western Desert in Egypt. The individuals from this Oasis were from Deir Abu Metta, a Christian church (Bowen 2003). Archaeological evidence indicates that this church was built in the 4th century AD and used throughout this century

(Bowen 2011). Human remains were found here along the external walls of a church, a Christian practice that has also been found in the ancient village of Kellis in the Dakhleh Oasis. All of the graves in this site were pit graves with an east-west orientation in the Christian pattern. The cemetery continued to be used after the church was no longer in use (Bowen 2011).

Sai Island is located along the Nile River between the second and third cataracts in Nubia. It is 12 km in diameter from north to south and 505 km from east to west (Geus 1995). The island has four Meroitic necropoli in its northern half and one in its southern half (Francigny 2009), and includes all periods of Nubia's history. The northern necropoli 8-B-5.A contained the highest status individuals, possibly the religious elite, and is believed to have been established in the 1st century AD. This cemetery includes monumental pyramids. An analysis of 88 individuals from collective graves found a healthy population that consumed protein and iron rich diets (Francigny 2010) and were buried with rich grave goods. No violence-related fractures were found and muscle attachment sites were not robust. Another northern necropolis, 8-B-5.SN, also contained rich grave goods and Meroitic graves. The Meroitic graves in this area are bordered by post-Meriotic Islamic and Christian burials (Francigny 2009) and Ottoman graves are found throughout the site (Francigny 2010) and were in the extended position with at least two individuals in each grave (Francigny 2009). During the Christian era, stillborn babies were placed in amphorae and buried in old Meriotic graves.

The American and Indian populations are the only populations in this study that are not archaeological. The individuals in the American group died at the beginning of the 20th century. These individuals are from the medical collections of Cornell University, Long Island Medical, and New York University. There were 204 individuals in the Cornell University collection, 182 were male and 21 were female. In the Long Island Medical Collection, there were 76 individuals, 60 of which were male and 16 of which were female. The New York University medical collection had 102 individuals, 91 were male and 9 were female. The women here were likely to also have high levels of maternal mortality. In 1913, the second leading cause of death in women between 15-44 years of age in the United States was mortality associated with childbirth (Meigs 1917). Obstructed labor as a result of small pelvic size was the third leading cause of death in this group, after complications related to the puerperium and to eclampsia.

According records at the American Museum of Natural History, the individuals from the Indian group were from Southern India, the Andaman Islands, the Chatham Islands, Ceylon, and Mysore and were collected between 1923 and 1954. Four of these individuals were recent skeletons exhumed from a native cemetery at the Honnametti Estate in India while the balance of this group represented archaeological groups. There were 134 individuals from India in the museum's collections; 59 were male and 34 were female while the remainder did not have a sex determined. There were also six subadults in this group.

The individual from the Democratic Republic of Congo was found in Medje. This individual was one of two pygmies collected at the same time. There was one adult male and one child in this collection.

The individuals from South Africa were from Douglas and the Orange River Colony. There were 18 total individuals from South Africa in the museum collections. Five of these individuals were Bushmen. There were two males and two females with a sex determined, the remainder did not have a recorded sex.

The individuals from Egypt were from El Hesa and Nubian Egypt and were collected between 1924 and 1937. There were 319 individuals from El Hesa in this collection. There were 141 males and 141 females with a recorded sex, the remainder did not have a sex determined. There were 10 individuals from Nubian Egypt. Of these, eight were male and two were female.

Measurement

Measurement methods were adapted from Tague (1994, 2009) and Campbell et al. (2010). The obstetrically relevant dimensions of the pelvis were taken both from these sources as well as from Williams Obstetrics (Cunningham et al. 2001). Methods of analysis were adapted from Rencher (2002) and multivariate analysis was done in R.

Nine measurements were taken from each pelvis to examine pelvic dimension and pelvic asymmetry (Cunningham et al. 2001, Campbell et al. 2011) (Table 2, Figures 3-5). Acting as the control, the old females should demonstrate the possible pelvic measurements necessary to survive childbirth. The variations of these measurements were used to examine if the young females possibly died in childbirth due to fetal-pelvic disproportion or asymmetry. This relative approach is necessary due to the lack of obstetric dimension data available for specific archaeological populations. Five of the measurements of the pelvis and sacrum were used to calculate the contractions of the pelvic inlet, midpelvis, and pelvic outlet (Cunningham et al. 2001), while the other four measure pelvic symmetry (Tague 2009). These measurements were analyzed using a multivariable statistical approach detailed below.

Table 2: Measurements included in the analysis (measurements adapted from Tague 1994, Campbell et al. 2011)

Contractions of pelvic capacity		
1	Transverse diameter	Greatest width of pelvic inlet
2	Inlet Anteroposterior diameter	Superior pubic symphysis – 1st sacral vertebrae
3	Outlet Anteroposterior diameter	Inferior pubic symphysis – 5th sacral vertebrae
4	Interischial spinous diameter	Distance between the ischial spines
5	Interischial tuberous diameter	Distance between the ischial tuberosities
Asymmetry of pelvic dimensions		
6	Sacral-ischial spine length	Distal sacral articulation – base of ischial spine
7	Greater sciatic notch width	Posterior-inferior iliac spine – base of ischial spine
8	Iliac blade length	Posterior-superior iliac spine – anterior-superior iliac spine
9	Alar-pubis length	Anterior point on auricular surface – inner point on pubis

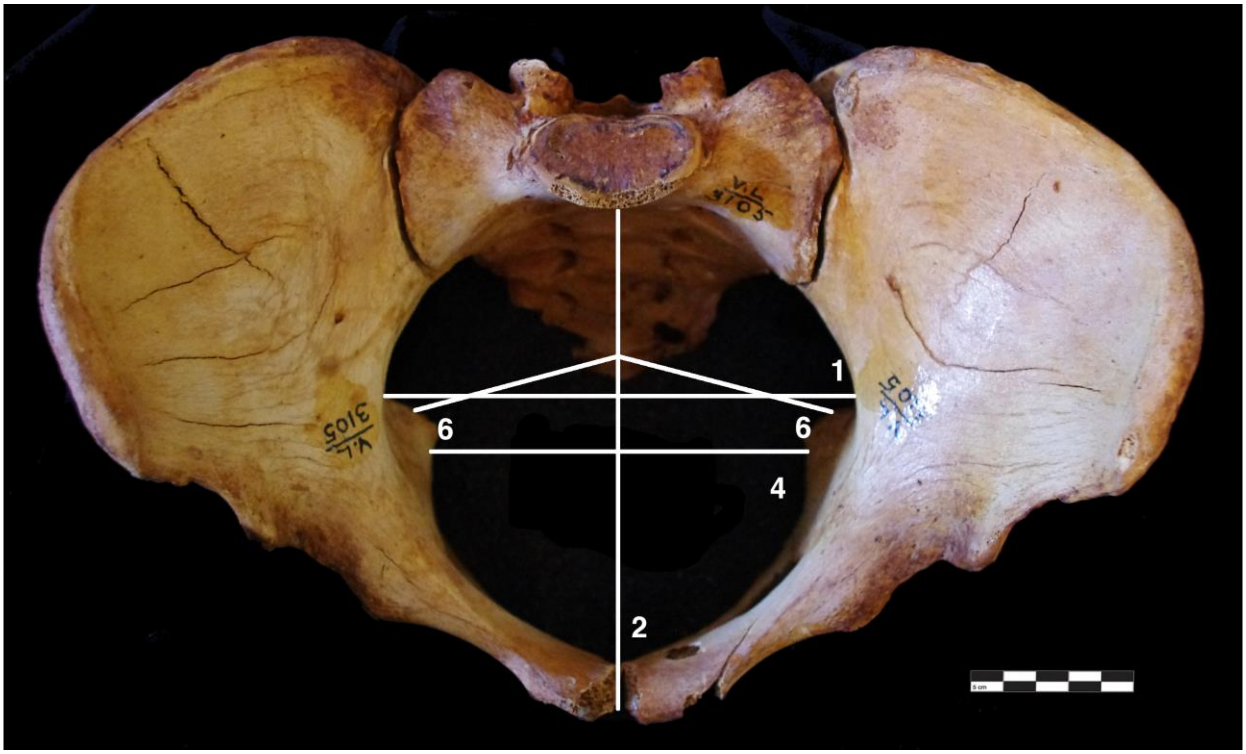

Figure 3: Superior view measurements (Pelvis VL 3105, AMNH). 1- transverse diameter, 2- inlet anteroposterior diameter, 4- interischial spinous diameter, 6- sacral-ischial spine length.

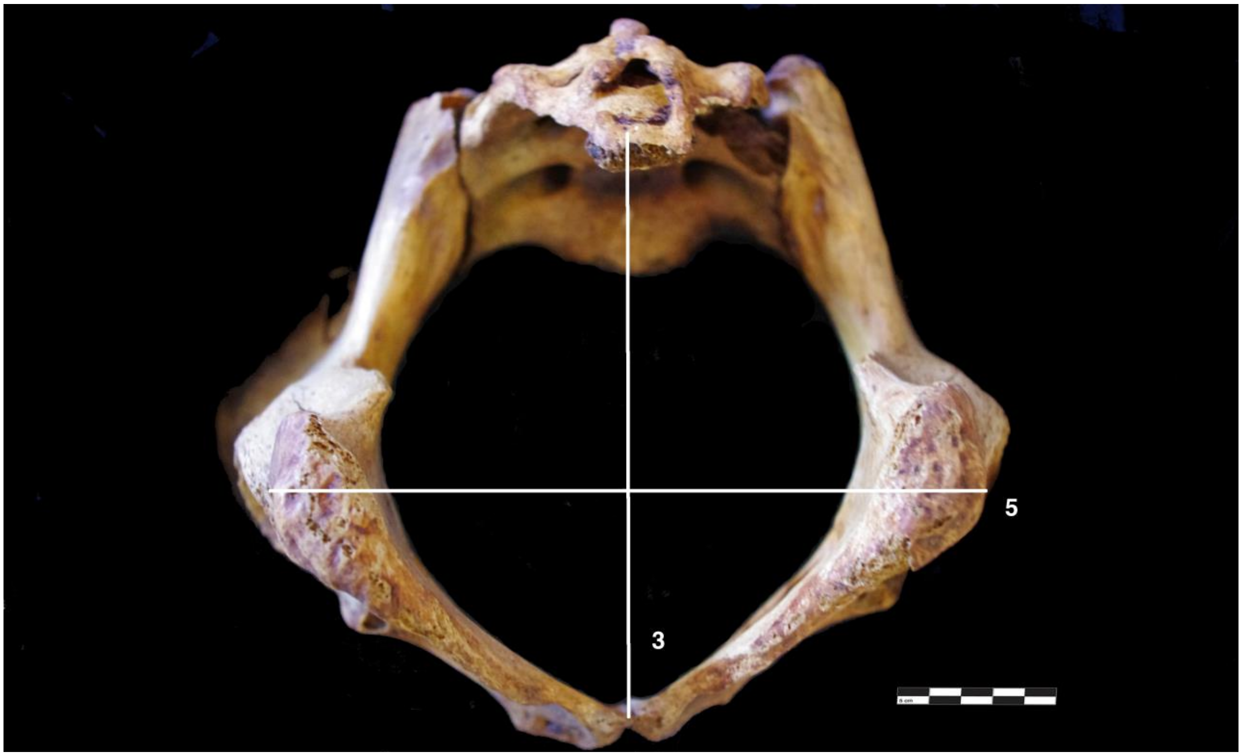

Figure 4: Inferior view measurements (Pelvis VL 3102, AMNH). 3- outlet anteroposterior diameter, 5- interischial tuberous diameter

