A morphometric analysis of parturition scarring on the human pelvic bone.

by

Sarah-Louise Decrausaz
BSc., University of Toronto, 2012

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in the Department of Anthropology

Supervisory Committee

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Abstract

Osteological studies have identified scarring on the bone surface of the human pelvic bone as evidence of childbirth, termed parturition scarring. It remains unknown whether a single or multiple births cause parturition scarring. Such scarring has also been found on male pelvic bones. This study examines parturition scarring within the broader morphometric and musculoskeletal context of the pelves of both sexes. This project investigates the influence of body size (stature and body mass) and pelvic size (individual pelvic measurements and pelvic canal size) and shape (pelvic canal shape) on the presence of parturition scarring on the pelvic bones of females and males. Two skeletal collections of known-age and sex were chosen for this project on the basis of access to parity (childbirth) records: the Maxwell Museum Documented Skeletal Collection and the Christ Church, Spitalfields collection. The dimensions of articulated and disarticulated pelves, femoral measurements and scores for six types of parturition scarring were recorded for all individuals (n=292). Skeletal proxies for body mass and stature were calculated for all individuals. Univariate, bivariate and multivariate statistical analyses were used to identify significant differences in parturition scarring between sexes, correlation between body size variables, parity status, pelvic canal size and pelvic canal shape (as represented by

principal components analysis) and parturition scarring. Parity status and pelvic canal shape do not associate with parturition scarring. Pubic tubercle variables associated variously with femoral head diameter and pelvic canal size in females or males only. Dorsal pitting correlates weakly with four pelvic dimensions in females. The results of this study suggest that the term ‘parturition scarring’ should be revised to reflect its non-connection with parity status and that future investigations should examine musculoskeletal interactions based on body and pelvic size variation that affect the presence of such scarring in males.

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Acknowledgments

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Dedication

For:
Christine, Philippe and Mark-Henry Decrausaz.

Chapter 1: Background

1.1. Introduction

Parturition scarring, which includes pitting or rugosity on the dorsal surface of the pelvic bone body (Figure 1), has been identified in previous studies as osteological evidence of childbirth (e.g. Stewart 1957; Angel 1969; Houghton 1974; Holt 1978; Cox 1989), however it is not known whether osteological responses to greater muscular loading and tendon use eventuate due to smaller, repetitive loading or due to less frequent and significantly increased loading (as would occur with one or multiple childbirth events). The discovery of parturition scarring on some male pelves also suggests causation alternative to childbirth. The precise musculoskeletal aetiology for the development of bony scar tissue from the event of parturition remains unknown.

The purpose of this study is to investigate the influence of body size (stature and body mass) and pelvic size and shape on the presence and type of parturition scarring on the human pelvic bone. More specifically, this study's approach does not assume that parturition scarring is directly attributable to the event of parturition, but examines parturition scarring within the broader morphometric and musculoskeletal context of the pelves of both sexes.

The examination of parturition scarring from a morphometric perspective will aid in determining whether parturition scarring is indeed caused by childbirth. If parturition scarring is recorded amongst males, the causation of such scarring cannot be parturition-related and the definition (and indeed terminology) of parturition scarring will need to be reconsidered. A morphometric perspective on parturition scarring will also contribute to understanding the variation in the presence of parturition scarring in

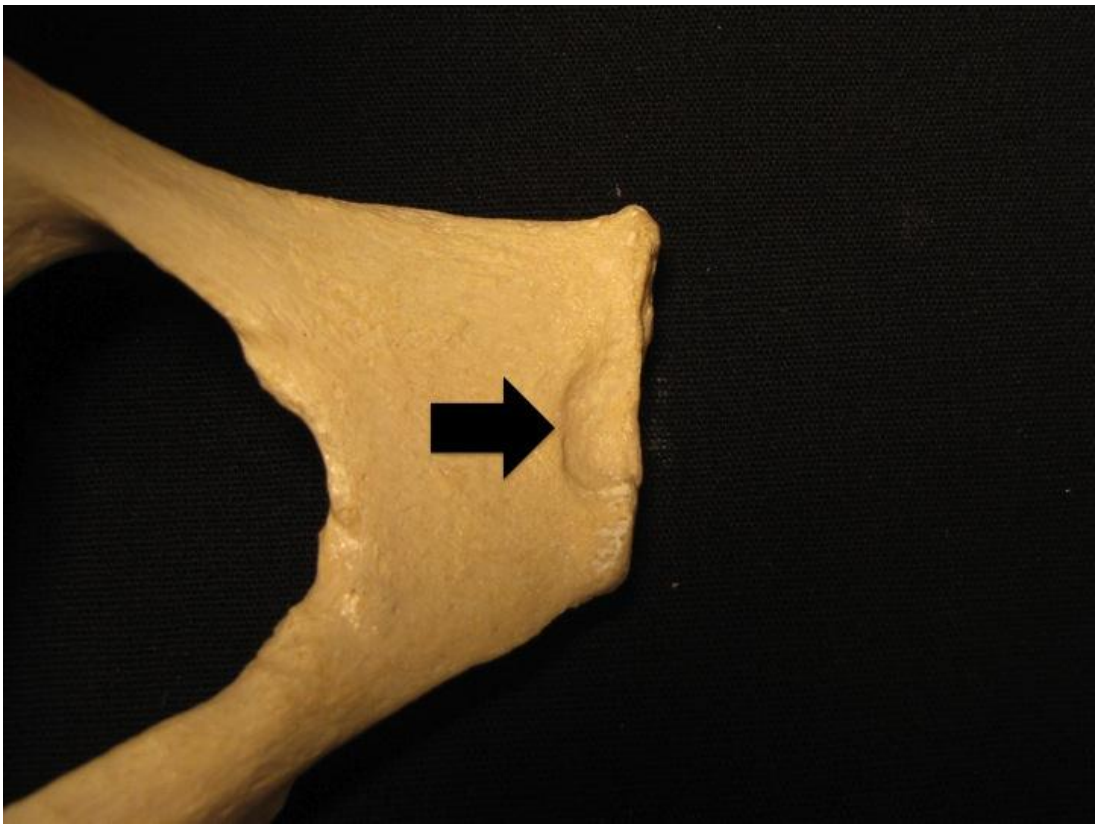


Figure 1. Pitting (arrow) at dorsal aspect of pubic bone.

females. It will further add to studies examining human morphometric variation, how this is reflected in the interaction between bone and muscle, and how this interaction is evidenced on bone. The results of this project will contribute to bioarchaeological investigations of demography and have possible forensic applications to the identification of skeletal remains. In addition, it will provide insight for studies examining the balance between obstetric and locomotor features found in the human pelvis.

1.2. Musculoskeletal stress markers and parturition scarring

The event of childbirth is a complex interaction between bone, muscle, cartilage and tendon. Musculoskeletal stress markers (MSM) on the pelvic bone surface may be predicted to give some indication as to parity status, as the muscle strain from the event

of childbirth may leave evidence on the bony pelvis. Parity status refers to the childbirth status of a woman: non-parous indicates that a woman has not given birth, parous indicates that a woman has given birth, primiparous indicates that a woman has given birth once and multiparous indicates that a woman has given birth more than once.

The attachment and origin sites of a ligament or a tendon on a bone (therefore the site of muscle and bone interaction) are known as entheses. There are two types of entheses in the human body: fibrous and fibrocartilaginous (Benjamin et al., 2002). Some muscles are attached to bone via 'fleshy' fibres, a collection of tendons coalescing into one attachment point or an aponeuroses (a broad or flat tendon that forms a tendinous sheet) that has formed on one muscle and allows another to glide over it (Benjamin et al., 2002). The tendon fibres of aponeuroses and entheses are interlaced into the matrix and periosteum of the bone, meaning that a muscular contraction exerts a pull on the attached bone (Martini et al., 2009). Muscle use is thus integral to the process of bone remodeling, as its usage places stress on bones necessary to activate osteoblasts (bone-building cells) (Weiss et al., 2012). The collagen fibres of the muscle that are woven into the periosteum are known as Sharpey's fibres. These fibres are so intricately woven into the periosteum, that they become a general structure of the bone itself, resulting in a bond of such strength that with a very powerful strain on the tendon or ligament, it is more likely that the bone will break before the collagen fibres at the bone surface are damaged (Martini et al., 2009). Due to these strong bonds, the tensile load of a muscle is balanced in a particular direction with increased load on that muscle; stress is dissipated away from the interaction site of bone and muscle into the bone, the muscle or both (Schlecht, 2012).

Evidence of such muscular stress and the dissipation of it into the bone can be found at the bone surface, particularly the diaphyses of long bones, in the form rugosity at the site of muscle attachment (Lane 1887; Churchill & Morris 1998; Steen & Lane 1998; Weiss 2003). Bioarchaeologists define these markings as MSM, and use them to make inferences about physical activities (both repetitive and isolated) practiced by individuals in the past. Parturition scarring may be an example of MSM, as it has been assumed to be the result of the muscular strain of childbirth in previous studies (e.g. Stewart 1957; Angel 196; Putschar 1976).

It has been suggested that the scarring of the bone surface associated with parturition appears as an outcome of the actions of the muscles of childbirth. Studies have not determined that scarring is directly due to any aspect of pregnancy or childbirth. The levator ani muscle group (Figure 2), which includes the pubococcygeus, iliococcygeus and puborectalis, is the major muscle group acting during parturition (Ashton-Miller and DeLancey, 2007). The iliococcygeus forms a relatively flat, almost horizontal shelf across the pelvic sidewalls, whilst the pubococcygeus (also known as the pubovaginalis muscle) originates at the pubis and attaches to the walls of the pelvic organs and the perineal body, and the puborectalis forms a type of sling around and posterior to the rectum (Ashton-Miller and DeLancey, 2007). These muscles tense the floor of the pelvis, support the organs of the pelvis, elevate and retract the anus, and flex the coccygeal joints in the pelvis (Martini et al., 2009). The major actions of the levator ani muscles include the compression of the rectum, vagina and urethra against the pubic bone in order to keep the urogenital hiatus closed, meaning that they are effectively in a state of continuous contraction, even when a woman is not engaged in

childbirth (Ashton-Miller and DeLancey, 2007). The contractile force of the levator ani muscles changes depending on a female's normal posture, with a 92% larger vaginal closure force occurring in an upright position than a supine position (Ashton-Miller and Delancey, 2009). Voluntary contraction of the levator ani muscles at maximum strength (such as during childbirth) further compresses the distal part of the vagina, the mid-urethra and rectum against the pubic bone (Ashton-Miller and DeLancey, 2007). The maximum voluntary contraction of these muscles can further increase vaginal closure force by 46%, also significantly increasing intra-abdominal pressure (Ashton-Miller and Delancey, 2009). These figures demonstrate the already significant contractile force of the levator ani muscles at rest; the further increase of contractile force output during the process of parturition suggests the possibility for the formation of MSM-like scarring on the bone surface.

Parturition scarring cannot be *directly* compared with MSM, as previous studies on MSM focus on their utility as limb-use indicators and not as a result of musculoskeletal trauma. Hawkey and Merbs (1995) examined MSM as indicators of limb use and detailed a number of different categories of MSM, including stress lesions or pitting on the bone surface. Hawkey and Merbs (1995) state that both of these types of MSM are caused by regular microtrauma at the site of muscular or tendinous attachment.

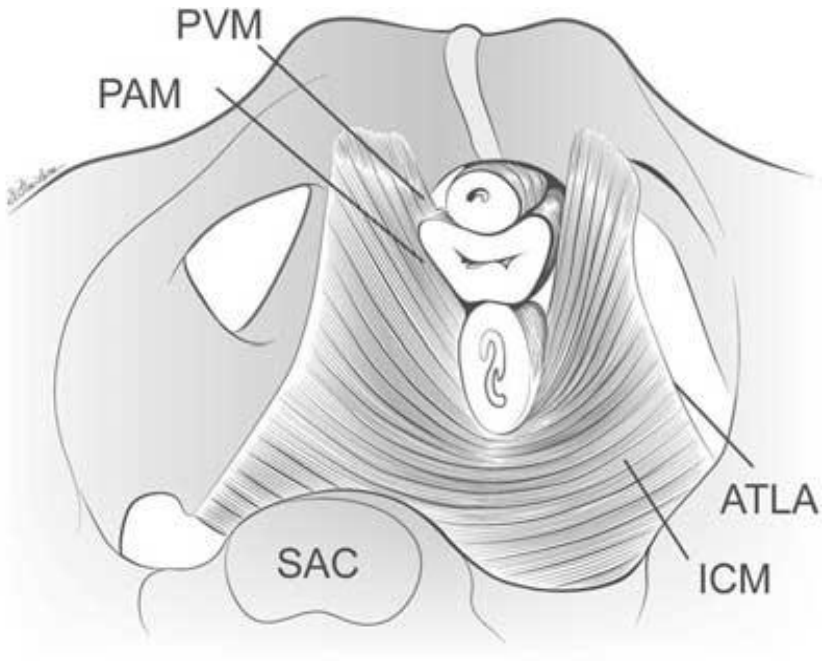


Figure 2. The levator ani muscles seen from above looking over the sacral promontory showing the pubovaginal muscle (PVM). The urethra, vagina and rectum have been transected just above the pelvic floor. PAM denotes puboanal muscle; ATLA; arcus tendineus; levator ani; and ICM; iliococcygeal muscle [Ashton-Miller and DeLancey, 2007:277].