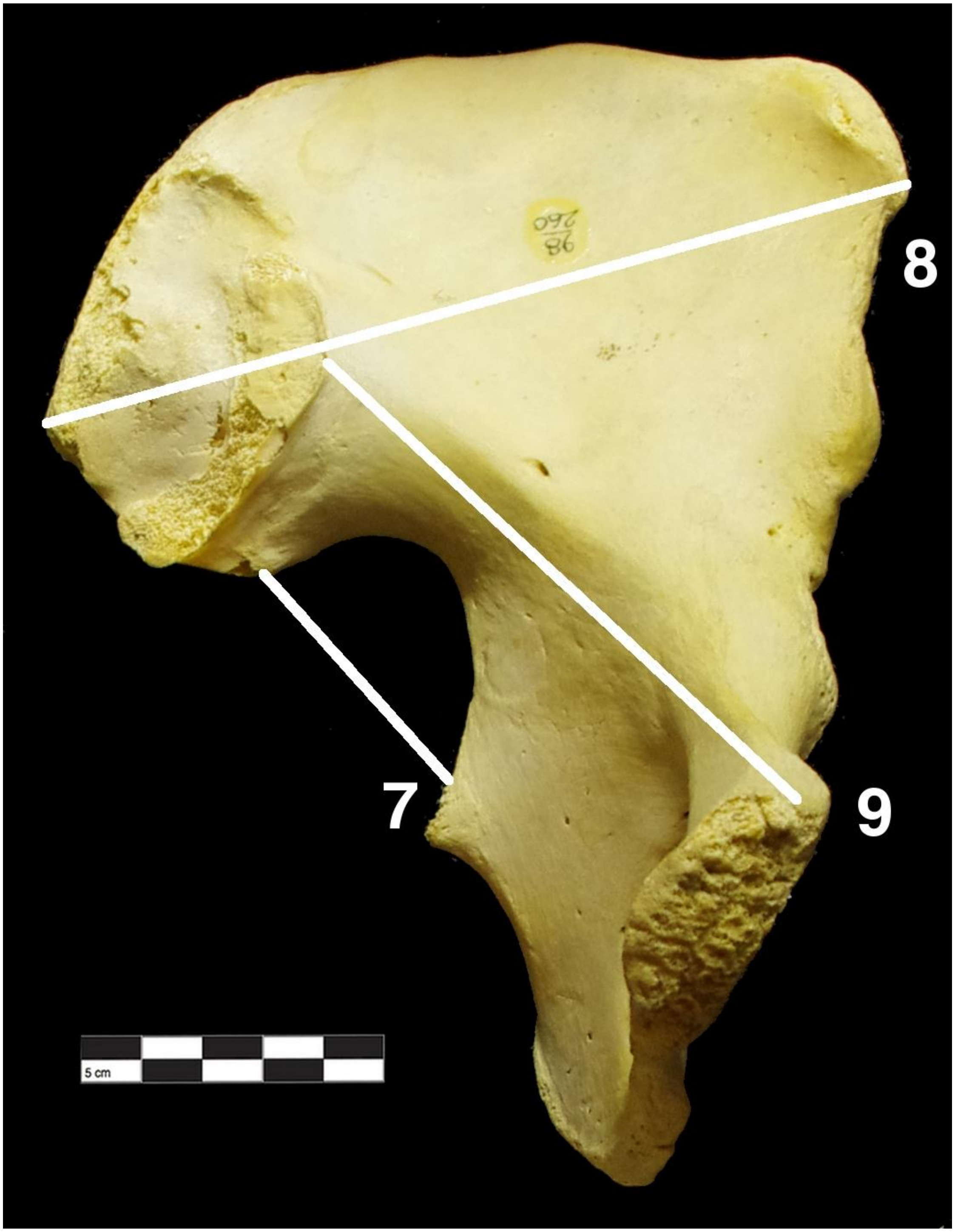

Figure 5: Medial view measurements (Os coxa 98/260, AMNH). 7- greater sciatic notch width, 8- iliac blade length, 9- alar-pubis length

Pelvic measurements were taken by articulating the os coxae and sacrum in a sandbox and encircling them in a wide loop of Velcro. This exerted enough pressure to maintain correct alignment of the pelvis while remaining loose enough not to damage delicate bones. This is in contrast to Tague's (1994, 2009) method of encircling the pelvis with several heavy rubber bands; many of the pelvises documented for this study were too delicate to withstand the amount of pressure this would have caused. The pubic symphyses touched in the articulation of the os coxae and sacrum, no compensation for symphyseal discs was made; this is in accordance with Tague's (1994, 2009) method of articulating the pelvis as well as a concession to the lack of concordance in the literature about standard pubic symphysis size (Becker et al. 2010). Sliding, spreading, and long arm calipers were used to measure the pelvises. The transverse diameter, inlet anteroposterior diameter, interischial spinous diameter, and sacral-ischial spine length were all measured while the pelvis was oriented with the superior aspect facing up (Figure 6), while the outlet anteroposterior diameter and interischial tuberous diameter was measured while the pelvis was oriented with the inferior aspect facing up (Figure 7). The long arm calipers were necessary to measure the pelvic dimensions too deep for standard calipers to reach, such as transverse diameter (Figure 8), outlet anteroposterior diameter, interischial spinous diameter, and sacral-ischial spine length. Once the dimension had been measured, sliding calipers were used to measure the distance between the points of the long arm calipers. The greater sciatic notch width, iliac blade length, and alar-pubis length were measured with sliding calipers while the pelvis was disarticulated. Both left and right measurements were taken for sacral-ischial spine length, greater sciatic notch width, iliac blade length, and alar-pubis length so that pubic symmetry could be assessed. The femur was measured with an osteometric board, although this measurement was ultimately not used.

Figure 6: View with pelvis oriented with the superior aspect facing up in sandbox with Velcro (Pelvis 99/8452, AMNH). This orientation was used to measure transverse diameter, inlet anteroposterior diameter, interischial spinous diameter, and sacral-ischial spine length.

Figure 7: View with pelvis oriented with the inferior aspect facing up in sandbox with Velcro (Pelvis 99/8452, AMNH). This orientation was used to measure outlet anteroposterior diameter and interischial tuberous diameter.

Figure 8: View of author measuring pelvic transverse diameter (Pelvis VL 3104, AMNH).

Measurement error was assessed by duplicating measurements on seven pelvises (13% of the sample). Overall average measurement error was 1.43 mm.

Analysis

Statistical analysis was completed using R. Statistical significance was assessed at the $\alpha=0.05$ level and Kruskal-Wallis tests, Mann-Whitney-Wilcoxan tests, and Pillai's (also called Pillai-Lawley) MANOVA (multivariate analysis of variance) test was used. The Kruskal-Wallis tests and Mann-Whitney-Wilcoxan tests were used as they are nonparametric tests and so do not require normality. The majority of the analysis focused on the differences between young and old females in terms of pelvic size and symmetry.

As the MANOVA test in R requires all variables be present in all individuals in the analysis, those individuals with missing measurements due to preservation issues were excluded from this portion of the analysis (Table 3). The sample sizes in this analysis are very small and the data does not have multivariate normality; results found here are very likely due to idiosyncrasies of the sample. All measurements available for each variable were used when assessing measurement averages, standard deviations, and asymmetry.

Table 3: Difference in number of individuals used in Kruskal-Wallis and MANOVA tests and total individuals

	Individuals with all variables measured	Total individuals
Young Females	4	10
Old Females	7	14
Young Males	9	12
Old Males	13	16
Total	33	52

Before any MANOVA tests were performed, equality of the covariance matrices was assessed with Box's M test (Rencher 2002). There needs to be equality of the covariance matrices for the result of the MANOVA test to be valid. This test is less robust to small sample size than the MANOVA test. Box's M test rejected the null hypothesis of equality of covariance matrices at the $\alpha=0.05$ level. Tabachnick and Fidell (2001) recommend using Pillai's criterion instead of Wilks' lambda in the MANOVA tests in this case. Therefore all the MANOVA tests were conducted using Pillai's criterion.

A MANOVA test was conducted to test for significant differences between the different geographic groups included in this analysis. As certain groups contained much larger proportions of males than females or conversely females than males, different tests were conducted on each sex to prevent sex differences in pelvic measurements obscuring geographic differences. There were no significant differences between populations for the variables analyzed here for females ($p=0.25$) or males ($p=0.17$).

Sex Differences

Differences between males and females were assessed through an overall MANOVA test and Kruskal-Wallis tests on individual variables. The Kruskal-Wallis tests were chosen because they are non-parametric and do not rely on assumptions of normality that an ANOVA test would require.

Size Differences

A MANOVA was conducted on the four groups (young females, old females, young males, and old males). Overall differences were assessed with this test. Bonferroni's correction was used on the critical values for the MANOVA tests to prevent Type I errors. Therefore, to test for a significance level of $\alpha \leq 0.05$, p-values were compared against $\alpha / 9 = 0.0056$ (Rencher 2002).

To assess differences between young and old females, Kruskal-Wallis tests were conducted on each variable. The Kruskal-Wallis tests were chosen because they are non-parametric and do not rely on assumptions of normality that an ANOVA test would require. To provide a comparison, differences between young and old males were assessed in the same way.