However, a number of scholars have pointed to the limitations in classifying MSM and interpreting their presence as evidence of occupational or habitual behaviours (Schlecht 2012; Weiss et al. 2012; Nolte and Wilczak 2013). Schlecht (2012) cautions that the osteotendinous interface in humans is poorly understood and that the types of classifications that Hawkey and Merbs (1995) outlined may be confounded by the age and sex of individuals. Weiss et al. (2012) have suggested that sex specific trends in body size in particular may affect the presence and magnitude of MSM, potentially confounding interpretations of occupational or habitual physical behaviours. Nolte and Wilczak (2013) also found that body size was the most significant variable for the presence of biceps brachii MSM amongst a sample of adult males and females from a

20th century American sample, implying that the causation of MSM is not entirely dependent on regularity of muscle use. Certainly, the muscular actions of upper and lower body muscles differ greatly from those of the levator ani muscles acting in relation to parturition scarring. However, examining the biomechanical aspects of parturition, and outlining how muscle actions may more generally affect the bone surface is an important basis for understanding causes for parturition scarring other than childbirth.

1.3. Parturition scarring as skeletal evidence of parity

Many of the interpretations of bony changes as osteological indications of parturition revolved around bony responses to increasing muscular forces from muscles situated on and around the pubis (dorsal pitting) (Angel 1969). These interpretations also revolved around the hormonal actions that initiated ligamentous movement, particularly in the sacroiliac region of the pelvis (Houghton 1975; Putschar 1976).

Stewart (1957) was the first to report specific types of abnormalities at the pubic symphysis on female pelves and attribute them to childbirth since similar abnormalities were not seen in male pelves of his Inuit sample. These abnormalities included sclerotic growths at the margin of the pubic symphysis (Figure 3) and pitting of the pubis on the dorsal aspect (Stewart, 1957) (Figure 1). Angel (1969) used parturition scarring to estimate the number of childbirth events that females experienced in a sample made of individuals from Greece during the Classic period, Middle Bronze period, Early Bronze period and Early Neolithic, and individuals from Early Neolithic Turkey. He created a

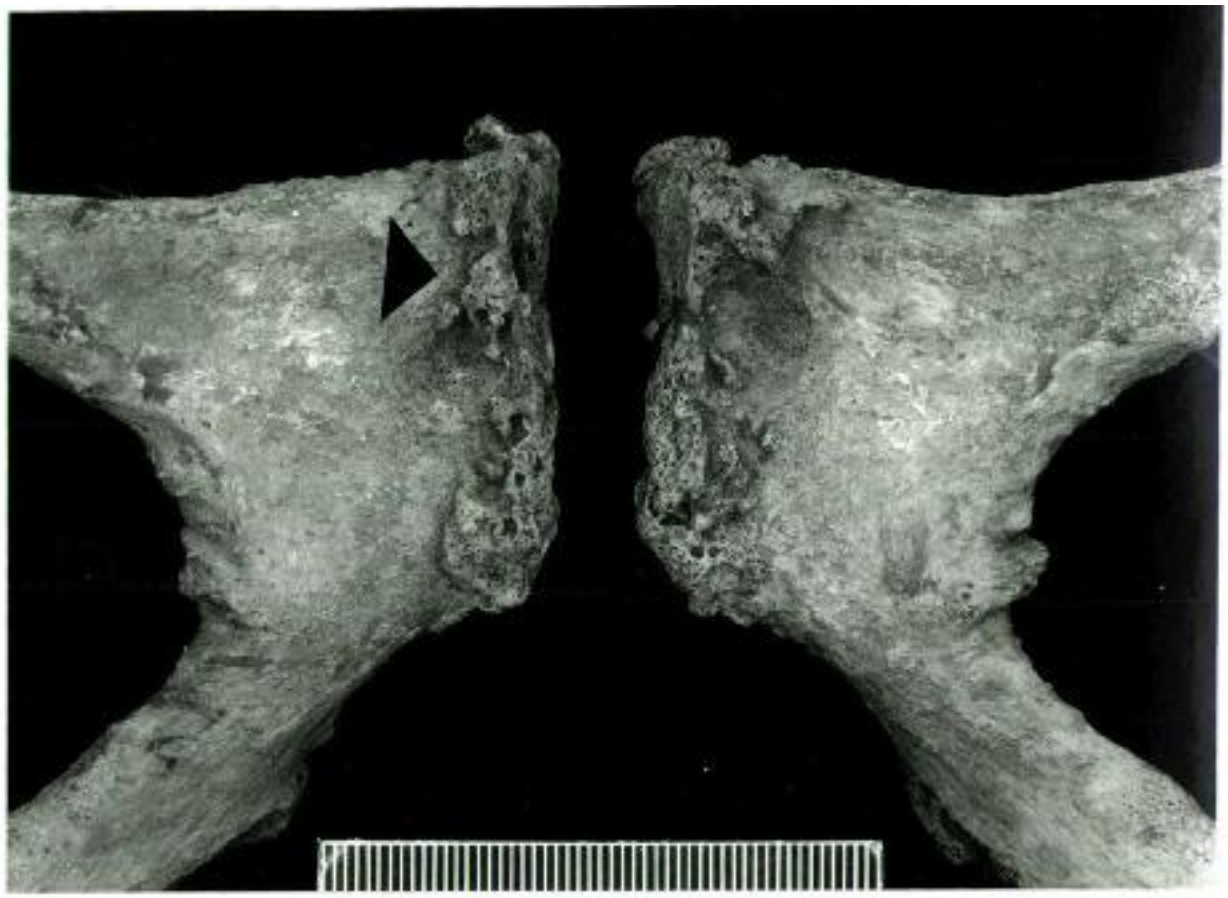


Figure 3. Anterior aspect of pubic bone of multiparous female displaying sclerotic tissue deposition at pubic symphysis (arrow) [Cox 1989:158].

within-sample scale ranking the degree of scarring, which he believed represented increasing parity. For example, he estimated that between four and eight childbirth events would produce a particularly deep groove on the posterior edge of the symphyseal face. Stewart (1968) also outlined the potential problems in identifying parturition scarring in females as a consequence of differences in skeletal development timelines. Stewart (1968) detailed how the ventral aspect of the pubic symphysis has not yet reached its point of maximum growth at the beginning of a female's childbearing period, whilst the dorsal aspect has. Lipping on the dorsal aspect of the symphysis can thus be observed prior to lipping on the ventral aspect of the symphysis. Differential

time points for the development of lipping affects age and sex estimation of skeletal remains, but furthermore, for younger individuals, may under-represent parturition scarring.

Holt (1978) found no relationship between scarring patterns and the parous or nulliparous status of individuals, in a sample of 68 females from the Hamann-Todd collection with known parity status. Six parous females did not exhibit parturition scarring. Holt thus suggested chronic inflammation of the pelvis, left femoral hernia and obesity as other possible aetiologies for the scarring on both the male and female pelves in his sample. Houghton's (1974) examination of parity-associated bony responses beyond the pubic symphysis and outlined the changes occurring at the pre-auricular groove of the ilium in parous females (Figure 4). Houghton identified two different types of grooves; the first was present in both male and female pelves, the second only in females. Houghton suggested that the first groove type (the "groove of ligament") is caused by the pathological and physiological changes occurring at the site of attachment of the pelvic joint ligament (not does not simply appear as a result of childbirth). Houghton proposed that the second groove type (the "groove of pregnancy") is caused by pregnancy. The sacroiliac joint is an important weight-bearing area that will undergo modifications to accommodate increased load during pregnancy, modification that is reflected by an active osteoclastic resorption of bone adjacent to ligamentous attachments (Houghton, 1974). Houghton's examination of bony changes at the sacro-iliac joint provides a wider biomechanical context for understanding the bony changes potentially associated with pregnancy.

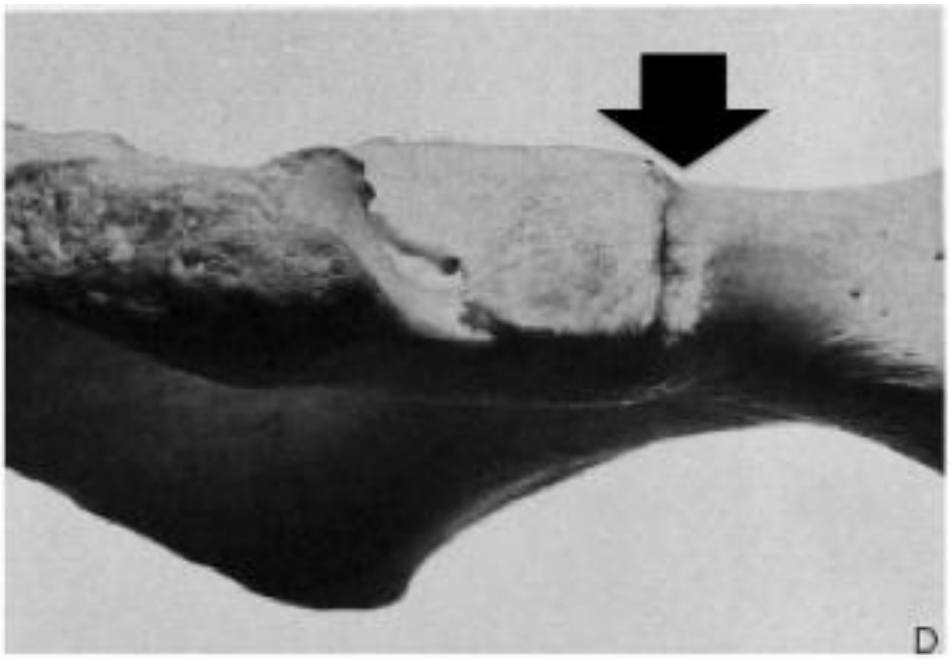


Figure 4.Left ilium of female of unknown parity, pre-auricular sulcus of the ilium (arrow) [Houghton 1974:389].

Bergfelder and Herrmann (1980) (Figure 5) investigated parity-related changes at the pubic tubercle. They examined the pubic tubercle for signs of extension as evidence of muscular strain on the rectus abdominis muscle occurring during pregnancy and parturition, but did not find a relationship between pubic tubercle extension and parity status. The individuals from Christ Church, Spitalfields archaeological collection also displayed pubic tubercle extension that correlated with increasing parity (Cox and Scott, 1992). MacLaughlin and Cox (1989) found a similar correlation between number of birth events and pubic tubercle length in a modern Dutch sample. Snodgrass and Galloway (2003) found pubic tubercle length to be related not to parity status, but to individual height. It is important to note that in their analysis of pubic tubercle extension Cox and Scott (1992) did not quantitatively measure the length of the pubic tubercle extension,

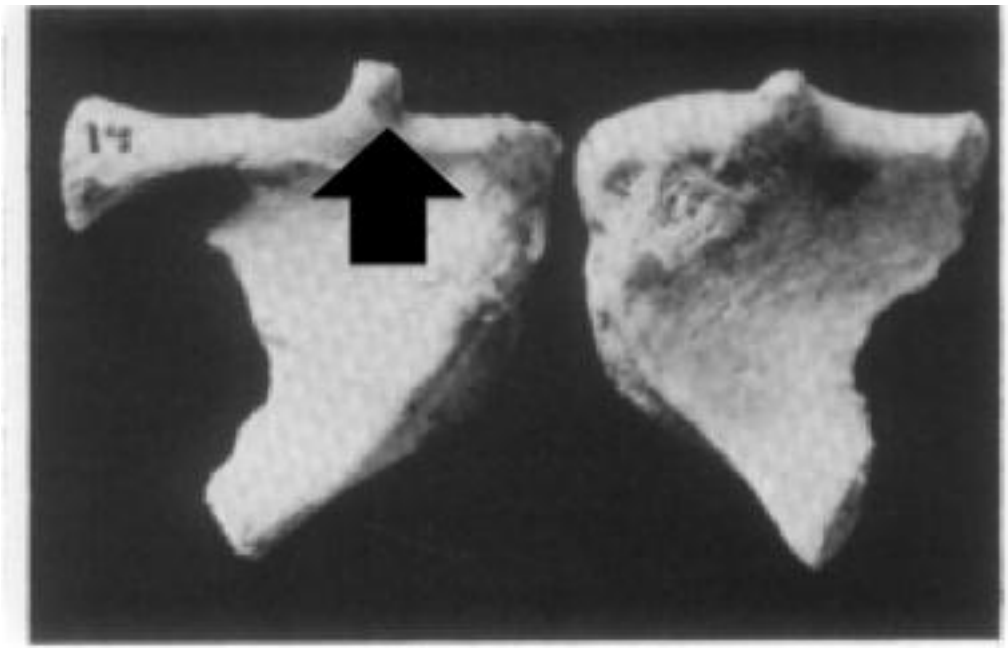


Figure 5. Anteriorly oriented pubic bones from two females, multiparous on the left, nulliparous on the right with extended pubic tuberlce (arrow). The pubic tubercle is the origin site of the rectus abdominis muscle, which inserts at the xiphoid process of the sternum [Bergfelder and Herrmann 1980:612].

but simply categorized its extension as undeveloped, discernible, extended and as having an elongated conical tubercle, whereas Snodgrass and Galloway (2003) measured pubic tubercle height quantitatively in millimetres.

Cox (1989) found a trend of increased presence of pitting on females with larger pelvic dimension in her assessment of parturition scarring amongst the individuals of the archaeological sample from Christ Church, Spitalfields. Cox (1989) also found a relationship between parturition scarring, stature and pelvic shape in some of the males in Spitalfields collection, again suggesting that childbirth is not the principal factor involved in parturition scarring, but that body size, proportionality and pelvic shape may also be important co-factors.

Suchey et al. (1979) examined the statistical significance of dorsal pitting as an accurate identification of parity status in forensic contexts. The sample used in this

study comprised only the pubis of the female pelvis instead of the entirety of the bony girdle. Suchey et al. (1979) found that medium to large dorsal pitting had a weak statistical relationship to females who had a 15-year or greater birth interval between infants, and that this type of dorsal pitting was found more commonly in females over 30 years old than in under 30-year olds. This finding thus reflected Stewart's (1968) observation of the differences in dorsal pitting prevalence according to age of the individual. Parity status of each individual in the sample was ascertained through childbirth information given by the decedent's relatives (Suchey et al., 1979). This source of information excludes potential miscarriages or even childbirth events that women may not have reported to their relatives (Suchey et al., 1979). The record of childbirth events also provides information on birth complications that can be examined in the light of parturition scarring causation.

A number of studies found that parturition scarring does not accurately represent parity status (Holt 1978; Suchey et al. 1979; Snodgrass and Galloway 2003). Parturition scarring has been found to associate positively with age of parous females (Suchey et al., 1979) and with broader bodily dimensions (Cox, 1989). Several other factors have been found to associate with scarring on the dorsal pubis, including general age changes, conditions such as urinary tract infection, lumbosacral anomalies and obesity, as well as repeated minor trauma, surgery, general joint laxity and pelvic instability, variation in sciatic notch angle and habitual posture, including squatting (Ubelaker and De La Paz, 2012).

1.4. Parturition scarring as evidence of obstetric pathology

Given that parturition scarring results from muscular and tendon damage at specific sites on the pelvis, pathologies resulting from the event of parturition may equally represent aetiologies for osteological responses to parturition. Medical literature has profiled a wide selection of case studies that pertain to pelvic disruption, osteitis pubis, pelvic prolapse and others, many as a result of or exacerbated by vaginal delivery (Harris 1974; Kotwal and Mittal 1996; Kotwal and Mittal 1998; Owens et al. 2002; Usta et al. 2003). During the event of childbirth, forces generated by the levator ani muscles could result in muscular injuries and tendon damage, as muscular force output can increase by 25% to 245% depending on the size of the foetal head and body (Svabík et al., 2009). Beyond the increase in muscular force, parturition represents a dramatic increase in levator ani muscle group stretch ratio. During parturition, the pubovisceral muscle can stretch up to 3.78 times its resting length (Ashton-Miller and Delancey, 2009). Increased muscular force and stretching of muscles during the event of parturition may also result in the damage or dislocation of parts of the pelvis. The pubic symphysis widens during the 10^{th} to 12^{th} week of pregnancy (Borg-Stein et al., 2005) as part of the action of hormone relaxin, which acts on cervical and uterine connective tissue to promote softening and remodelling of these tissues prior to delivery (Owens et al., 2002). Augmented mobility at the pubic symphysis and other joints in the pelvis, combined with even a momentary increase in muscular force can produce pubic disruption (Harris, 1974). Harris (1974) describes three case studies of multiparous women, all of whom did not experience any complications during the deliveries of their children, which illustrate the pain that can be experienced postpartum as a result of this

pubic disruption. The pelvis of one of these women displayed intense sclerosis (hardening of tissue), marginal erosion of the symphysis (destruction of the bone surface margin) and physical instability at the pubis (Harris,1974).

Birth position is another factor that could have consequences for the display of parturition scarring on the female pelvis. Some birth positions may demand greater or lesser muscular force, and in addition may increase or decrease the relative size of the obstetric outlet. Michel et al. (2002) found that a squatting position, and a position that allows a woman in labour to pull back her knee with her hand, increased the dimensions of the sagittal and interspinous outlet of the pelvis, which could be beneficial particularly in the second stage of labour (full cervical dilation). Indeed it seems that the supine position for childbirth has been adopted as a consequence of anaesthetic administration rather than obstetric advantage (Michel et al., 2002). Historically, medical doctors were only involved in the event of childbirth if a natural birth was impossible, if midwives and other female relatives were unable to help the woman in labour (Ellison, 2001). Case studies of obstetric pathologies infrequently take birth position into account as current medical practice for childbirth includes supine delivery. Instead, medical literature focuses on treatment options and does not typically include a more long-term perspective that could relate osteological responses to parturition, either in the immediate or indeed through remodelling throughout a female's lifetime. Nevertheless, obstetric case studies provide important opportunities to examine the biomechanics of parturition in a woman's lifetime, and how musculoskeletal mechanics may leave evidence on the skeleton.

Studies of sports injuries amongst male athletes may also give some indication

as to the cause of the build-up of pelvic sclerotic tissue similar to parturition scarring. Meyers et al. (2000) found that some male athletes experience similar pelvic pain to that experienced by women postpartum. Amongst male high performance athletes, a tear of the rectus abdominis muscle near the pubis has been known to lead to pubic symphysis tenderness and edema (Meyers et al., 2000). It could be suggested that such symptoms may be caused by different muscular actions to those in females, and that parturition-like scarring may be visible on similar parts of the male pelvis.

1.5. Parturition scarring and the obstetric dilemma

Parturition scarring may also be understood as evidence of obstetric plasticity within a broader evolutionary context. The obstetric dilemma (OD) outlines the interplay between the differing pressures acting on the female pelvis; obstetrics and locomotion on one hand, and the delivery of a comparatively encephalized infant on the other. This results in a uniquely difficult childbirth process for humans (Washburn, 1960). It would be logical to suppose that the female pelvis demonstrates a particular trend in shape for optimized parturition that also balances the morphological necessities for bipedal locomotion (an average shape matrix with little variation around it), reducing the potential for labour complications resulting in the death of mother or infant. Interestingly, Kurki (2013a) found that female pelvic canal shape is surprisingly variable even within populations, and that there is not a significant difference in pelvic canal shape variability between males and females. The differences in pelvic canal *size* between the sexes do however indicate an obstetric advantage for females. Differences in *shape* between the sexes also indicate obstetric advantage for females - within and among populations,

male and females pelvic shapes differ too (Kurki, 2007). Betti (2014) examined the particular skeletal aspects that contributed to greater pelvic canal size amongst females, and found that the larger pelvic canal size in females is a function of differences in pelvic bone shape and the orientations among the pelvic bone and the sacrum of females. The demonstrable variation in both size and shape of the female pelvis and bony canal exhibits the complexity inherent in assuming parturition scarring is evidence of parity. If there is such extensive variation amongst females in pelvic canal size, would parturition scarring (if it *is* an indication of musculoskeletal microtrauma caused by either complicated or normal labour) not also vary significantly even within populations?

Obstetric constraints must also be contextualized within human evolutionary history. Whilst human life history is very similar to that of great apes, great apes demonstrate some significant differences in pregnancy, parturition and pelvic shape and size. These are results of differences in locomotion (bipedality vs. knucklewalking) and reproductive physiology. In humans, the pelvic inlet is wider transversally, whilst the pelvic outlet is much wider anteroposteriorly than it is in apes, which necessitates rotational movement by the human infant during birth (Trevathan 1996; Trevathan and Rosenberg 2000; Tague 2007; Parente et al. 2011). In nonhuman primates, both the pelvic inlet and outlet are wider anteroposteriorly, and the pelvis is lengthened and flattened compared to humans (Parente et al., 2011). The combination of the shape of the nonhuman primate pelvis and the relative size of the neonate allows for a more comfortable fit between the maternal canal and the infant head (Figure 6), which does not create the same need for assistance in the birth process for nonhuman primates as

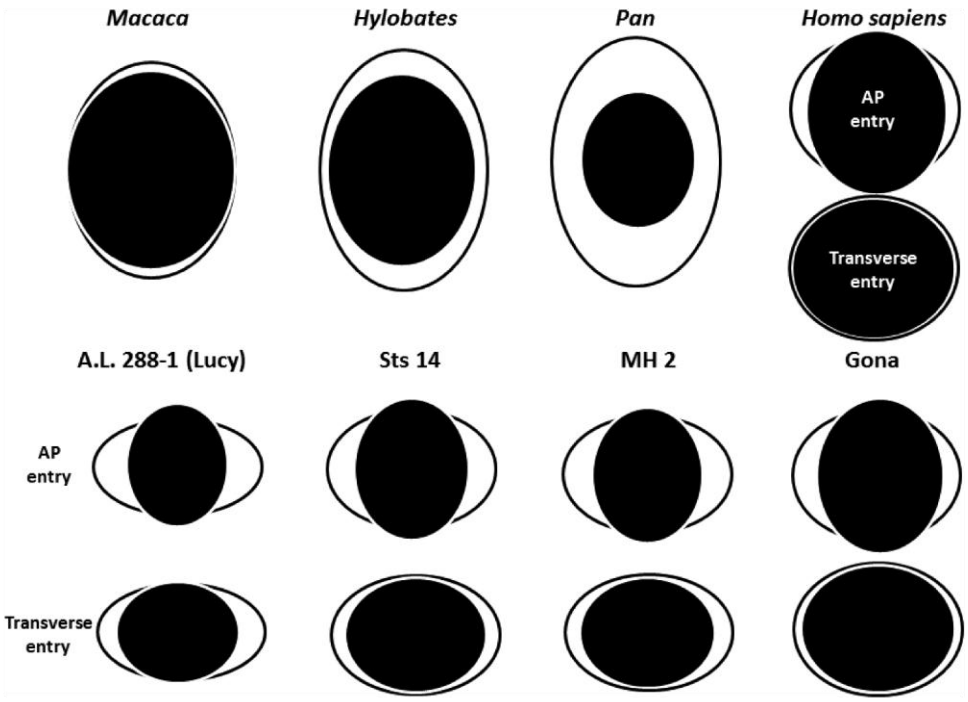


Figure 6.Relative cranial dimensions in infant primates (filled ovals) are superimposed on pelvic openings (outer oval), with the offspring head in anterior–posterior orientation (upper row) and transverse orientation (lower row). All pelves are scaled so that the mediolateral dimensions are equal. Notice the anteroposteriorly deep birth canal in chimpanzees (*Pan*), allowing for relatively easy passage of the neonatal head. Broad ape shoulders may require some rotation as has been observed recently (Hirata et al., 2011). Monkeys, lesser apes (*Hylobates*) and humans present more of an ‘‘obstetric dilemma’’ with the neonatal head close to, or even exceeding, the dimensions of the birth canal. In the bottom row are four hominin fossils illustrating the relative difficulty of birth in Australopithecus and early Homo. Modeled here are the inlet dimensions of the birth canal. As in humans, the maximum dimension of the pelvic inlet in early hominins is oriented medio- laterally, indicating that the neonatal cranial entered the pelvic inlet obliquely or transversely during birth. Based on estimates of cranial dimensions and minimum dimensions of the birth canal, birth was particularly difficult in the earliest australopiths represented here by Lucy and Sts 14 [Wells et al. 2012:44].

it does in humans (Rosenberg & Trevathan, 2002). Indeed, nonhuman primates primarily assume a squatting position whilst giving birth, which includes the mother assisting the delivery by pulling the infant out of the birth canal (Goodall and Athumani, 1980), and they usually give birth alone (Rosenberg, 1992). Parturition scarring would thus not be expected in most nonhuman primates given the musculoskeletal ease that is experienced during childbirth compared to the tight fit between the human maternal pelvis and infant head. However, Morbeck et al. (1992) found areas of bone roughness

on the dorsal pubis adjacent to the pubic symphysis and on the pre-auricular sulcus of the ilium on a selection of male and female Gombe chimpanzee (*Pan paniscus*) skeletons though the actual parity status of the female chimpanzees was unknown.