Symmetry Differences

To test differences in pelvic symmetry between groups, Mann-Whitney-Wilcoxon tests on individual variables were used. These variables included sacral-ischial spine length, greater sciatic notch width, iliac blade length, and alar-pubis length (Table 4). Measurements of the right and left sides of the pelvis were taken for each of these variables and the Mann-Whitney-Wilcoxon tests were conducted on the absolute value of the difference between these measurements. This non-parametric test was used because sample sizes were not sufficient to perform ANOVA tests. An overall test including all variables was not used, as there were not a sufficient number of individuals in the young female category that had all four measures of bilateral symmetry available. Preservation issues rendered several of the measurements that assessed symmetry particularly problematic. These issues included missing the superior corner of the pubic symphysis or the inferior portion of the sacrum, which made taking sacral-ischial spine length and alar-pubis length impossible to measure. Sample sizes were much improved by assessing variables individually.

Table 4: Sample sizes for measurements of pelvic symmetry

Measurement	Young females	Old females	Young males	Old Males
Sacral-ischial spine length	4	7	9	15
Greater sciatic notch width	6	13	11	16
Iliac blade length	6	11	11	14
Alar-pubis length	4	10	12	14

CHAPTER 4: RESULTS

There were several notable differences in size, symmetry, and shape in these groups. The four groups considered here are young females, old females, young males, and old males (Table 5).

Table 5: Measurement averages and standard deviations for each group. Measurements are in millimeters.

	Young Female		Old Female		Young Male		Old Male	
Measurement	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average	Std Dev
Transverse diameter	126.45	9.14	124.81	9.52	114.45	7.45	113.14	11.65
Inlet Anteroposterior diameter	122.86	6.51	121.01	10.81	109.48	11.03	107.73	9.74
Outlet Anteroposterior diameter	110.40	6.90	122.05	9.39	108.07	11.33	110.55	12.14
Interischial spinous diameter	108.00	4.74	107.99	10.72	83.63	7.52	85.45	12.94
Femur Length	427.83	26.25	429.76	31.04	464.25	33.25	439.73	45.11
Interischial tuberous diameter	143.35	8.03	148.25	14.98	124.89	11.21	127.25	16.10
Sacral-ischial spine length	70.45	3.57	69.53	6.48	56.43	5.96	57.66	6.06
Greater sciatic notch width	46.20	4.14	46.58	5.08	38.45	3.89	37.91	4.19
Iliac blade length	143.89	9.23	148.93	10.42	150.59	8.26	147.80	15.77
Alar-pubis length	123.94	7.47	123.15	7.68	110.36	6.85	112.97	15.57

Differences in Sex

There were several significant differences between male and female groups when considered as a whole (Table 6). All measurements except iliac blade length had significant differences based on sex, showing the evolutionary differences between male and female pelvises.

Table 6: Significance levels from Kruskal-Wallis and MANOVA tests when male and female groups are considered

Measurement	Significance level	P-value
Overall	0.05	4.987e-08
Transverse diameter	0.05	0.005966
Inlet Anteroposterior diameter	0.05	0.0008922
Outlet Anteroposterior diameter	0.05	0.04703
Interischial spinous diameter	0.05	2.659e-05
Interischial tuberous diameter	0.05	0.0001562
Sacral-ischial spine length	0.05	3.716e-05
Greater sciatic notch width	0.05	6.595e-06
Iliac blade length	Not significantly different	0.2365
Alar-pubis length	0.05	0.0007775

Differences in Size

There was a statistically significant difference at the $\alpha=0.05$ significance level when all four groups and all measurements were included in the MANOVA. Therefore the null hypothesis of equality of means is rejected; this means that there were significant differences between mean values in the measurements between groups. There were significant differences at the α=0.05 level for inlet anteroposterior diameter when all groups were included (Table 7).

Table 7: Significance levels from Kruskal-Wallis and MANOVA tests when all 4 groups are considered

Measurement	Significance level	P-value
Overall	0.05	0.00172
Transverse diameter	Not significantly different	0.05022
Inlet Anteroposterior diameter	0.05	0.008789
Outlet Anteroposterior diameter	Not significantly different	0.3497
Interischial spinous diameter	Not significantly different	0.8152
Interischial tuberous diameter	Not significantly different	0.6642
Sacral-ischial spine length	Not significantly different	0.5258
Greater sciatic notch width	Not significantly different	0.3006
Iliac blade length	Not significantly different	0.5258
Alar-pubis length	Not significantly different	0.7638

When only young and old females were considered, there was not a statistically significant difference overall. However, there was a significant difference in the outlet anteroposterior diameter at the α=0.05 level between these two groups (Table 8). This is in contrast to the analysis of young and old males in which there were no significant differences. The overall results of this measurement are summarized in Figure 9. Other measurements did not have statistically significant differences between young females and old females.

Table 8: Significance levels from Kruskal-Wallis and MANOVA tests when group subsets are considered

Measurement	Young females and old females Significance level	Young males and old males Significance level
Overall	Not significantly different	Not significantly different
Transverse diameter	Not significantly different	Not significantly different
Inlet Anteroposterior diameter	Not significantly different	Not significantly different
Outlet Anteroposterior diameter	0.05 $p = 0.01402$	Not significantly different
Interischial spinous diameter	Not significantly different	Not significantly different
Interischial tuberous diameter	Not significantly different	Not significantly different
Sacral-ischial spine length	Not significantly different	Not significantly different
Greater sciatic notch width	Not significantly different	Not significantly different
Iliac blade length	Not significantly different	Not significantly different
Alar-pubis length	Not significantly different	Not significantly different

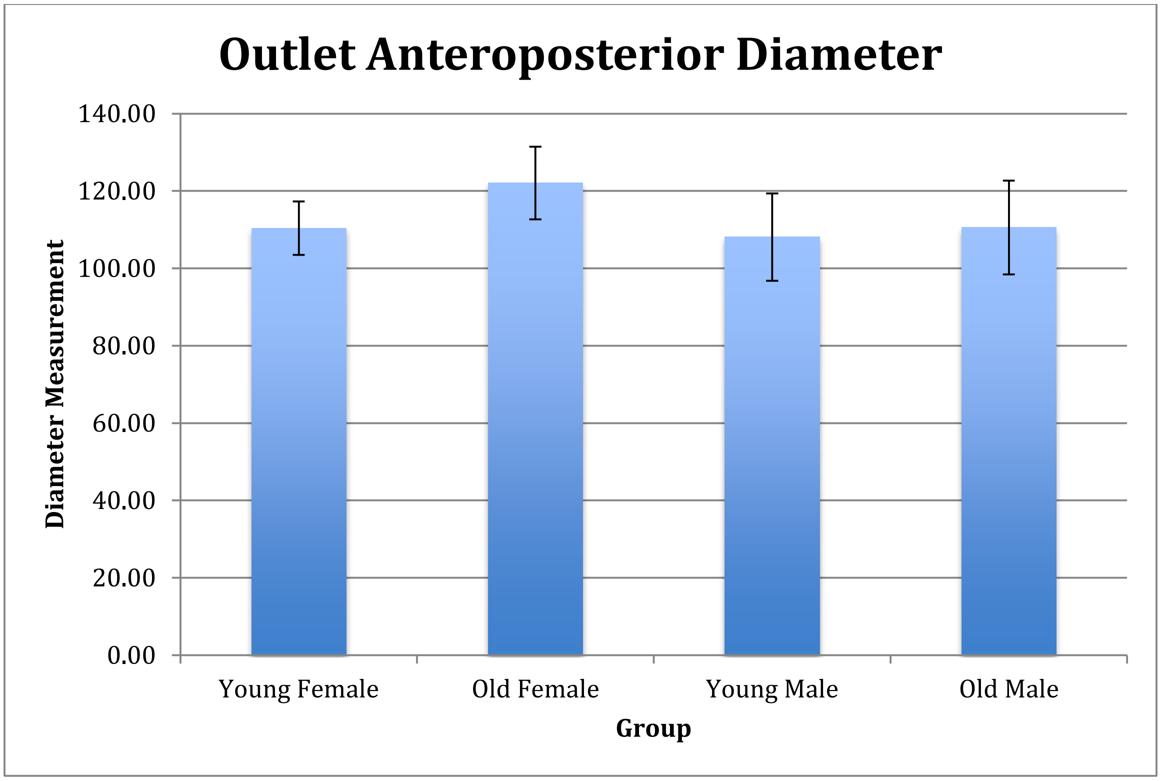

Figure 9: Pelvic outlet anteroposterior diameter for all groups. The bars represent standard deviation.

Differences in Symmetry

There were also significant differences between young and old females in pelvic symmetry. Alar-pubis length symmetry was significantly different at the $\alpha=0.05$ level between young and old females. However, sacral-ischial spine length, greater sciatic notch width, and iliac blade length symmetry were not significantly different between young and old females (Tables 9 and 10). There were no significant differences in symmetry between young and old males. Exact p-values for all measurements can be found in Appendix B.

Table 9: Average difference between left and right measurements in each measurement

Measurement	Young Female		Old Female		Young Male		Old Male	
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average	Std Dev
Sacral-ischial spine length	2.37	0.98	2.05	1.73	3.50	2.72	2.68	2.10
Greater sciatic notch width	2.71	2.63	1.74	1.39	1.95	1.06	2.02	1.62
Iliac blade length	2.81	2.22	1.57	1.44	1.47	1.12	2.08	1.76
Alar-pubis length	2.98	0.98	2.07	2.36	2.22	2.02	2.54	1.36

Table 10: Differences in symmetry between groups

Measurement	Young females and old females Significance level	Young males and old males Significance level
Sacral-ischial spine length	Not significantly different	Not significantly different
Greater sciatic notch width	Not significantly different	Not significantly different
Iliac blade length	Not significantly different	Not significantly different
Alar-pubis length	0.05 $p = 0.03596$	Not significantly different

<u>Differences in Shape</u>

There were also several differences in shape in individual pelvises. Pelvises were characterized into gynecoid, android, anthropoid, and platypelloid shapes using Greulich and Thoms' (1938) criteria. Groups were divided fairly evenly between gynecoid, android, and anthropoid shapes; no platypelloid pelvises were found (Table 11).

Table 11: Pelvic shapes for each group

Shape	Young Female	Old Female	Young Male	Old Male
Gynecoid	2 (33.3%)	6 (60.0%)	4 (36.4%)	6 (40.0%)
Android	1 (16.7%)	2 (20.0%)	3 (27.3%)	5 (33.3%)
Anthropoid	3 (50.0%)	2 (20.0%)	4 (36.4%)	4 (26.7%)
Platypelloid	0	0	0	0

Gynecoid pelvises were more frequent in the old female groups while anthropoid pelvises were more common in the young female groups.

CHAPTER 5: DISCUSSION

There are many potential complications of pregnancy and childbirth, many of which were possibly experienced by the individuals studied here. The young females included in this sample may have died in childbirth due to complications stemming from compressed or asymmetrical pelvises that caused fetal-pelvic disproportion, in contrast to the older, presumable multiparous old females here, which served as controls.