It has equally been suggested that the obstetric dilemma is a historical phenomenon that has been produced by the process of phenotypic plasticity (Wells et al., 2012). Wells and colleagues propose that with the advent of agriculture, female growth and developent was compromised by poor diet quality (compared to higher quality diets prior to the advent of agriculture). This reduction in diet quality (caused by climate change and food availability) resulted in delayed skeletal development and thus compromised female pelvic capacity, leading to a greater number of maternal deaths via childbirth (Wells et al., 2012). This was further compounded by the increased disease burden that developed with the inception of agriculture (Wells et al., 2012). Whilst diet previous to agriculture allowed for adequate female growth and development, labour complications did occur. However, the *risk* for labour complications created by compromised pelvic capacity was *lower* prior to agricultural practices than the risk present after the advent of agriculture (Wells et al., 2012). Wells et al. suggest that maternal growth is more plastic than originally thought and that the appearance of the obstetric dilemma is not universal, but appears with a specific human ecological transition.

The obstetric dilemma cannot be examined without also considering the plasticity of neonate. Human neonate altriciality is another unique element of human life history and the process of childbirth. Dunsworth et al. (2012) have suggested that human altriciality is a consequence of the metabolic draw on the developing infant's mother,

prompting human birth to occur at an early developmental stage. This energetic model would also fit with the notion proposed by Wells and colleagues, given ecological shifts affecting food resource availability. Neonatal mass likely increased as a result of dietary shifts (Wells et al., 2012), creating a scenario in which the neonate is relatively larger for the mother since maternal pelvic capacity is compromised by a poor diet. This ultimately led to an aggravation of OD in the last few thousand years, which would increase the potential for labour complications due to obstetrically inefficient pelvic capacity. Should the presence and extent of parturition scarring signify greater muscular work during a childbirth event (a female with a less obstetrically efficient pelvic canal), it should appear with greater frequency amongst human groups practicing agriculture. However, this does not account for the presence of parturition scarring found on male pelves, nor indeed the presence of it on women who are confirmed as non-parous.

It is possible that parturition scarring may not reflect the event of childbirth, but rather the change in pelvic load (and therefore changes in locomotion) that occurs with pregnancy. Anatomically modern females have broader pelves and a smaller overall stature compared to males in many geographic groups, which results in a relatively greater body surface area (Wall-Scheffler, 2012). Thermoregulation is of greater importance in females than males owing to the importance of maintaining a cool temperature to aid in embryonic development (Ziegert et al., 1999), suggesting that the combination of a smaller body size and a broader pelvis is under selection (Wall-Scheffler, 2012). It is particularly interesting that these features should be selected for, given that Wall-Scheffler and Myers (2013) have found that women bearing frontal loads have a compromised locomotion speed, but that this is offset by wider pelves that allow

for greater stride length and muscular support during slowed locomotion with heavier frontal loads. The morphological constraints placed on the pelvis for reproductive purposes may therefore extend into possible strains accrued through pregnancy, and not just the event of childbirth. Parturition scarring may also be evidence of these strains, particularly given the possible ecological and regional variation associated with particular pelvic shapes and proportions.

It is clear that there are numerous aspects of pelvic and body size and shape that may influence the development of scarring both as a true result of parturition or pregnancy, but also independent of these, particularly to explain scarring on males. For example, a large pelvic canal in females may exacerbate the muscular pull on the bones of the pelvis during parturition, leading to increased scarring. A small pelvic canal in females may also exacerbate muscular pull during parturition, as *a greater* amount of muscular force may be required to deliver a child vaginally. Alternatively, a large pelvis in males may increase the risk of muscular strain during certainly high effort activities, also exacerbating the bony response at the muscle-bone interface.

1.6. Significance of study

Despite the number of times parturition scars have been evaluated, their aetiology has not been considered beyond childbirth; the prevalence of pubic scarring on female pelves led to the conclusion that such osteological responses were caused by parturition. Scarring of this nature has also been found on male pelves. In this study, parturition scarring is examined in females *and* males in an effort to reorient the definition of parturition scarring; such scarring cannot be related to parturition if it is

found on males and if it is found on females who are nonparous. Using a sample that includes parity information on females, parturition scarring type and presence in different regions of the bony pelvis is compared between males and females, and between parous and non-parous females. Differences between the sexes are also considered alongside relevant factors of body size and pelvic size and shape. In this way, variations in body and pelvic size can be quantified in *both* sexes.

Previous works on parturition scarring have not simultaneously examined morphometric and biomechanical perspectives on potential causes for the scarring. Bergfelder and Hermann's (1980) examination of pubic tubercle extension as an example of parturition scarring focused exclusively on the role of the rectus abdominis and obliquus abdominus muscles during parturition. Holt (1978) suggested obesity as a possible cause for parturition scarring amongst males, however did not carry out further investigation on possible associations between body mass, stature and parturition scarring. In this study, parturition scarring is examined as possible evidence of the skeletal response to differences in body mass, stature, pelvic canal size and pelvic canal shape instead of examining parturition scarring as only representative of the act of childbirth. Parturition scarring may be exacerbated by childbirth, but an understanding of its associated morphometric components is an essential element in explaining its presence amongst males and nonparous females.

Differences in body size, childbirth practices and parturition scarring can also contribute to wider understandings of the evolutionary development of particular obstetric adaptations, namely the details of the obstetric dilemma as a uniquely human adaptation. This is especially relevant for the current bloom of literature re-examining

the obstetric dilemma (Wells et al. 2012, Dunsworth et al. 2012, Kurki 2013b). The analysis of parturition scarring as a function of body size, pelvic size and pelvic shape expands the scope of research on this osteological response that is not limited to parous females nor to the act of childbirth itself. It includes an appreciation of pelvic biomechanics in both males and females living in specific cultural and temporal contexts, and highlights some of the key components of reproductive evolutionary anatomical adaptations.

Chapter 2: Materials and Methods

2.1. Materials

2.1.1 Collection background

A sample of 292 individuals (141 females and 151 males) from the Maxwell Documented Skeletal Collection (Maxwell Museum, University of New Mexico, USA) and the Christ Church, Spitalfields collection (Natural History Museum, London, UK) were used for this study (Table 1). Parity data is available for both of these collections, which is a necessary component for the examination of parturition scarring in relation to parity status.

Table 1. Summary of male and female specimens from each collection used in study sample.

	Maxwell Museum Documented Collection	**Christ Church, Spitalfields**
Female	77	64
Male	93	58
TOTAL	170	122

The Spitalfields skeletal collection is comprised of individuals who were buried in the crypt of Christ Church in London, England between the years 1729 to 1829 (Cox, 1989). The collection is currently curated at the Natural History Museum in London. The crypt of Christ Church was excavated between 1984 and 1986, after a plan was created in 1965 to restore the church to its original design (Cox, 1989). The excavation occurred under particularly difficult conditions, which resulted in the loss of some skeletal remains. Cox (1989) provides the most comprehensive overview of the sample due to her involvement with the initial compiling of the anthropological analyses. Individuals were buried in coffins with legible coffin plates, which can be cross-referenced with

parish records. The identification of individuals through coffin plates also enables parity status to be determined, as their names could associated with baptism records for the church. Christ Church parishioners were middle class, with vocations such as merchants, silk tailors, craftsmen and artisans more generally. Of the listed parishioners, 41.6% were French in origin, reflecting the communities of Huguenots (French religious refugees) who moved into England between the 16th and 18th centuries, mostly from Normandy, Picardy and Poitou (Cox,1989). The diets of the parishioners most likely included a significant amount of vegetables and grains, with animal proteins remaining a relative luxury, as evidenced by the presence of anaemic conditions amongst the collection (Cox,1989). There is some evidence of tuberculosis , as well as lead poisoning (water was piped through homes in lead pipes) though many pathologies are associated with nutritional stress more generally (Cox,1989).

The Maxwell Documented Skeletal Collection was established in 1984 at the Laboratory of Human Osteology, which is part of the University of New Mexico's Maxwell Museum of Anthropology in Albuquerque, New Mexico (Anonymous, 2010). The skeletal remains were obtained by donation. Remains were donated prior to death by the individual in question, by the family of the deceased or through the Office of the Medical Investigator when the kin of the deceased could not be located (Anonymous, 2010). Most skeletal remains have associated sex, age, population affinity and cause of death information available, and from 1995 onwards the family of the deceased was asked to provide health and occupational information (Anonymous, 2010), which included parity status. Information on occupation of the deceased also provides an indication of the socioeconomic variables that could have impacted on health of the

individual, which may or may not be visible on the skeletal level. Komar and Grivas (2008) caution that the Maxwell collection is not entirely unbiased due to the compilation methods associated with the collection, citing the preponderance of White, elderly males or individuals who have died unnatural deaths as examples of biases in the collection. When considering parity status in a modern population, it is important to recognize the limitations involved in documented skeletal collections, as some women may chose to omit their parity status entirely or falsely report their number of children due to emotional trauma associated with abortions, stillbirths or foetal death (Suchey et al.,1979).

2.1.2. Sample selection

As mentioned above, both of the skeletal collections selected to create the sample for this study were specifically chosen for the availability of associated parity data for female individuals. Only adult specimens were used in this study, as previous studies have only examined parturition scarring in adults (Cox 1989; Cox and Scott 1992; Snodgrass and Galloway 2003; Suchey et al. 1979) and no studies have examined the influences of growth and development in creating parturition scarring-type markings on the pelvis. In this study, ‘adult’ status was determined by examining the epiphyseal fusion of the primary ossification centres of the pelvic bone, with adult status defined as complete union of all primary ossification centres of the pelvic bone (Buikstra and Ubelaker, 1994). Both the Maxwell and Spitalfields collections have been extensively examined by researchers (Cox 1989; Cox and Scott 1992; Fibiger & Knusel 2005; De Groote & Humphrey 2011; Groves et al. 2003; Mays 2002; Mays 2001; Rogers et al. 1981; Vilotte et al. 2010) .

Selection of individuals for the sample from both collections was made based degree of completeness of the pelvis and femur. Individuals with sacra ossified to the pelvic bones were excluded, as this made some pelvic measurements difficult to complete accurately. Individuals with evidence of pathology or trauma to the pelvis or femur were also excluded. Damage to the pubis of the pelvic bone made it impossible to accurately collect pelvic canal measurements, so specimens with broken pubi were not included in the sample. Though both collections include individuals with damaged pubi that resulted in variation in sample sizes for individual measurements, there was a more significant variation in sample sizes for individual measurements in the Spitalfields sample due to pubi damage.

2.2 Methods

2.2.1. Osteometric variables

Dimensions of the articulated pelvis, right and left pelvic bones and the right femur were measured. Osteometric variables (Table 2, Figures 7 and 8) collected included the measurements of key points of three pelvic canal planes (inlet, midplane and outlet) of the articulated pelvis as well as length and breadth measurements of the pelvic bones. Measurements of the pelvic canal, bi-iliac breadth, bi-acetabular breadth and pelvic bones were used to represent size and shape of the pelvis. Femoral measurements were collected in order to estimate stature and body mass. Pre-auricular sulcus width and length was measured as an example of parturition scarring (see Table 2 and Figure 8).

Measurement of femora and articulated pelves were carried out with an osteometric board, sliding callipers, digital callipers and measuring tape. Pelvic measurements were carried out with the pelvic bones and sacrum articulated, held together by masking tape at the pubic symphysis and sacroiliac articulations, and the entire girdle was held with a rubber band. No accommodations were made for the cartilage components of the sacroiliac region and pubic symphysis that would be present in a living individual. Pre-auricular sulcus width and length were not collected from individuals with ossified sacroiliac joints, as it was not possible to open the callipers without damage to the specimen or inaccurate measurements.

Pelvic measurements were collected across three different planes to facilitate the exploration of A-P (anterior-posterior) and M-L (medio-lateral) shape differences throughout the pelvic canal (Table 2, Figure 7). Posterior measurements were taken as this aspect of the midplane and outlet levels is more sexually dimorphic than the anterior portion of the canal, being expanded in females due to the orientation of the sacrum and the greater sciatic notch. Sexual dimorphism is greater in the *posterior* aspect of the canal, as females display a longer costal process of the first sacral vertebra than males as a result of selection for obstetric sufficiency of the female pelvis (Tague, 2007). Both posterior and anterior inlet measures were taken as the inlet is a complete bony ring at the level of the pelvic inlet.

Table 2. Osteometric variables and description of measurement points (see Figures 7 and 8).

Variable		Description
FMLG	femoral length	Maximum length of the femur
FBLG	femoral bicondylar length	Both condyles adjusted to the vertical part of the osteometric board.
FMHD	femoral head diameter	Maximum diameter of the femoral head
BIIL	bi-iliac	Maximum breadth across iliac blades (Fig. 7 A)
BIAC	bi-acetabular	Distance between acetabulae (B)
INAP	inlet AP	Sacral promontory to dorsomedial superior pubis (C)
INML	inlet ML	Maximum distance between linea terminalis (D)
INPT	inlet posterior	Curved length of linea terminalis from INML to apex of auricular surface (F)
INAT	inlet anterior	Curved length of linea terminalis from INML to dorsomedial superior pubis (E)
MDAP	midplane AP	From junction of fourth and fifth sacral vertebrae to dorsomedial inferior pubis (G)
MDML	midplane ML	Between ischial spines (H)
MDPT	midplane posterior	S4-S5 junction to ischial spine (I)
OTAP	outlet AP	Apex of fifth sacral vertebrae to dorsomedial inferior pubis (J)
OTML	outlet ML	Distance between inner margins of transverse ridge of ischial tuberosities (K)
OTPT	outlet posterior	Apex of S5 to ischial tuberosity (L)
DPPL	depth	Apex of auricular surface to ischial tuberosity (M)
PBLG	pubic length	Distance from point A to superior aspect of symphyseal face (N)
PSW	pre-auricular sulcus width	the maximum outer width of the sulcus, at right angles to the length (Fig. 8 G)
PSL	pre-auricular sulcus length	the maximum length of the sulcus from the posterior inferior iliac spine to the auricular point where the arcuate line intersects with the anterior border of the auricular surface (Fig. 8 F)

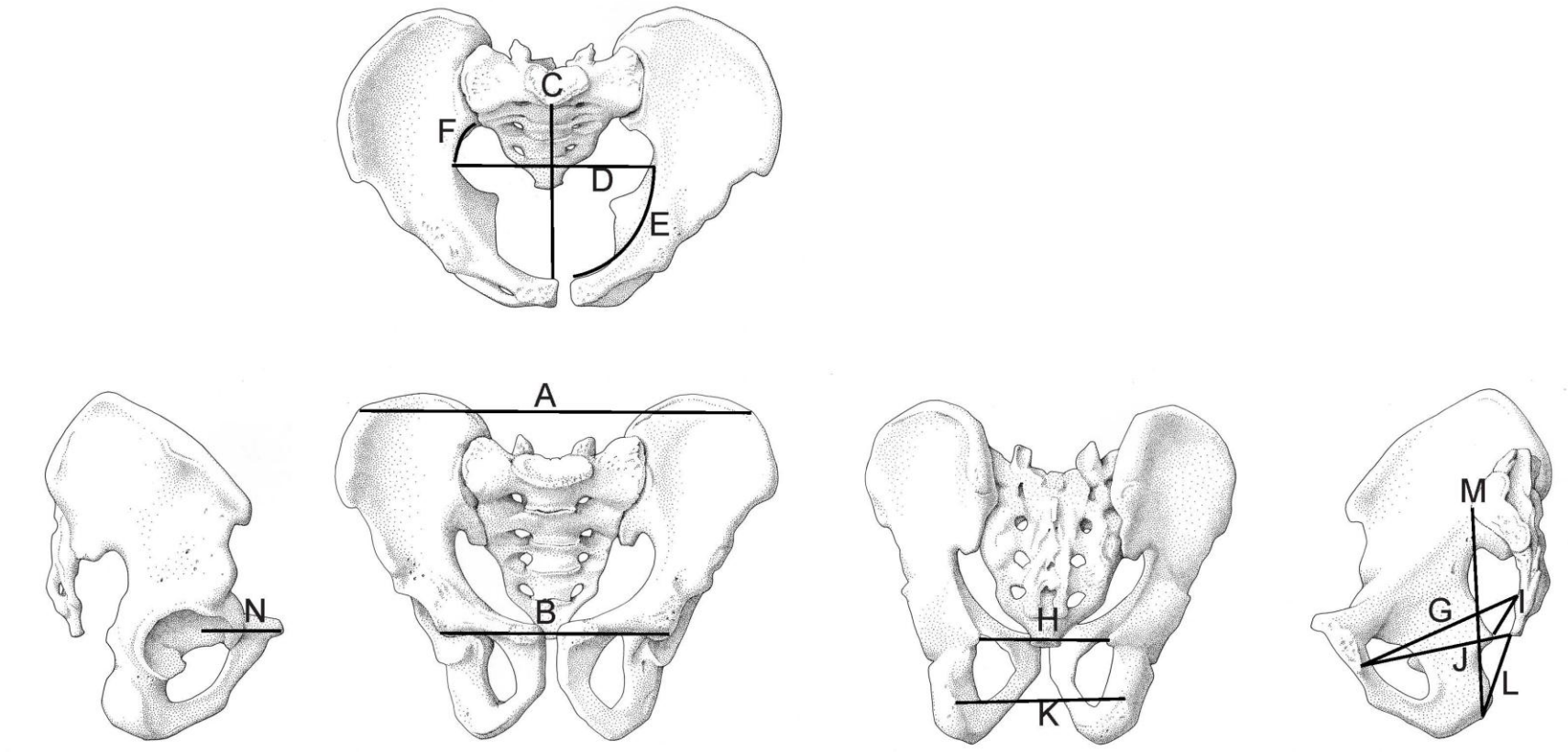


Figure 7.Measurements of the bony elements as described in Table 2. A: BIIL; B: BIAC; C:INAP; D: INML; E: INAT; F: INPT; G: MDAP; H: MDML; I:MDPT; J:OTAP; K:OTML; L:OTPT; M:DPPL; N:PBLG.

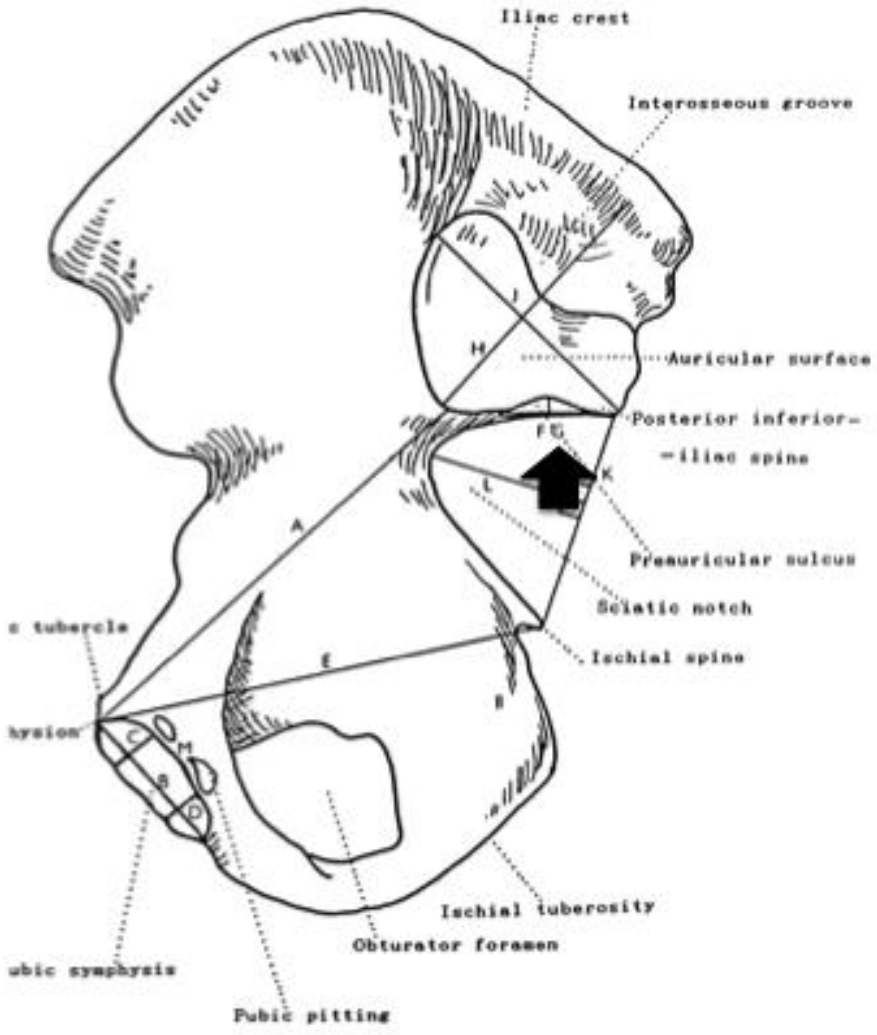


Figure 8.Locations of variables pre-auricular suclus length and pre-auricular sulcus width as described in Table 2.3 (arrow). F: PSL, G: PSW. [Cox 1989:149].

2.2.2. Body mass and stature estimations

Stature estimations were based on the relationship between specific long bone lengths (eg. maximum femur length) and stature (Auerbach and Ruff, 2004). Body mass was taken as the average of the mechanical (femoral head) and morphometric (stature and bi-iliac breadth) estimates. The morphometric method is based on bi-iliac breadth and stature (Ruff et al., 2005), while the mechanical method is based on femoral head breadth measurements (Ruff et al., 2012). Stature was estimated using femoral length formulae. Ruff et al.'s (2012) femoral formulae was used in estimating stature for all White individuals in both the Maxwell Documented Skeletal Collection and the Spitalfields collections. In the Maxwell collection, the stature of African-American individuals was estimated using Trotter and Gleser's (1952) formulae, and Genovés' (1967) formulae was applied to Hispanic individuals. Sex-specific calculations were used when formulae had sex-specific calculations available.

2.2.3. Pubic tubercle variables

Pubic tubercle variables were measured using one of two methods: 1) digital callipers on dry bone (pubic tubercle distance) and 2) from photographs using the image processing program ImageJ (Rasband, 1997). Pubic tubercle height and arcuate angle measures were collected using ImageJ, whist digital callipers were used to collect pubic tubercle distance measures. Measurements were only collected on specimens presenting with pubic tubercles. Pubic tubercle measurements were taken from the right side of the pelvis, and left side when the right side was damaged. Pubic tubercle height (Table 3, Figure 9) measurements were collected using ImageJ tools. Once the scale of

Table 3. Pubic tubercle scarring variables and description of measurement points**.**

Variable	Description
pubic tubercle height (PTH)	the maximum height that the tubercle protruded from the bone (Figure 9 A)
pubic tubercle distance (PTD)	the pubic tubercle at its most anterior point to the anteriormost margin of the symphyseal surface (Figure 9 B)
arcuate angle (AA)	formed by the continuation of the arcuate line to the pubic tubercle (Figure 9 C)

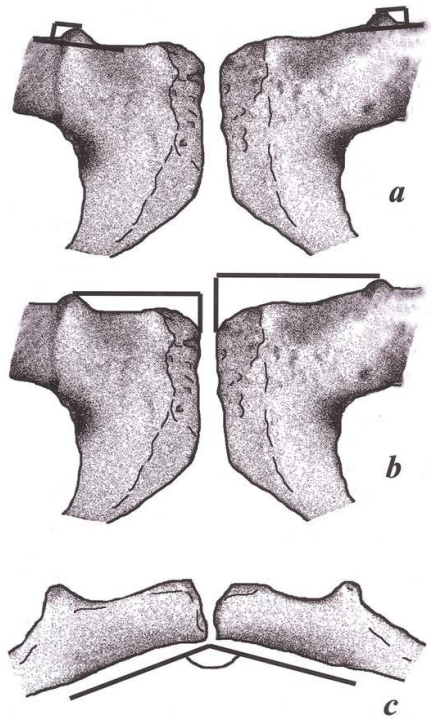


Figure 9. Measurements of the pubic tubercle as described in Table 3. A: Pubic tubercle height, B: Pubic tubercle distance, C: Arcuate angle. [Snodgrass and Galloway, 2003:1227].