The size differences found here between young and old females in pelvic outlet anteroposterior diameter may also be the result of continued pelvic growth into the third decade of life as Tague (1994) hypothesized for the differences in linea aspera length he found in young and old females. This is less likely here as the young age group was extended to definitely encompass the end of pelvic growth and there is only one old female with a pelvic outlet anteroposterior diameter equal to or less than the young female mean, instead of 21.7%-28.7% of the old females' linea aspera length in Tague's (1986) study. Additionally, no significant differences were found between young and old males were found as would be expected if differences in size were due to continued pelvic growth.

Sex Differences

The differences found between males and females show the evolutionary differences between these groups. While the male pelvis is only influenced by evolutionary pressures related to bipedalism, the female pelvis has both these pressures and those associated with childbirth to consider. The female pelvis must be large enough to accommodate the fetus and be shaped correctly to direct the fetus's movements during childbirth (Tague 1986). The pelvis is the portion of the skeleton that is the most influenced by childbirth pressures (Byers 2007). The female pelvis is accordingly wider and shorter than the male pelvis with an oval pelvic inlet in contrast to the heart shaped male pelvic inlet. The morphological features of the os coxa also vary between females and males; a wide greater sciatic notch, subpubic concavity, and a sharp ischiopubic ramus ridge are all female characteristics while a small greater sciatic notch, no subpubic concavity, and a flat ishiopubic ramus ridge are male characteristics (Buikstra & Ubelaker 1994). This dimorphism causes the female pelvic capacity to exceed that of the male pelvis (Tague 1986). These differences are reflected in the group studied here, as all dimensions were significantly different except for iliac blade length. Iliac blade length may be more closely tied to bipedal locomotion than other dimensions or the lack of significant differences may be due idiosyncrasies of this group.

Pelvic Contraction

Pelvic inlet contractions prevent the fetus from descending into the pelvic cavity before the onset of labor (Cunningham et al. 2001). The majority of birth presentations are cephalic (Sekulic 2000), where the fetus' head is floating over the pelvic inlet or resting in the iliac fossa, which allows it to assume other, more dangerous presentations with very little influence (Cunningham et al. 2001). The pelvic inlet dimension is best measured by the inlet anteroposterior and transverse diameters of the pelvis. Midpelvic contractions are more common than inlet contractions and often cause transverse arrest of the fetal head, which leads to difficult delivery or, in modern times, delivery by caesarean section. Midpelvic contraction is best measured through interischial spinous diameter and the outlet anteroposterior diameter. Pelvic outlet contraction is rare when not accompanied by midpelvic contraction, but when present, forces the fetal head posteriorly. Even if this contraction does not lead to severe dystocia, perineal tears may increase due to the occiput being forced down to the ischiopubic rami where the perineum becomes more distended and is at greater risk of disruption. Pelvic outlet contraction is best measured with the interischial tuberous diameter.

The young female pelvises in this sample are significantly different from the old female pelvises in one dimension, the outlet anteroposterior diameter. This is also the dimension that is closest to the very small dimensions of the individuals from Kulubnarti, Nubia as well as the young females from Indian Knoll and Pecos Pueblo (Table 12). This dimension is also smaller than the normal modern United States pelvis. However, the old female outlet anteroposterior diameter is larger than all but the Haida Native American group.

Table 12: Comparison between young female and old female pelvic dimensions from this study, Kulubnarthi female pelvic dimensions from Sibley et al. (1992), North American Indian female pelvic dimensions from Tague (1994, 1986), and normal female US pelvic dimensions from Cunningham et al. (2010). Measurements are in millimeters, all groups are female.

Dimension		Present Study		Kulub-narti Nubia	Indian Knoll		Pecos Pueblo		Libben		Haida	US
		Young	Old		Young	Old	Young	Old	Young	Old		
Inlet AP Diameter	Mean	122.86	121.01	103	107	109	90	91	101	97	112	105
	Std Dev	6.51	10.81	8	8	6	5	8	6	9	10	-
Outlet AP Diameter	Mean	110.40	122.05	110	111	117	108	115	125	120	135	115
	Std Dev	6.90	9.39	7	7	10	8	9	8	5	10	-
Transverse Diameter	Mean	126.45	124.81	116	133	135	131	134	130	136	135	135
	Std Dev	9.14	9.52	7	6	7	5	6	6	7	8	-

Tague (1994) posits two explanations for the differences in linea terminalis length between the young and old females in his study. In the first, the difference is due to continued growth of the pelvis through early adulthood in females. Growth in the female pelvis may be complete in the inferior border by the age of 18 as it is in the male pelvis but the superior border of the female pelvis may continue to grow into the third decade of life. The other potential explanation is that this difference is due to differential maternal mortality based on pelvic size. This explanation is supported by Fuller (1998). The data here is more indicative of death in childbirth than Tague's (1986) data, as in Tague's study, between 21.7 % and 28.7% of old females had linea terminalis lengths equal to or less than the young female mean. However, in this study only one old female had an outlet anteroposterior diameter measurement less than the young female mean measurement. This shows that the differences found here were less likely to be the result of continued growth instead of being a cause of death in childbirth.

The contracted outlet anteroposterior diameter found here might be a cause of fetal-pelvic disproportion. This measurement is associated with midpelvis contractions (Cunningham et al. 2001). This is the most common dimension to be contracted and can cause transverse arrest of the fetal head (Cunningham et al. 2010). In addition, pelvic outlet contraction is generally associated with midpelvis contraction and can cause perineal tearing that can lead to later infection.

There are only marginal changes to the inlet circumference due to relaxin, the hormone that makes ligaments become more pliable during childbirth so that the birth canal becomes larger (Tague 1994). However, the pelvic outlet may increase up to 20-30% in area during this process (Russell 1969). This could indicate that the pelvises in the young females in this study were still inadequate for labor even after this increase in size. It could also point to the possibility that the difference between young and old females here was a result of idiosyncrasies of the group measured due to the small sample size and that a small pelvic outlet would not have caused maternal mortality.

Pelvic Asymmetry

Asymmetrical obstetric dimensions can prevent normal labor and may increase the likelihood of infection (Campbell et al. 2011). There were significant differences between young and old females in pelvic symmetry in the alar-pubis length in these groups (Table 13). This is in accordance with the results found by Campbell et al. (2011). Campbell et al.'s study involved skeletally mature adults from Native American groups from Alaska and New Mexico divided into sex and age categories. Measurements analyzed were greater sciatic notch width, iliac blade length, alar-pubic length, and sacral-ischial spine length; for comparative purposes these measurements were taken from the same points as Campbell et al. In Campbell et al.'s study, young females had significant directional asymmetry in greater sciatic notch width, alar-pubic length, and sacral-ischial spine length while older females did not have significant directional asymmetry in any measurements. Young males did not have significant directional asymmetry for any measurement while older males had significant directional asymmetry for alar-pubic length.

Table 13: Comparison between young female and old female absolute asymmetry from this study and from Campbell et al. (2011). Measurements are in millimeters and all groups are female.

	Present Study		Campbell et al. (2011)	
Dimension	Young Females	Old Females	Young Females	Old Females
Sacral-ischial spine length	2.37	2.05	4.71	4.11
Greater sciatic notch width	2.71	1.81	5.31	3.60
Iliac blade length	2.81	1.60	1.94	1.41
Alar-pubis length	2.98	2.17	4.60	2.78

The results both here and in Campbell et al. (2011) indicate that pelvic asymmetry may influence maternal mortality. Unlike Campbell et al.'s population, there was less absolute asymmetry in the individuals in this study. However, both groups still had significant results that indicated that asymmetry is increased in individuals who die as young adults.

Differences in alar-pubis length found here may have skewed the pelvises, so that the pubic symphysis was closer to the auricular surface on one side of the pelvis than the other. This skew may then have interfered with the rotations the fetus makes during childbirth. The fetus rotates as it descends towards the pubic symphysis and again as the fetal shoulders emerge (Cunningham et al. 2010). An asymmetrical opening may force the fetal head one way or the other and prevent easy rotation and cause the fetal-pelvic disproportion, as the fetus is unable to easily emerge.

Pelvic Shape

Pelvic shape is affected by activity patterns and nutrition in childhood and adolescence. Differences in pelvic shape can influence success in childbirth as well. Vigorous physical activity in adolescence is associated with android pelvises in females (Abitol 1996). Late acquisition of an upright posture and standing unaided is associated with anthropoid pelvises while early acquisition is associated with platypelloid pelvises. Anthropoid and gynecoid pelvises are linked to more privileged economic backgrounds (Greulich & Thoms 1938). There are several similarities between Greulich and Thoms' (1938) groups and this study (Table 14).

Table 14: Comparison between young and old females from this study and three groups of females from Greulich and Thoms (1938). The nurses group refers to student nurses from a privileged economic background, the clinic groups refer to series of clinic patients, and the children group refers to a group of girls between 5 and 15 years of age.

	Present Study		Greulich & Thoms 1938			
Shape	Young Female	Old Female	Nurses	Clinic 1	Clinic 2	Children
Gynecoid	33.3%	60.0%	46.0%	43.9%	45.1%	33.6%
Android	16.7%	20.0%	17.0%	34.1%	34.5%	8.3%
Anthropoid	50%	20.0%	37.0%	13.6%	15.5%	57.9%
Platypelloid	0	0	0	8.3%	4.9%	0

The young female group is most similar to Greulich and Thoms' (1938) children group while the old female group is more comparable to the student nurses group. Greulich and Thoms suggest that anthropoid and gynecoid pelvis shapes are more prevalent in childhood and adolescence, which may be why the younger age group was more like this one; the young female group had the greatest prevalence of anthropoid and gynecoid pelvises. The old females, like the student nurse group and the clinic groups, had a majority of gynecoid pelvises. This shape required operatic intervention during childbirth in less than one fifth of cases (Greulich and Thoms 1938). However, the anthropoid pelvis required operatic intervention in the fewest cases, making pelvic shape an unlikely source of difficulty in childbirth in the young female group as half of this group has an anthropoid pelvic shape.

Limitations

There were several limitations that constrained the scope of this study. Due to the lack of access to collections to record date in Egypt, the focus of the project was shifted to encompass a variety of archaeological and modern groups instead of a single population from the Dakhleh Oasis. Sample size was also an issue, as limited time to collect data prevented the acquisition of a larger group of pelvises for this analysis.