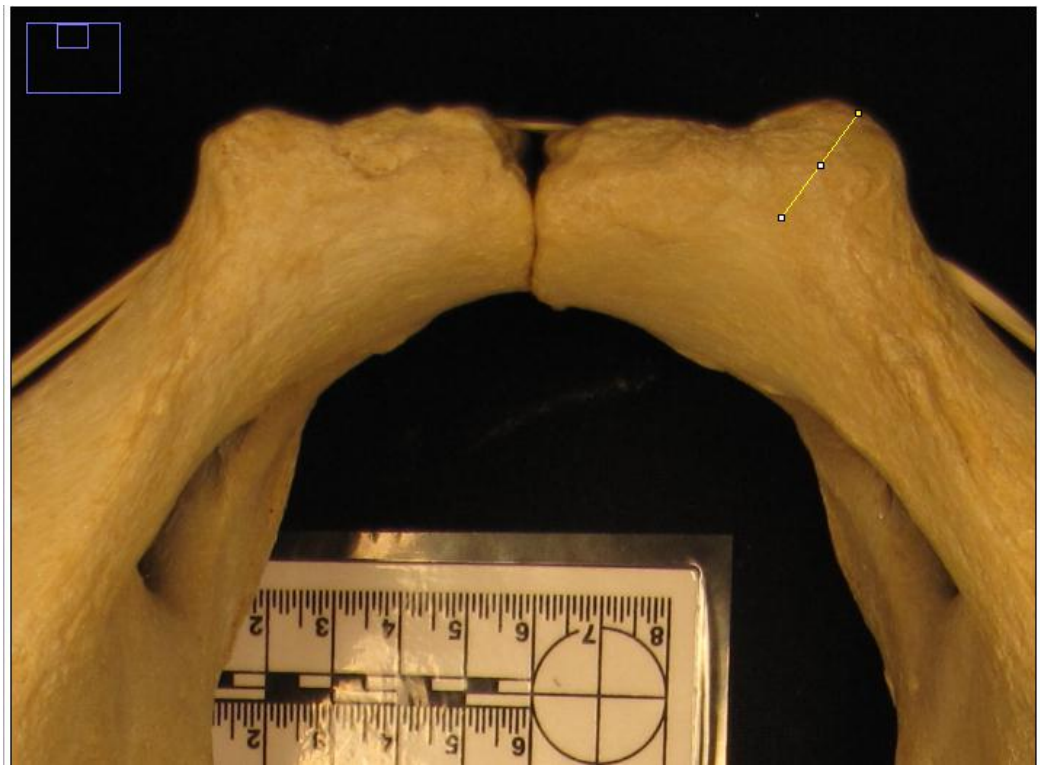


Figure 10. Measurement of pubic tubercle height using ImageJ.

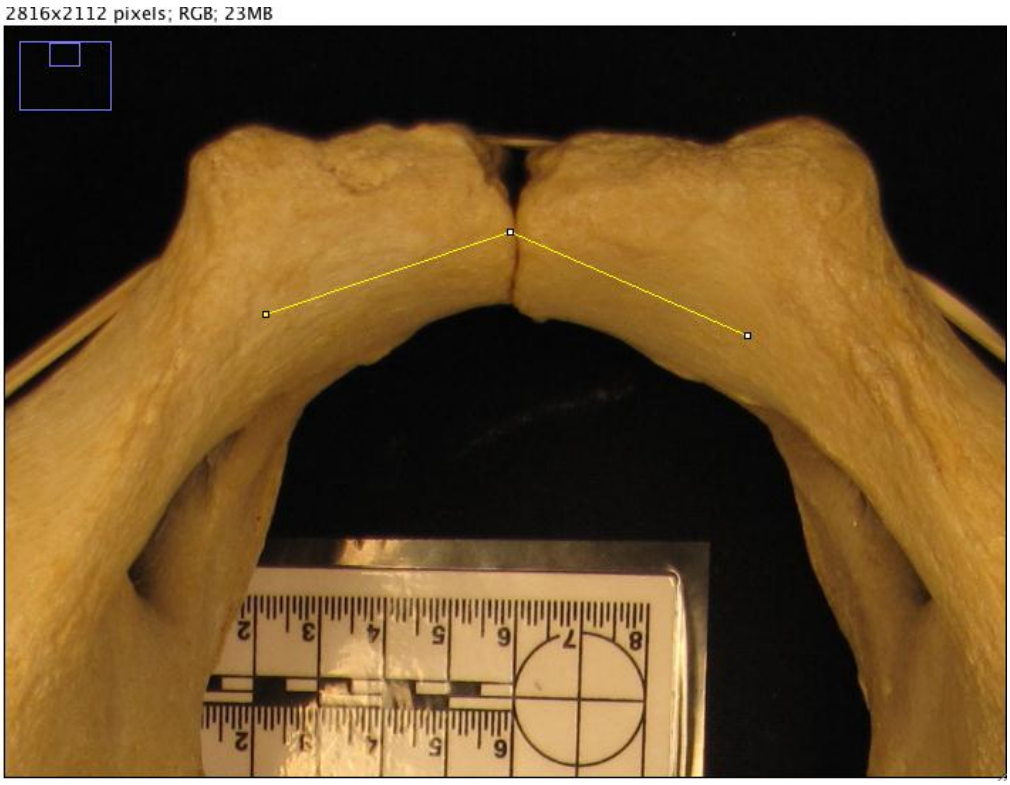


Figure 11. Arcuate angle of pelvic inlet measured using ImageJ.

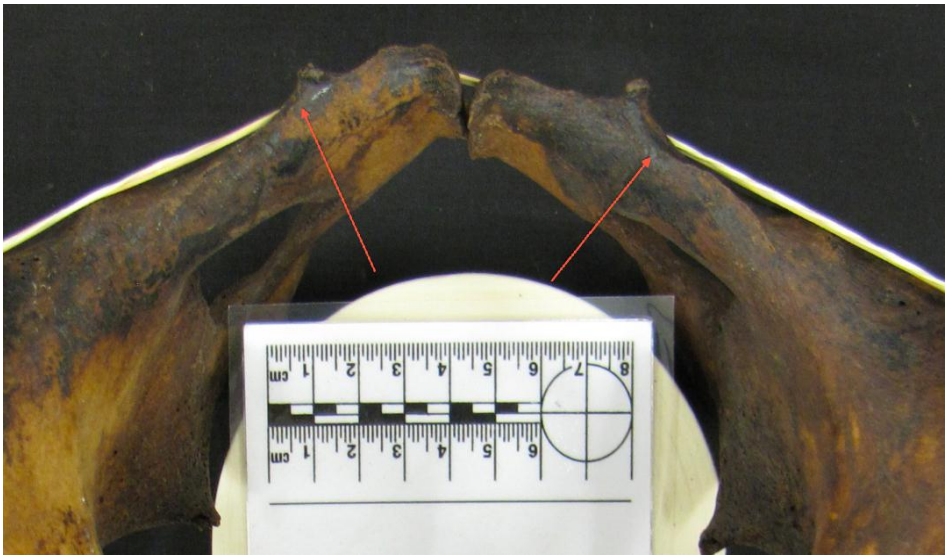


Figure 12. Arrows indicate the placement points for arcuate angle measurement points on ImageJ.

the image had been calibrated using ImageJ, the measurement point was placed at the base of the pubic tubercle and extended to the tip of the pubic tubercle. Arcuate angle of the pelvic inlet was measured using ImageJ's angle measurement application from photographs of a superior view of the articulated os coxae (Figure 10). The landmarks for the angle measurement were placed at the point on the bone where the pectineal line veers from the pelvic inlet to make a ridge that forms the point of maximum elevation on the pubic tubercle (Figure 11). Pubic tubercle distance was measured with digital callipers as per Snodgrass and Galloway's (2003) method (Figure 12).

2.2.4. Parturition scarring variables

Presence and types of parturition scarring were collected for every individual, as were photographs of each example of parturition scarring. Definitions of parturition scarring types were based on previous work on parturition scarring (Table 4, Figures 13

to 19). A numerical scoring system was used for each type of parturition scarring. The numerical scoring systems used in this study were either established in other studies (Cox,1989; Houghton, 1974; Suchey et al.,1979) and used in this project, or were slightly modified from other studies to fit the aims of this project. Two modifications to previous definitions of parturition scarring were made in this study. Firstly, Suchey et al. (1979) framed dorsal pitting scores as 'dorsal changes', whereas in this study dorsal pitting scores are termed 'dorsal pitting'. Secondly, pre-auricular sulcus type 4 was defined by Cox (1989) but was not used alongside Houghton's (1974) sulcus categories in previous studies, whilst in this study sulcus type 4 is used as a sulcus category alongside Houghton's (1974) sulcus categories. Dorsal pitting scores are termed 'dorsal pitting' in this study to reflect a focus on the pits *alone*, and the variation of their presence (trace, medium, large) on the dorsal aspect of the pubis. Pre-auricular sulcus type 4 was included in this study alongside other sulcus types as Cox (1989) identified the occurrence of sulcus type 4 in males in particular. Sulcus type 4 as a defined sulcus type was included in this study in order to examine the presence of sulcus types that are not associated with pregnancy or childbirth.

In Suchey et al.'s (1979) system of dorsal changes classification, dorsal pitting is considered absent when the dorsal aspect of the pubic symphysis is smooth and shows no depression in bone surface (Figure 13). Trace dorsal (Score = 1) pitting shows very shallow and very few depressions in the bone surface (Figure 14). Medium dorsal pitting shows depressions with a defined outline, even if the depression in the bone surface is not very deep (Figure 15). Large dorsal pitting shows very defined, deep depressions with clearly outlined depression edges, as if bone material has been 'scooped' out of the

bone surface (Figure 16). Sclerotic tissue deposition is scored as present/absent. It is considered present on the pubic symphysis when new bone formation is random and disorganized, showing spicules of bone rising from the bone surface in multiple layers, usually concentrated around the pubic tubercle and the edge of the symphyseal face (see Figure 2 in Chapter 1). The preauricular sulcus is classified into four types based on the depth, breadth and length of the sulcus when present, as well as the texture of the sulcus floor (Table 4). These categories are based on Houghton (1974) and also on Cox's (1989) classification of sulcus type 4, which Cox found more frequently in males. Houghton's (1974) groove of pregnancy appears as an impression made by a series of pits combining together into one groove (Figure 17), the floor of which is ridged, with the areas between these ridges being smooth-surfaced. Houghton (1974) described the groove of the ligament as a short, narrow groove with a straight edge and an even, flat floor; the essential difference between the groove of pregnancy and the groove of the ligament (Figure 18).

Table 4. Definitions of parturition scarring that will be used in the collection of parturition scarring data, adapted from Cox 1989:151-155.

Parturition scarring type	Numerical scale	Description of scale point
Dorsal pitting (Suchey et al., 1972)	0	Pitting is absent (Fig. 2.7)
	1	Trace to small amounts of pitting (see Figure 2.8).
	2	Medium amounts of pitting (see Figure 2.9).
	3	Large amounts of pitting (see Figure 2.10).
Sclerotic tissue deposition at the pubic symphysis (Cox,1989)	0	Tissue deposition is absent.
	1	Tissue deposition is present (see Figure 1.2 in Chapter 1).
Pre-auricular sulcus type (Houghton, 1974) (Cox, 1989)	0	Pre-auricular sulcus is absent.
	1	Pre-auricular sulcus presents as a groove of pregnancy (Houghton,1974) (see Figure 2.11).
	2	Pre-auricular sulcus presents as groove of ligament (Houghton,1974). (see Figure 2.12).
	3	Pre-auricular sulcus is very wide, clearly demarcated margin and a grainy, textured floor. It does not fit either of Houghton's (1974) categories (Cox,1989).
	4	Pre-auricular sulcus is short and narrow, does not resemble a true sulcus but rather an accentuated tubercle piriformis near the posterior inferior iliac spine (see Figure 2.13) (Cox,1989).