The collections at the American Museum of Natural History, while excellent, had several drawbacks for this project. Overall, there were many more male skeletons in these collections than female skeletons. There were also more old females than young females in the collections. There were also several preservation issues with pelvises in the museum collections as many were fragmented from storage or, in the medical collections, from bring sawed apart. A more unique issue was the number of pelvises at the museum that had been articulated, which made them ineligible for this study. As the articulated pelvises had compensation made for the pubic symphysis, they would not be comparable to pelvises articulated with no such compensation. Although originally included as a way to scale measurements, the lack of femurs associated with every pelvis resulted in femur length being discarded from the measurements used in this analysis. This was not considered a detriment, however, as the absolute size of the pelvises is important for determining scale differences in pelvises.

Another drawback in this study was the temporal and geographic heterogeneity of the groups studied here. While Nuger (2008) shows the changes that can occur in pelvic dimensions due to climate and latitude, the groups in this study were by necessity fairly widely divergent. This was due to the lack of a single museum collection with a sufficient number of female pelvises to use as the study group.

CHAPTER 6: CONCLUSION

The contracted pelvises and asymmetrical pelvises may indicate that the young females in this study died in childbirth due to these conditions. Fetal-pelvic disproportion is more likely with a compressed pelvis, which can lead to many other complications during labor and delivery. In modern medicine, fetal-pelvic disproportion is the most common cause of cesarean section (Cunningham et al. 2010); in archaeological populations this would have ended with death. While adolescent pregnancies can include many complications, the younger adolescents were not included in this study population as they are not skeletally mature and only adult skeletons were studied here. Therefore the high levels of toxemia, hypertension, and premature births that are present in modern adolescent groups (Utian 1967, Lewis & Nash 1967, Rasheed et al. 2010) are not as likely to be responsible for complications and maternal deaths found here. In this study it was found that pelvic shape in the young female group was also conducive to easier labor and so was unlikely to be a cause of distress or mortality.

It is also possible that the conditions that caused compressed and asymmetrical pelvises in the younger female group could have contributed to their deaths. Childhood nutrition and activity patterns in childhood and adolescence play a major role in pelvic shape (Abitol 1996, Greulich & Thoms 1938) and could also play a role in overall health in a group. Greulich and Thoms (1938) found that the group with the pelvic shapes most conducive to easy labor and delivery were also the healthiest and from the wealthiest backgrounds.

Overall, the results found here could support the hypothesis that young females will exhibit more contracted pelvic dimensions and greater pelvic asymmetry than older, multi-parous females. This may indicate that contracted pelvic size and asymmetric pelvises increase the risk of death in childbirth and indicate that the young females in these populations had contracted, more asymmetrical pelvises than older, multiparous females. However, small sample size prevents definitive conclusions. The results from this pilot project will be used in the future on a larger sample from the Dakhleh Oasis.

Future Directions

The next logical step in this research is to incorporate infant size into the analysis. In an assemblage like that found at the Kellis 2 Cemetery, there is a large infant population (Wheeler 2009). The size of perinates and infants, especially clavicle length, could provide an interesting counterpoint to maternal pelvic size. If the majority of infants and perinates had a clavicle length longer than normal, there may have been issues with shoulder dystocia. Although most fetal-pelvic disproportion is caused by maternal pelvic size (Cunningham et al. 2001), large infants combined with small pelvic sizes would provide a good argument for fetal-pelvic disproportion.

Another interesting aspect of analysis would be to collect the measurements analyzed here in a temporally and geographically bounded population. In such a population, differences between groups would not be clouded with considerations of changing body size based on climate or time period.

APPENDIX A: COLLECTED DATA

SITE	ID	SEX	AGE	AGE #	TOTAL DIAMETER	INLET AP DIAMETER	OUTLET AP DIAMETER	INTERISCHIAL SPINOUS DIAMETER	FEMUR LENGTH	INTERISCHIAL TUBEROUS DIAMETER
El Hesa	VL3102	F	Y		123.91	127.59	109.65	101.33	436.0	140.49
El Hesa	VL3123	M	O		123.83	101.03	99.76	99.21	439.0	142.19
El Hesa	VL 3105	F	Y		125.33	125.62	100.58	113.22	436.0	148.23
El Hesa	VL3168	F	Y		135.66	122.99	104.94	107.70	426.5	135.38
El Hesa	VL3014	M	Y		119.25	111.08		91.34		138.84
El Hesa	VL3124	M	Y		122.60	117.17		92.82		145.37
El Hesa	VL3163	F	Y		123.03	127.54		112.97	399.5	156.96
El Hesa	VL 3167	F	Y			109.94	121.10		395.5	
El Hesa	VL3111	F	Y			119.51	111.20		410.5	
El Hesa	VL3146	F	Y				108.60		413.5	
El Hesa	VL3104	M	Y		122.71	92.95	100.24	84.59	496.5	127.44
El Hesa	3175	F	O		130.64	123.81		116.17	423.0	164.31
El Hesa	VL3174	M	Y		117.18	98.81	95.17	71.25	424.0	112.47
El Hesa	VL3124	M	O		115.35	108.68	108.42	84.24		125.22
South Africa	99 8452	M	O		106.66	94.60	100.24	105.07	381.0	132.65
South Africa	2470	M	O		103.48	115.44	126.54	87.15	431.0	119.06
South Africa	2471	M	O		108.17	115.40	123.31	79.64	454.0	123.94
Nubian Egypt	3223	M	O		123.14	101.20	118.84	84.30	430.0	118.44
Nubian Egypt	3222	M	Y		108.44	123.33	111.80	89.19	491.0	127.63
Nubian Egypt	3221	M	O		100.56	96.90	116.01	75.54	487.5	114.19

SITE	ID	SEX	AGE	AGE #	TOTAL DIAMETER	INLET AP DIAMETER	OUTLET AP DIAMETER	INTERISCHIAL SPINOUS DIAMETER	FEMUR LENGTH	INTERISCHIAL TUBEROUS DIAMETER
Nubian Egypt	3226	M	Y		114.92	118.96	113.29	87.32	499.0	128.75
Sai Island	TO28-1	M	O		127.04	115.85	92.27	74.66		123.94
Sai Island	TO28-2	M	Y		118.27	104.34	100.59	84.11		123.13
Sai Island	T312-2	F	O		116.13	114.74	132.20	98.21	407.5	133.57
Sai Island	T312-1	M	Y						485.5	
Sai Island	TO34A-3	F	Y		112.91	119.45	116.76	104.10		137.01
Sai Island	TO34A-1	M	Y		119.56	116.08	133.83	89.33		124.51
Sai Island	TO34A-2	F	O		118.61	113.68	124.33	98.84		136.04
Sai Island	TO35-2	M	O		117.71	111.34	129.26	78.69		118.27
Sai Island	TO35-1	M	O		109.27	114.72	107.13	73.86		121.67
Pygmy-Democratic Republic of Congo	99-7189	M	O		88.21	97.48	98.58	69.61	364.5	103.11
India	99-8421	F	O		117.17	97.17	113.97	116.95	364.0	153.78
India	99-8422	M	Y		109.02	117.00	109.11	77.04	447.5	114.60
India	99-9955	M	Y		108.15	113.58	106.40	81.19	454.5	124.92

SITE	**ID**	**SEX**	**AGE**	**AGE #**	**TOTAL DIAMETER**	**INLET AP DIAMETER**	**OUTLET AP DIAMETER**	**INTERISCHIAL SPINOUS DIAMETER**	**FEMUR LENGTH**	**INTERISCHIAL TUBEROUS DIAMETER**
India	99-8420	M	O		102.96	104.08	103.93	80.42		112.18
India	99-8419	F	O		109.57	110.01	115.44	95.36	381.5	132.10
India	99-9959	M	O		101.21	93.58		75.94	417.0	112.46
India	99-9957	M	Y		98.83	90.99	102.22	71.75	416.0	106.17
Dakhleh Oasis, Egypt	DAM-TR9-38	M	O		120.18	99.55	95.39		444.9	134.32
Dakhleh Oasis, Egypt	DAM-TR14A-10	M	O		124.49	118.46	124.48	83.58	471.4	142.58
Dakhleh Oasis, Egypt	DAM-TR4-6	F	O		125.55	102.38	102.66		394.1	
America	98-260	F	Y	24					462.5	
America	98-200	F	Y	25	137.84	130.25		108.70	470.5	142.01
America	98-356	F	O	31	121.78	119.52	132.17	106.36	467.0	152.65
America	98-99	F	O	47	128.27	131.97	123.32	107.34	423.5	143.73
America	98-258	F	O	34					437.5	
America	98-193	F	O	40	130.00	136.73	125.17	115.12		165.72
America	98-117	F	O	40	141.56	129.24	127.23	126.56	440.0	172.71
America	98-366	F	O	46		124.27	115.97		415.5	
America	98-291	F	O	50					476.0	
America	98-166	F	O	55	131.86	127.60		116.15	455.0	149.46
America	98-364	M	O	39	120.52	119.34	114.14	99.15	533.5	154.72

(Collected Data Table continued)

ID	SACRAL-ISCHIAL SPINE LENGTH		GREATER SCIATIC NOTCH WIDTH		ILIAC BLADE LENGTH		ALAR-PUBIS LENGTH	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
VL3102	67.34	69.47	56.60	54.14	146.55	151.09	130.46	
VL3123	63.22	62.53	41.27	40.19	163.26	163.61		107.30
VL 3105	74.19	71.22		46.79	147.18	141.36	115.87	
VL3168	66.70	67.80	40.35	43.81		137.34		126.46
VL3014			47.14	48.37	155.81	157.45	115.63	109.45
VL3124			40.77	42.47	162.57	160.84	114.10	114.89
VL3163			45.64	45.27	143.91	145.52	123.24	120.23
VL 3167		73.85		42.26		129.78		122.50
VL3111		66.75		47.06		135.77		115.73
VL3146	76.11		41.93		141.48			
VL3104	55.28	56.43	39.56	37.63	146.46	149.77	111.44	113.09
3175			41.26	40.42	146.90	145.63	123.80	122.64
VL3174	57.72	54.55	35.18	32.74	150.23	150.08	108.69	109.28
VL3124	59.28	58.18	36.89	39.10	146.55	150.46	116.17	112.85
99 8452	64.44	67.43	36.58	41.94	133.27	132.16	92.84	93.22
2470	60.94	55.31	39.45	38.95	148.41	144.90	110.75	112.31
2471	50.99	55.87	40.31	39.56	145.48	142.90	112.46	116.98
3223	57.55	57.21	32.65	33.36	153.19	153.05	105.73	108.68
3222	64.78	55.66	38.50	36.04	157.85	156.02	115.94	112.90
3221	58.49	51.59	30.79	30.73	148.72	149.73	98.86	96.95
3226	54.59	52.92	42.45	42.62	153.00	152.32	112.49	112.84
TO28-1	53.08	54.77	39.75	38.97		166.00	118.19	
TO28-2	60.61	63.68		37.76		149.15	102.48	108.18
T312-2	76.37	77.28	48.95	47.58	142.00	141.73	116.67	119.36
T312-1			36.46	35.80	156.07	157.28	108.51	106.74