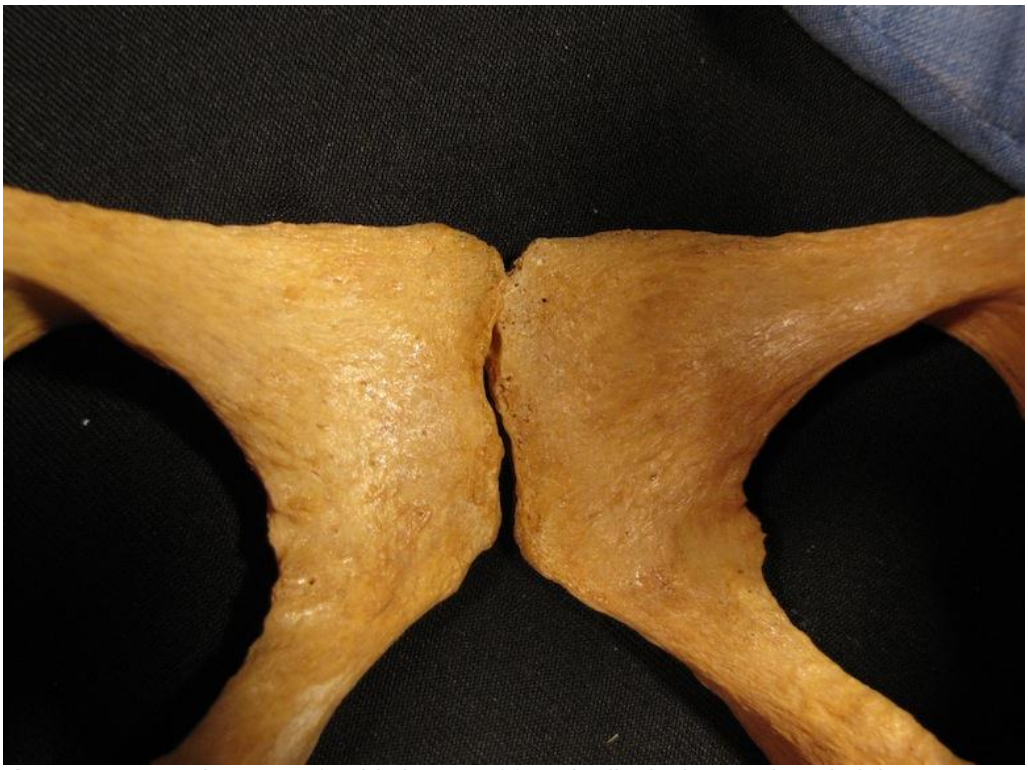


Figure 13. Dorsal aspect of pubic bones of female displaying no dorsal pitting.

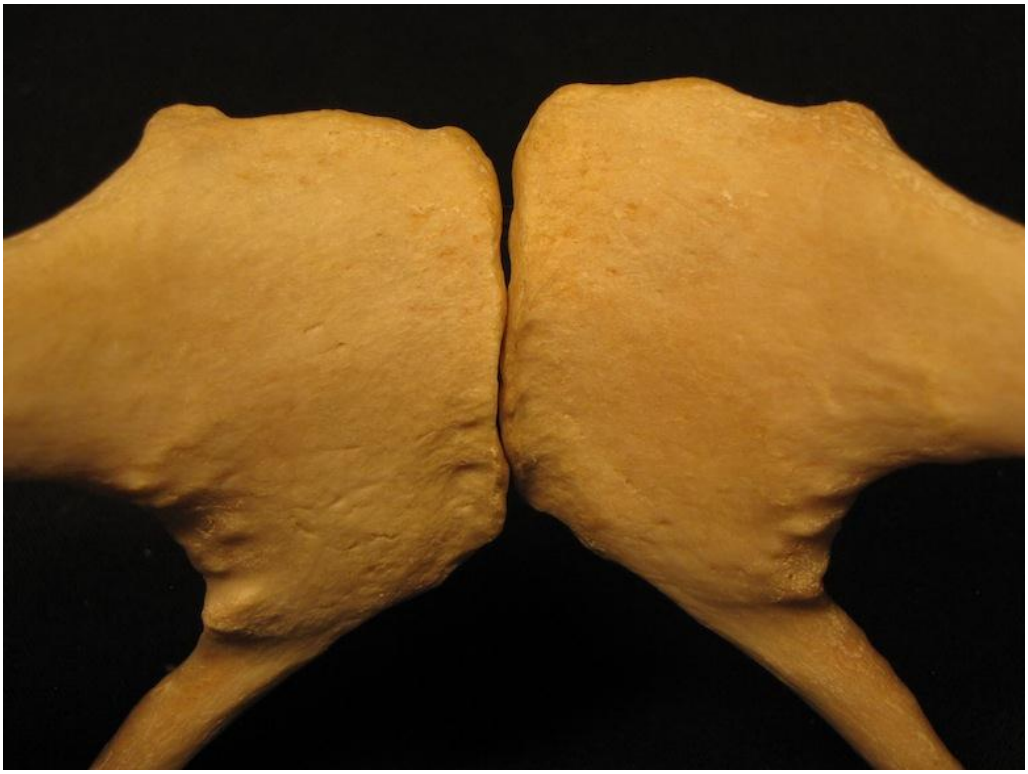


Figure 14. Dorsal aspect of pubic bones of female displaying trace to small dorsal pitting.

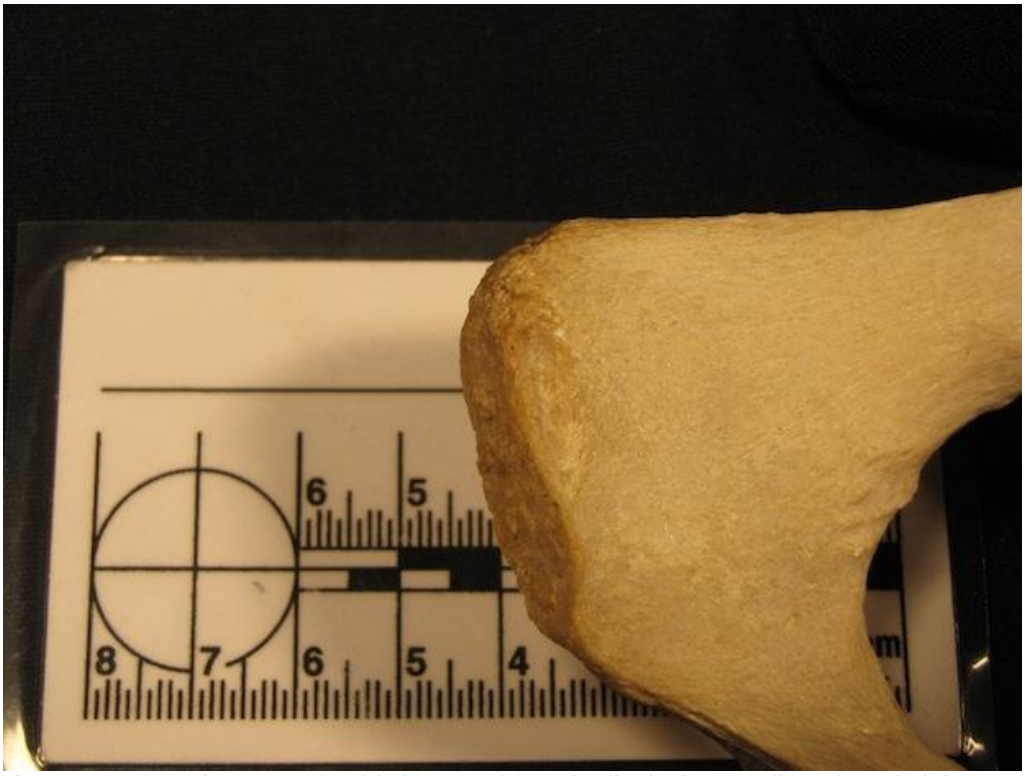


Figure 15. Dorsal aspect of pubic bones of female displaying medium dorsal pitting.

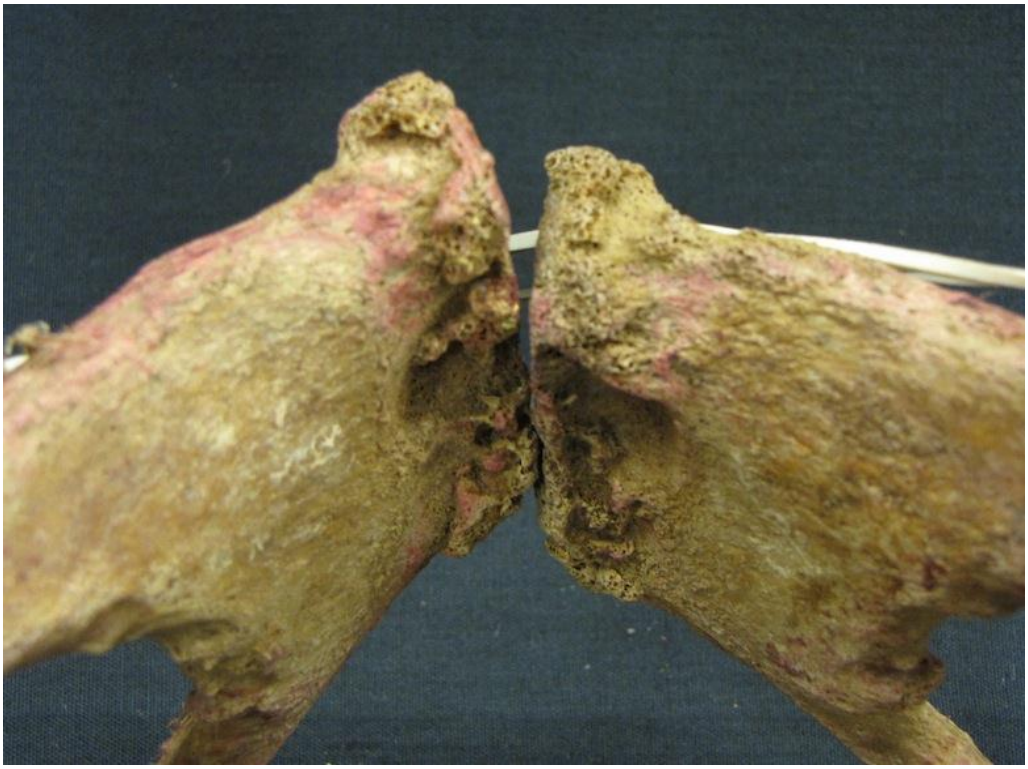


Figure 16. Dorsal aspect of pubic bones of female displaying large dorsal pitting.

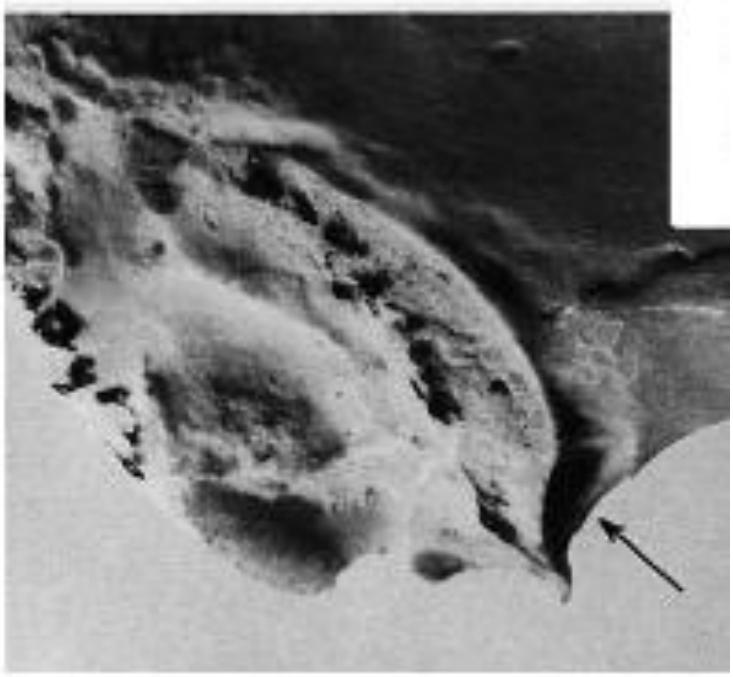


Figure 17. Groove of pregnancy presentation of pre-auricular sulcus (arrow) [Houghton,1974:387**].**

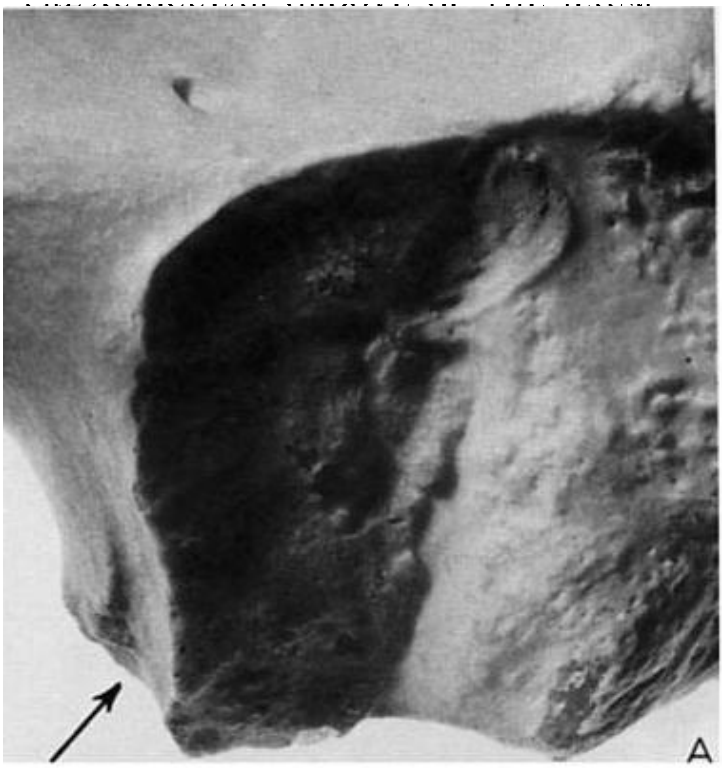


Figure 18. Groove of ligament presentation of pre-auricular sulcus (arrow) [Houghton, 1974:387].