ID	SACRAL-ISCHIAL SPINE LENGTH		GREATER SCIATIC NOTCH WIDTH		ILIAC BLADE LENGTH		ALAR-PUBIS LENGTH	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
TO34A-3	69.64	66.36	47.42	45.63	144.03	147.73	116.54	114.92
TO34A-1	67.40	64.39	35.95	39.74	155.46	155.23	122.93	119.29
TO34A-2	68.04	67.95	46.16	46.35	146.85	145.37	118.48	120.49
TO35-2	64.96	60.24	43.10	41.95	159.92	157.76	119.43	117.64
TO35-1	51.35	53.43	31.07	31.86	143.00	136.30	110.87	110.44
99-7189	45.28	44.74	36.41	32.35	119.81	118.31	91.52	95.48
99-8421	70.71	66.99	40.59	41.36	128.85	127.17	104.03	112.93
99-8422	55.70	54.53	38.62	35.87	149.47	147.69	107.33	108.36
99-9955	53.20	55.49	38.24	35.32	139.06	138.79	114.77	113.09
99-8420	55.13	54.20	34.75	37.12	134.33	132.24	104.27	105.37
99-8419	67.33	63.14	45.66	47.13	128.46	124.95	109.26	110.89
99-9959			31.23	32.71	116.82		100.22	95.85
99-9957	48.34	41.48	33.17	34.55	133.85	130.55	93.15	92.97
DAM-TR9-38	57.50	56.49	42.05	44.85	166.35	164.35	138.89	135.72
DAM-TR14A-10	71.46	69.06	41.01	45.21	171.35	169.35	156.26	153.26
DAM-TR4-6		58.57	36.95	36.19				139.18
98-260			44.21	44.83	145.90	147.05	129.43	133.35
98-200			53.78	46.25	164.34	164.30	133.89	137.25
98-356	73.48	74.00	49.54	47.92	148.61	148.96	123.01	123.84
98-99	62.94	61.58	51.50	48.76	147.82	147.81	123.26	123.86
98-258			43.72	44.45	152.84	154.05	123.74	122.83
98-193	68.59	71.85	51.14	52.43	156.76	161.29	132.53	134.50
98-117	78.07	74.04	50.39	55.93	160.27	161.51	123.31	122.84
98-366	74.84		46.54	49.62	145.47	142.73	119.54	121.19
98-291			48.79	47.18				
98-166			36.79	38.14	160.92	160.27	116..21	120.62
98-364	55.67	59.94	42.56	38.52	159.02	159.09	113.74	116.90

Note: All measurements are in millimeters. Pelvises 99-7189 and 99-8421 were excluded from the analysis.

APPENDIX B: R PROCEDURES

Box's M Test (from Rencher 2002)

```
> x1 = read.csv("~/Desktop/Thesis/DATA F1.csv") ; x1
```

x1 includes all variables for the young female group

```
      TD   IAPD   OAPD    ISD    ITD SISLAv GSNWAv  IBLAv  APLAv
1 123.91 127.59 109.65 101.33 140.49 68.940 55.370 148.82 130.46
2 125.33 125.62 100.58 113.22 148.23 71.965 46.790 144.27 115.87
3 135.66 122.99 104.94 107.70 135.38 67.525 42.080 137.34 126.46
4 112.91 119.45 116.76 104.10 137.01 68.000 46.525 145.88 115.73
> x2 = read.csv("~/Desktop/Thesis/DATA F2.csv") ; x2
```

x2 includes all variables for the old female group

```
      TD   IAPD   OAPD    ISD    ITD SISLAv GSNWAv   IBLAv   APLAv
1 116.13 114.74 132.20  98.21 133.57 76.825 48.265 141.865 118.015
2 118.61 113.68 124.33  98.84 136.04 67.995 46.255 146.110 119.485
3 109.57 110.01 115.44  95.36 132.10 65.235 46.395 126.705 110.075
4 121.78 119.52 132.17 106.36 152.65 73.740 48.730 148.785 123.425
5 128.27 131.97 123.32 107.34 143.73 62.260 50.130 147.815 123.560
6 130.00 136.73 125.17 115.12 165.72 70.220 51.785 159.025 133.515
7 141.56 129.24 127.23 126.56 172.71 76.055 53.160 160.890 123.075
> x3 = read.csv("~/Desktop/Thesis/DATA M3.csv") ; x3
```

x3 includes all variables for the young male group

```
      TD   IAPD   OAPD   ISD    ITD SISLAv GSNWAv   IBLAv   APLAv
1 122.71  92.95 100.24 84.59 127.44 56.145 38.595 148.115 112.265
2 117.18  98.81  95.17 71.25 112.47 55.345 33.960 150.155 108.985
3 108.44 123.33 111.80 89.19 127.63 60.220 37.270 156.935 114.420
4 114.92 118.96 113.29 87.32 128.75 53.755 42.535 152.660 112.665
5 118.27 104.34 100.59 84.11 123.13 62.145 37.760 149.150 105.330
6 119.56 116.08 133.83 89.33 124.51 65.895 37.845 155.345 121.110
7 109.02 117.00 109.11 77.04 114.60 55.115 37.245 148.580 107.845
8 108.15 113.58 106.40 81.19 124.92 54.345 36.780 138.925 113.930
9  98.83  90.99 102.22 71.75 106.17 44.910 33.860 132.200  93.060
> x4 = read.csv("~/Desktop/Thesis/DATA M4.csv") ; x4
```

x4 includes all variables for the old male group

```
       TD   IAPD   OAPD    ISD    ITD SISLAv GSNWAv   IBLAv   APLAv
1  123.83 101.03  99.76  99.21 142.19 62.705 40.730 163.435 107.300
2  123.14 101.20 118.84  84.30 118.44 57.295 33.005 153.120 107.205
3  115.35 108.68 108.42  84.24 125.22 58.730 37.995 148.505 114.510
4  106.66  94.60 100.24 105.07 132.65 65.935 39.260 132.715  93.030
5  103.48 115.44 126.54  87.15 119.06 58.125 39.200 146.655 111.530
6  108.17 115.40 123.31  79.64 123.94 53.430 39.935 144.190 114.720
7  100.56  96.90 116.01  75.54 114.19 55.040 30.760 149.225  97.905
8  127.04 115.85  92.27  74.66 123.94 53.925 39.360 166.000 118.190
9  117.71 111.34 129.26  78.69 118.27 62.600 42.525 158.840 118.535
```

```
10 109.27 114.72 107.13  73.86 121.67 52.390 31.465 139.650 110.655
11 102.96 104.08 103.93  80.42 112.18 54.665 35.935 133.285 104.820
12 124.49 118.46 124.48  83.58 142.58 70.260 43.110 170.350 154.760
13 120.52 119.34 114.14  99.15 154.72 57.805 40.540 159.055 115.320
> s1 <- cov(x1, y = NULL, use = "everything")
> s1
                TD        IAPD       OAPD         ISD        ITD
SISLAv     GSNWAv
TD      86.6338917  13.5575917 -47.604475  16.6175083  -3.436858 -
0.7847417 -18.127738
IAPD    13.5575917  12.4014917 -14.290142   0.6882417  11.153175
3.5550917  12.360163
OAPD   -47.6044750 -14.2901417  47.959625 -27.6942583 -24.097958 -
8.7794250   8.770429
ISD     16.6175083   0.6882417 -27.694258  26.3522250  18.102392
6.9424583 -16.563346
ITD     -3.4368583  11.1531750 -24.097958  18.1023917  32.649825
11.3525750   8.585454
SISLAv  -0.7847417   3.5550917  -8.779425   6.9424583  11.352575
3.9747417   2.103304
GSNWAv -18.1277375  12.3601625   8.770429 -16.5633458   8.585454
2.1033042  30.873906
IBLAv  -32.9065917   5.3136417  14.267808 -11.8787083   9.881958
2.8071750  23.982204
APLAv   37.4627667  14.8367333  -3.040033 -21.5257667 -16.102233 -
6.3491500  17.591033
             IBLAv       APLAv
TD     -32.9065917  37.4627667
IAPD     5.3136417  14.8367333
OAPD    14.2678083  -3.0400333
ISD    -11.8787083 -21.5257667
ITD      9.8819583 -16.1022333
SISLAv   2.8071750  -6.3491500
GSNWAv  23.9822042  17.5910333
IBLAv   23.7237583  -0.8031333
APLAv   -0.8031333  56.0951333
> s2 <- cov(x2, y = NULL, use = "everything") ; s2
                TD       IAPD      OAPD       ISD       ITD    SISLAv
GSNWAv     IBLAv
TD     111.01846  89.858367 17.238336 112.63859 153.21529 15.473115
25.644223 109.04906
IAPD    89.85837 106.686933  8.455450  89.63265 130.09695 -2.621475
```

```
23.670200  94.80332
OAPD    17.23834   8.455450 33.256895  15.68948  25.73166 24.629686
4.362121  33.42812
ISD    112.63859  89.632650 15.689481 121.36389 172.06423 21.238901
27.336694 109.57973
ITD    153.21529 130.096950 25.731662 172.06423 261.41263 34.173952
38.465196 161.39917
SISLAv  15.47312  -2.621475 24.629686  21.23890  34.17395 30.522824
4.728860  24.97173
GSNWAv  25.64422  23.670200  4.362121  27.33669  38.46520  4.728860
6.808379  25.04291
IBLAv  109.04906  94.803317 33.428124 109.57973 161.39917 24.971730
25.042905 129.95704
APLAv   51.26890  63.837383 16.821002  51.33535  84.66271  6.318957
13.252814  70.47125
           APLAv
TD     51.268899
IAPD   63.837383
OAPD   16.821002
ISD    51.335351
ITD    84.662711
SISLAv  6.318957
GSNWAv 13.252814
IBLAv  70.471255
APLAv  50.244299
> s3 <- cov(x3, y = NULL, use = "everything") ; s3
              TD       IAPD       OAPD      ISD      ITD    SISLAv
GSNWAv    IBLAv
TD     55.899261  -2.697739   9.935365 23.22225 32.79631 30.133963
8.285627 37.27033
IAPD   -2.697739 143.054261  85.730390 50.75505 50.60815 33.885882
15.736377 55.62011
OAPD    9.935365  85.730390 128.312644 50.27302 34.10420 35.872224
11.461777 39.71829
ISD    23.222253  50.755053  50.273019 48.77722 51.02867 28.959286
13.481271 36.10886
ITD    32.796311  50.608149  34.104203 51.02867 63.91544 28.536907
16.176696 37.62081
SISLAv 30.133963  33.885882  35.872224 28.95929 28.53691 35.476559
4.713758 36.91181
GSNWAv  8.285627  15.736377  11.461777 13.48127 16.17670  4.713758
6.606487 10.08104
```

```
IBLAv  37.270328  55.620109  39.718288 36.10886 37.62081 36.911814
10.081040 61.72627
APLAv  35.067802  58.740808  54.647152 39.42021 47.83707 34.791821
10.050466 44.61967
          APLAv
TD      35.06780
IAPD    58.74081
OAPD    54.64715
ISD     39.42021
ITD     47.83707
SISLAv 34.79182
GSNWAv 10.05047
IBLAv   44.61967
APLAv   60.63446
> s4 <- cov(x4, y = NULL, use = "everything") ; s4
              TD       IAPD       OAPD        ISD       ITD    SISLAv
GSNWAv      IBLAv
TD      86.80526  25.425439 -15.509459  11.920609  63.46824 16.789079
16.978195  92.582166
IAPD    25.42544  72.199740  32.453306 -24.704656  32.02099 -4.834942
14.505446  42.336335
OAPD   -15.50946  32.453306 136.178308 -23.397783 -16.30956 11.736013
8.083516  19.498004
ISD     11.92061 -24.704656 -23.397783 101.888908  86.77273 29.098262
16.384576  -4.707495
ITD     63.46824  32.020992 -16.309558  86.772733 160.00533 34.210421
28.367892  73.641408
SISLAv  16.78908  -4.834942  11.736013  29.098262  34.21042 28.366579
13.349646  23.158083
GSNWAv  16.97819  14.505446   8.083516  16.384576  28.36789 13.349646
16.120771  23.398928
IBLAv   92.58217  42.336335  19.498004  -4.707495  73.64141 23.158083
23.398928 144.682920
APLAv   74.23184  88.023425  66.179250 -33.326713  69.30476 34.431106
31.888919 118.273344
            APLAv
TD       74.23184
IAPD     88.02342
OAPD     66.17925
ISD     -33.32671
ITD      69.30476
SISLAv   34.43111
```

```
GSNWAv  31.88892
IBLAv  118.27334
APLAv  214.94786
> d1 <- det(s1) ; d1
[1] 2.770818e-83
> d2 <- det(s2) ; d2
[1] -4.231508e-35
> d3 <- det(s3) ; d3
[1] 4.059581e-06
> d4 <- det(s4) ; d4
[1] 2.890173e+13
> spl <- (((3 * s1) + (6 * s2) + (8 * s3) + (12 * s4)) * (1/29))
> spl
              TD      IAPD       OAPD       ISD        ITD    SISLAv
GSNWAv     IBLAv
TD      83.271365 29.770563  -5.034965 36.362394  66.654156 18.380177
12.741568  67.74908
IAPD    29.770563 92.695070  37.349830 22.394661  55.281321  7.172558
16.519243  53.02613
OAPD    -5.034965 37.349830 103.588314  4.567754   5.490173 18.939648
8.316566  27.41705
ISD     36.362394 22.394661   4.567754 83.452575  87.454989 25.141870
14.441214  29.45597
ITD     66.654156 55.281321   5.490173 87.454989 141.303887 30.273164
25.047442  75.26566
SISLAv 18.380177  7.172558  18.939648 25.141870  30.273164 28.250779
8.020307  25.22219
GSNWAv 12.741568 16.519243   8.316566 14.441214  25.047442  8.020307
13.095626  20.12550
IBLAv  67.749076 53.026128  27.417052 29.455971  75.265663 25.222187
20.125500 106.23858
APLAv  54.873318 67.370416  45.625315  5.478480  57.724941 24.495660
20.529681  75.74675
           APLAv
TD      54.87332
IAPD    67.37042
OAPD    45.62531
ISD      5.47848
ITD     57.72494
SISLAv  24.49566
GSNWAv  20.52968
IBLAv   75.74675
```

```
APLAv  121.86901
> dpl <- det(spl) ; dpl
[1] 7.669021e+13
> M1 <- ((0.5) * ((3 * log(d1)) + (6 * log(abs(d2))) + (8 * log(d3)) +
12 * log(d4))) - (14.5 * log(dpl))
> M1
[1] -849.8516

therefore, ln(M)=-849.8516
therefore, -2ln(M)=1699.7032


In the chi-squared approximation of Box's M,
```

$$c_1 = 0.595753512$$
$$u = -2(1 - c_1)ln\mathrm{M}$$
$$u = 1012.604151$$
$$u > \chi^2_{0.5}(135)$$

```
therefore, we reject H0
```

MANOVA test for geographic differences in all males

```
> data = read.csv("~/Desktop/Thesis/DATAMGEO.csv"); data
# data includes all variables for all males
> manova <- manova (cbind(TD, IAPD, OAPD, ISD, ITD, SISLAv, GSNWAv,
IBLAv, APLAv) ~ as.factor(X), data=data)
> summary(manova)
             Df Pillai approx F num Df den Df Pr(>F)
as.factor(X)  4 2.2089   1.3703     36     40 0.1661
Residuals    15
```

Kruskall-Wallis tests for male and female groups

```
> datamf = read.csv("~/Desktop/Thesis/Data/DATAMF.csv") ; datamf
> kruskal.test(TD ~ X, data = datamf)

    Kruskal-Wallis rank sum test

data:  TD by X
Kruskal-Wallis chi-squared = 7.5605, df = 1, p-value = 0.005966

> kruskal.test(IAPD ~ X, data = datamf)

    Kruskal-Wallis rank sum test
```

```
data:  IAPD by X
Kruskal-Wallis chi-squared = 11.0389, df = 1, p-value = 0.0008922

> kruskal.test(OAPD ~ X, data = datamf)

    Kruskal-Wallis rank sum test

data:  OAPD by X
Kruskal-Wallis chi-squared = 3.9443, df = 1, p-value = 0.04703

> kruskal.test(ISD ~ X, data = datamf)

    Kruskal-Wallis rank sum test

data:  ISD by X
Kruskal-Wallis chi-squared = 17.6471, df = 1, p-value = 2.659e-05

> kruskal.test(ITD ~ X, data = datamf)

    Kruskal-Wallis rank sum test

data:  ITD by X
Kruskal-Wallis chi-squared = 14.2965, df = 1, p-value = 0.0001562

> kruskal.test(SISLAv ~ X, data = datamf)

    Kruskal-Wallis rank sum test

data:  SISLAv by X
Kruskal-Wallis chi-squared = 17.0112, df = 1, p-value = 3.716e-05

> kruskal.test(GSNWAv ~ X, data = datamf)

    Kruskal-Wallis rank sum test

data:  GSNWAv by X
Kruskal-Wallis chi-squared = 20.3072, df = 1, p-value = 6.595e-06

> kruskal.test(IBLAv ~ X, data = datamf)

    Kruskal-Wallis rank sum test
```

```
data:  IBLAv by X
Kruskal-Wallis chi-squared = 1.4016, df = 1, p-value = 0.2365

> kruskal.test(APLAv ~ X, data = datamf)

    Kruskal-Wallis rank sum test

data:  APLAv by X
Kruskal-Wallis chi-squared = 11.2941, df = 1, p-value = 0.0007775
```

MANOVA test for all groups

```
> data = read.csv("~/Desktop/Thesis/DATA.csv")
```

data includes all variables for all groups; 1: young female, 2: old females, 3: young males, 4: old males

```
> data
> manova <- manova (cbind(TD, IAPD, OAPD, ISD, ITD, SISLAv, GSNWAv,
IBLAv, APLAv) ~ as.factor(X), data=data)
> summary(manova)
             Df Pillai approx F num Df den Df  Pr(>F)
as.factor(X)  3 1.4586   2.4182     27     69 0.00172 **
Residuals    29
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> summary.aov(manova)
 Response TD :
             Df  Sum Sq Mean Sq F value  Pr(>F)
as.factor(X)  3  789.77 263.258  3.1614 0.03945 *
Residuals    29 2414.87  83.271
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 Response IAPD :
             Df Sum Sq Mean Sq F value   Pr(>F)
as.factor(X)  3 1464.6  488.19  5.2666 0.005045 **
Residuals    29 2688.2   92.70
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 Response OAPD :
             Df Sum Sq Mean Sq F value   Pr(>F)
as.factor(X)  3 1437.1  479.03  4.6244 0.009205 **
Residuals    29 3004.1  103.59
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 Response ISD :
             Df Sum Sq Mean Sq F value    Pr(>F)
as.factor(X)  3 3952.3 1317.43  15.787 2.831e-06 ***
Residuals    29 2420.1   83.45
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 Response ITD :
             Df Sum Sq Mean Sq F value    Pr(>F)
as.factor(X)  3 3491.2  1163.7  8.2356 0.0004078 ***
Residuals    29 4097.8   141.3
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 Response SISLAv :
             Df  Sum Sq Mean Sq F value    Pr(>F)
as.factor(X)  3 1108.89  369.63  13.084 1.394e-05 ***
Residuals    29  819.27   28.25
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 Response GSNWAv :
             Df Sum Sq Mean Sq F value    Pr(>F)
as.factor(X)  3 890.74 296.914  22.673 9.295e-08 ***
Residuals    29 379.77  13.096
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 Response IBLAv :
             Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  3  181.46  60.485  0.5693 0.6397
Residuals    29 3080.92 106.239

 Response APLAv :
             Df Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  3  790.4  263.46  2.1619  0.114
Residuals    29 3534.2  121.87
```

MANOVA tests for all females

```
> dataf = read.csv("~/Desktop/Thesis/Data/DATAF.csv") ; dataf
# dataf includes all variables for all female groups; 1: young female, 2: old females
> manovaf <- manova (cbind(TD, IAPD, OAPD, ISD, ITD, SISLAv, GSNWAv,
IBLAv, APLAv) ~ as.factor(X), data=dataf)
> summary(manovaf)
             Df  Pillai approx F num Df den Df Pr(>F)
as.factor(X)  1 0.96961   3.5448      9      1 0.3918
Residuals     9
> summary.aov(manovaf)
 Response TD :
             Df Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1   1.43    1.43  0.0139 0.9087
Residuals     9 926.01  102.89

 Response IAPD :
             Df Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1   6.87   6.867  0.0912 0.7695
Residuals     9 677.33  75.258

 Response OAPD :
             Df Sum Sq Mean Sq F value   Pr(>F)
as.factor(X)  1 798.53  798.53  20.927 0.001338 **
Residuals     9 343.42   38.16
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 Response ISD :
             Df Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1   0.15   0.146  0.0016 0.9687
Residuals     9 807.24  89.693

 Response ITD :
             Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1  154.74  154.74  0.8357 0.3845
Residuals     9 1666.43  185.16

 Response SISLAv :
             Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1   3.822   3.822  0.1763 0.6844
Residuals     9 195.061  21.674

 Response GSNWAv :
```

```
             Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1   6.151  6.1507  0.4147 0.5356
Residuals     9 133.472 14.8302

 Response IBLAv :
             Df Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1  26.66  26.656  0.2819 0.6083
Residuals     9 850.91  94.546

 Response APLAv :
             Df Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1   0.73   0.734  0.0141 0.9082
Residuals     9 469.75  52.195
```

MANOVA tests for all males

data includes all variables for all male groups; 3: young males, 4: old males

```
> manova2 <- manova ( cbind(TD, IAPD, OAPD, ISD, ITD, SISLAv, GSNWAv,
IBLAv, APLAv) ~ as.factor(X), data=data, subset = as.factor(X) %in%
c("3", "4"))
> summary(manova2)
             Df  Pillai approx F num Df den Df Pr(>F)
as.factor(X)  1 0.16825  0.26972      9     12 0.9715
Residuals    20
> summary.aov(manova2)
 Response TD :
             Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1    6.22   6.225  0.0836 0.7754
Residuals    20 1488.86  74.443

 Response IAPD :
             Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1    1.63   1.633  0.0162 0.8999
Residuals    20 2010.83 100.542

 Response OAPD :
             Df Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1  111.0  111.00  0.8344 0.3719
Residuals    20 2660.6  133.03

 Response ISD :
             Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)  1   57.46  57.460  0.7125 0.4086
```

```
Residuals     20 1612.88  80.644

 Response ITD :
              Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)   1  177.74  177.74   1.462 0.2407
Residuals     20 2431.39  121.57

 Response SISLAv :
              Df Sum Sq Mean Sq F value Pr(>F)
as.factor(X)   1  27.03  27.030   0.866 0.3632
Residuals     20 624.21  31.211

 Response GSNWAv :
              Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)   1   2.384  2.3837  0.1936 0.6647
Residuals     20 246.301 12.3151

 Response IBLAv :
              Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)   1   52.72  52.721  0.4728 0.4996
Residuals     20 2230.01 111.500

 Response APLAv :
              Df  Sum Sq Mean Sq F value Pr(>F)
as.factor(X)   1   47.97   47.97  0.3131  0.582
Residuals     20 3064.45  153.22
```

Individual Kruskal-Wallis tests for variables

data includes specified variables for all 4 groups

```
> data = read.csv("~/Desktop/Thesis/Data/DATA.csv") ; data
> kruskal.test(TD ~ X, data = data)

    Kruskal-Wallis rank sum test

data:  TD by X
Kruskal-Wallis chi-squared = 7.805, df = 3, p-value = 0.05022

> kruskal.test(IAPD ~ X, data = data)

    Kruskal-Wallis rank sum test

data:  IAPD by X
```

```
Kruskal-Wallis chi-squared = 11.6239, df = 3, p-value = 0.008789

> kruskal.test(OAPD ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  OAPD by X
Kruskal-Wallis chi-squared = 0.8745, df = 1, p-value = 0.3497

> kruskal.test(ISD ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  ISD by X
Kruskal-Wallis chi-squared = 0.0546, df = 1, p-value = 0.8152

> kruskal.test(ITD ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  ITD by X
Kruskal-Wallis chi-squared = 0.1885, df = 1, p-value = 0.6642

> kruskal.test(SISLAv ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  SISLAv by X
Kruskal-Wallis chi-squared = 0.4025, df = 1, p-value = 0.5258

> kruskal.test(GSNWAv ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  GSNWAv by X
Kruskal-Wallis chi-squared = 1.0713, df = 1, p-value = 0.3006

> kruskal.test(IBLAv ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  IBLAv by X
```

```
Kruskal-Wallis chi-squared = 0.4025, df = 1, p-value = 0.5258

> kruskal.test(APLAv ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  APLAv by X
Kruskal-Wallis chi-squared = 0.0903, df = 1, p-value = 0.7638
```

Individual Kruskal-Wallis tests for variables: all females

```
# data includes specified variables for all female groups
> dataf = read.csv("~/Desktop/Thesis/DATAF.csv")
> kruskal.test(TD ~ X, data = dataf)

    Kruskal-Wallis rank sum test

data:  TD by X
Kruskal-Wallis chi-squared = 0.0357, df = 1, p-value = 0.8501

> kruskal.test(IAPD ~ X, data = dataf)

    Kruskal-Wallis rank sum test

data:  IAPD by X
Kruskal-Wallis chi-squared = 0.0357, df = 1, p-value = 0.8501

> kruskal.test(OAPD ~ X, data = dataf)

    Kruskal-Wallis rank sum test

data:  OAPD by X
Kruskal-Wallis chi-squared = 6.0357, df = 1, p-value = 0.01402

> kruskal.test(ISD ~ X, data = dataf)

    Kruskal-Wallis rank sum test

data:  ISD by X
Kruskal-Wallis chi-squared = 0.1429, df = 1, p-value = 0.7055

> kruskal.test(ITD ~ X, data = dataf)
```

```
    Kruskal-Wallis rank sum test

data:  ITD by X
Kruskal-Wallis chi-squared = 0.1429, df = 1, p-value = 0.7055

> kruskal.test(SISLAv ~ X, data = dataf)

    Kruskal-Wallis rank sum test

data:  SISLAv by X
Kruskal-Wallis chi-squared = 0.1429, df = 1, p-value = 0.7055

> kruskal.test(GSNWAv ~ X, data = dataf)

    Kruskal-Wallis rank sum test

data:  GSNWAv by X
Kruskal-Wallis chi-squared = 0.3214, df = 1, p-value = 0.5708

> kruskal.test(IBLAv ~ X, data = dataf)

    Kruskal-Wallis rank sum test

data:  IBLAv by X
Kruskal-Wallis chi-squared = 0.5714, df = 1, p-value = 0.4497

> kruskal.test(APLAv ~ X, data = dataf)

    Kruskal-Wallis rank sum test

data:  APLAv by X
Kruskal-Wallis chi-squared = 0, df = 1, p-value = 1
```

Individual Kruskal-Wallis tests for variables: all males

data includes specified variables for all male groups

```
> datam = read.csv("~/Desktop/Thesis/DATAM.csv")
> kruskal.test(TD ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  TD by X
Kruskal-Wallis chi-squared = 0.1884, df = 1, p-value = 0.6642
```

```
> kruskal.test(IAPD ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  IAPD by X
Kruskal-Wallis chi-squared = 0.0279, df = 1, p-value = 0.8674

> kruskal.test(OAPD ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  OAPD by X
Kruskal-Wallis chi-squared = 0.8745, df = 1, p-value = 0.3497

> kruskal.test(ISD ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  ISD by X
Kruskal-Wallis chi-squared = 0.0546, df = 1, p-value = 0.8152

> kruskal.test(ITD ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  ITD by X
Kruskal-Wallis chi-squared = 0.1885, df = 1, p-value = 0.6642

> kruskal.test(SISLAv ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  SISLAv by X
Kruskal-Wallis chi-squared = 0.4025, df = 1, p-value = 0.5258

> kruskal.test(GSNWAv ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  GSNWAv by X
Kruskal-Wallis chi-squared = 1.0713, df = 1, p-value = 0.3006
```

```
> kruskal.test(IBLAv ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  IBLAv by X
Kruskal-Wallis chi-squared = 0.4025, df = 1, p-value = 0.5258

> kruskal.test(APLAv ~ X, data = datam)

    Kruskal-Wallis rank sum test

data:  APLAv by X
Kruskal-Wallis chi-squared = 0.0903, df = 1, p-value = 0.7638
```

Individual Mann-Whitney-Wilcoxon tests for variables: all females for asymmetry

```
# data includes specified variables for all female groups
> dataf = read.csv("~/Desktop/Thesis/Data/DATAF APL.csv") ; dataf
> wilcox.test(APL ~ X, data=dataf)

    Wilcoxon rank sum test

data:  APL by X
W = 35, p-value = 0.03596
alternative hypothesis: true location shift is not equal to 0

> dataf2 = read.csv("~/Desktop/Thesis/Data/DATAF GSNW.csv") ; dataf2
wilcox.test(GSNW ~ X, data=dataf2)

    Wilcoxon rank sum test

data:  GSNW by X
W = 47, p-value = 0.5214
alternative hypothesis: true location shift is not equal to 0

> dataf3 = read.csv("~/Desktop/Thesis/Data/DATAF IBL.csv") ; dataf3
> wilcox.test(IBL ~ X, data=dataf3)

    Wilcoxon rank sum test

data:  IBL by X
W = 45, p-value = 0.2561
```

```
alternative hypothesis: true location shift is not equal to 0

> dataf4 = read.csv("~/Desktop/Thesis/Data/DATAF SISL.csv") ; dataf4
> wilcox.test(SISL ~ X, data=dataf4)

    Wilcoxon rank sum test

data:  SISL by X
W = 16, p-value = 0.7879
alternative hypothesis: true location shift is not equal to 0
```

Individual Mann-Whitney-Wilcoxon tests for variables: all males for asymmetry

data includes specified variables for all male groups

```
> datam1 = read.csv("~/Desktop/Thesis/Data/DATAM APL.csv") ; datam1
> wilcox.test(APL ~ X, data=datam1)

    Wilcoxon rank sum test

data:  APL by X
W = 65, p-value = 0.3474
alternative hypothesis: true location shift is not equal to 0

> datam2 = read.csv("~/Desktop/Thesis/Data/DATAM GSNW.csv") ; datam2
> wilcox.test(GSNW ~ X, data=datam2)

    Wilcoxon rank sum test

data:  GSNW by X
W = 94, p-value = 0.7897
alternative hypothesis: true location shift is not equal to 0

> datam3 = read.csv("~/Desktop/Thesis/Data/DATAM IBL.csv") ; datam3
> wilcox.test(IBL ~ X, data=datam3)

    Wilcoxon rank sum test with continuity correction

data:  IBL by X
W = 60, p-value = 0.3663
alternative hypothesis: true location shift is not equal to 0

> datam4 = read.csv("~/Desktop/Thesis/Data/DATAM SISL.csv") ; datam4
> wilcox.test(SISL ~ X, data=datam4)
```

```
    Wilcoxon rank sum test

data:  SISL by X
W = 85, p-value = 0.3175
alternative hypothesis: true location shift is not equal to 0
```

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