Figure 19. Pre-auricular sulcus Type 4 (Table 2) [Cox, 1989:153].

2.2.5. Demographic and parity variables

The Maxwell and the Spitalfields collections have associated documention for each individual available, including sex, age, occupation, pathologies and parity status. However not all information is available for every individual; for example, some individuals do not have associated documentation on occupation, whilst others have all associated documentation except parity status.

For the Maxwell Documented Skeletal Collection information on age, sex, ethnicity, parity status, height, weight and pathological conditions for the each individual was taken from collection documentation. In order to remain consistent with the Spitalfields sample, the documented weight and height at death for all individuals in the

Maxwell sample were not used in analyses, and the estimated body mass and stature values for individuals in the Maxwell sample were used. Sex, age, and parity status information in the Christ Church, Spitalfields population were obtained from a database created by Margaret Cox, Theya Molleson and archivists from the Hueguenot Society of Great Britain and Ireland.

2.3. Quantitative analysis procedures

2.3.1. Intra-observer error analysis

Measurements of osteometric variables, parturition scarring categories and pubic tubercle variables were repeated on approximately 10% of each collection used in the sample in order to assess intra-observer error. Measuring mean difference in osteometric data collection allows scholars to measure the accuracy and precision of their methodology, whilst the display of standard deviation around mean difference quantifies the error in measurement (Bland and Altman, 2010). Intra-observer error was assessed through the use of a one-sample t-test for comparison of differences in the mean of the measurements taken the first and the second time. A Mann-Whitney U-test was used examine the error in categorizing parturition scarring scores. Measurement methodology is considered sound when the means of the first and second measurements do not differ significantly from 0 and 95% of the mean differences between measurements fall within two standard deviations of the averaged mean (Kurki, 2005).

2.3.2. Univariate analyses

The study sample was broken down into subsamples in order to compare mean differences between the subsamples: males, females, parous females and non-parous females. Mean differences in study variables were examined between males and females, and between parous and non-parous females. Testing mean differences between these subsamples may bring out patterns that are results of changes relating to a parity amongst the females in the sample. Statistical differences between study subsamples were analyzed using Student's t-tests (osteometric variables) and Wilcoxon Signed-Rank tests (categorical parturition scarring variables).

2.3.3. Bivariate analyses

The bivariate analyses in this study examine the statistical relationships between variables that represent body size (mass and stature), pelvic canal size (geometric mean of canal measures and individual canal measures), parturition scarring (dorsal pitting, sclerotic tissue deposition and pre-auricular sulcus type) and pubic tubercle variables (pubic tubercle height, pubic tubercle distance and arcuate angle). These analyses were completed in order to test for associations between aspects of body and pelvic size and parturition scarring presence. Bivariate analyses were completed using parametric and non-parametric tests on each sex separately, and on parous and non-parous females separately. The relationships between metric variables (e.g., body mass, stature, pelvic canal size, and pubic tubercle variables) were examined using Pearson's product-moment correlations. Spearman's rank correlation tests were used to

examine the relationships involving the categorical parturition scarring variables. An alpha of 0.05 was used for all tests.

2.3.4. Multivariate analyses

Principal components analysis (PCA) is a multivariate analysis method that identifies patterns of variation in data in multivariate space and reduces a large number of variables into a smaller set of descriptive components (the eigenvectors). These eigenvectors reflect maximal variance in the sample data. Each component represents a weighted combination of the original variables (indicated by the loading coefficients for each variable) (Joliffe, 2002). The eigenvalue of a principal component (eigenvector) indicates the amount of variance in multivariate space that is encompased by the component. PCA is based on covariance matrices and is the most common method used in morphometric analyses (Kurki, 2007). The principal components extracted from a PCA can then be used in further analyses to understand how shape variance in the sample differs is associated with body size and parturition scarring.

The ability to examine multiple variables in multiple dimensions is well-suited to analyses investigating the influence of shape on specific variables. Holliday (1997) uses PCA to examine body size differences in parallel to ecogeographic patterning, whilst Fleagle and colleagues (2010) use PCA in conjunction with geometric morphometric data points to identify the major axes of cranial shape amongst diverse primate groups. Kurki (2005; 2007; 2013a) spearheads the use of PCA in analyses of pelvic canal variables, examining the resultant principal components alongside body shape, canal shape and sexual dimorphism within and amongst populations. Betti (2014) also

demonstrates the success of PCA analyses of pelvic variables in considering the sexual dimorphism of specific bony elements of the pelvis, highlighting both the generalized and more specific applications of the analysis.

The extraction of pelvic canal shape using PCA analyses is achieved following the isometric size adjustment of each pelvic measurement variable. Firstly, a geometric mean is calculated from all of the pelvic canal measurements, representing the *nth* root of the product of all *n* variables (Jungers et al., 1995). This geometric mean represents the overall size of the pelvic canal. The original pelvic canal variables, and the geometric mean are then log-transformed to convert the variables from allometric space into isometric space, which transforms allometric relationships into parallel linear relationships (Jungers et al., 1995).The log-tranformed geometric mean is subtracted out of the log-transformed pelvic variables, effectively removing size from the transformed variables (Darroch and Mosimann, 1985) (Mosimann and James, 1979). This leaves log-shape adjusted variables that represent *shape* components specifically (Jungers et al., 1995). These log-shape variables are then entered into the PCA to determine the main aspects of shape variation in the sample.

PCA analyses were conducted on the log-shape variables and the resultant principle components were examined in relation to parturition scarring type to determine any relationships between pelvic canal shape and parturition scarring. PCA analyses were carried out on males and females separately in order to reduce the influence of sexual dimorphism in pelvic canal shape. In addition, only specimens with a full complement of pelvic measurements were used (no missing values for any variable category).

The total number of principal components to be extracted must be determined in order to complete further analyses. The number of principal components to be extracted for further analyses is defined by the Cattell scree test plot (Cattell, 1966), which has been used successfully in morphometric analyses (Groeneveld et al., 2011). The scree plot displays the components on the on the x-axis and the eigenvalues on the y-axis, with the dots on the plot connected by a line. As the dots move towards the right (with increasing components), the eigenvalues drop, which is mirrored in the line connecting the dots. Once the drop in the line terminates, an ‘elbow’ in the line is present and the line smoothes out to a less steep decline. The ‘elbow’ point is the cut off point for the number of components used in further analyses. Bivariate plots of the principal components was examined for clustering of individuals by parturition scarring category (dorsal pitting, sclerotic tissue deposition and sulcus type). Individuals who plot near to each other on these bivariate plots share aspects of pelvic shape represented by the principal components. Linear regression was also used to analyze whether any of the first four principal components (which represent components of pelvic canal shape) covary with mean pelvic canal size (log-tranformed geometric mean of the canal variables).

2.4. Research questions and hypotheses

The goal of this project is to investigate whether parturition scarring on the hip bone is influenced by body size (stature and body mass), pelvic canal size, individual pelvic dimensions, or finally pelvic canal shape. An examination of canal shape alongside the presence of parturition scarring may show associations between

presence and degree of scarring and canal shape. Examining pelvis size, parturition scarring and body mass and stature may additionally highlight biomechanical considerations in the presence of parturition scarring.

Previous analyses on parturition scarring have identified scarring on males, and factors other than parity status in females that relate to the presence of scarring, including aspects of body size and shape (Cox, 1989; Cox and Scott, 1992). These previous analyses have also collated different parturition scarring types into one analysis. However these studies did not capture pelvic shape variation in multivariate space: capturing such data makes it possible to examine the role played by shape *alone* when considering parturition scarring, and not just individual aspects of canal *size* (e.g. inlet breadth, midplane mediolateral length, etc.). Therefore in this project, pelvic size and shape and body size are broken down into elements in order to examine the influence of each element on parturition scarring type and presence. Body size is considered to be made of body mass and stature. Pelvic size is represented by both individual measurements and a geometric mean of canal size, whilst pelvic canal shape is constructed from principal components. The null hypothesis tested for each body size, pelvic canal size and pelvic canal shape variable is of no relationship with parturition scarring:

Null hypothesis 1: There is no significant relationship between body mass and the presence of parturition scarring of any degree of development in either sex in both samples.

Null hypothesis 2: There is no significant relationship between stature and the presence of parturition scarring of any degree of development in either sex in both samples.

Null hypothesis 3: There is no significant relationship between pelvic canal size (as represented by geometric mean) and the presence of parturition scarring of any degree of development in both sexes from both samples.
Sub null hypothesis 3: There is no significant relationship between individual pelvic measurements and the presence of parturition scarring of any degree of development in females from both samples.

Null hypothesis 4: There is no significant relationship between pelvic canal shape (as represented by the principal components) and the presence of parturition scarring of any degree of development in either sex in both samples.

The rejection of any of the null hypotheses above will indicate the support of an alternative hypothesis; that a particular type and degree of development of parturition scarring is statistically associated with the body size or pelvic size or shape variable under investigation. The support of an alternative hypothesis for any of these research questions would support the notion that parturition scarring may be exacerbated by specific body size and body shape dimensions, regardless of parity events and therefore regardless of sex.

Chapter 3: Results

In total, data on 292 specimens were collected (141 females and 151 males). For all analyses, females from both collections were combined into a sample of females, as were the males from both collections combined into a sample of males. Details of age, body mass, stature and parity for the males and females of each collection used in the sample are presented in Table 5. Details of the number of parous and non-parous females from each collection included in the sample, including parity status for parous females, is presented in Table 6.

Table 5. Information on age, stature and body mass for the males and females from each collection used in the sample.

		Females			Males		
		Age	Stature (cm)	Body mass (kg)	Age	Stature (cm)	Body mass (kg)
MAXWELL	N	77	77	77	92	93	93
	Range	78	42.4	36.9	81	43.3	46.0
	Minimum	22	133.7	33.8	19	152.6	35.5
	Maximum	100	176.0	70.7	100	195.9	81.5
	Mean	70.6	160.2	56.6	60.9	169.9	67.0
	Std. Deviation	17.8	6.9	6.6	17.9	7.7	7.5
		Females			**Males**		
		Age	Stature (cm)	Body mass (kg)	Age	Stature (cm)	Body mass (kg)
SPITALFIELDS	N	64	56	62	58	51	57
	Range	72	36.0	42.7	69	32.2	48.6
	Minimum	17	142.4	47.0	22	155.7	40.2
	Maximum	89	178.4	89.8	91	187.9	88.8
	Mean	58.6	157.2	69.3	56.8	172.2	68.4
	Std. Deviation	17.2	7.7	9.1	14.5	7.9	11.7

Table 6. Information on number of parous and non-parous females in the collections used in the sample, including parity status for parous females**.**

MAXWELL		**SPITALFIELDS**	
Parity	N	Parity	N
0	58	0	33
1	4	1	7
2	7	2	8
3	5	3	4
4	1	4	6
5	2	5	1
		6	1
		8	1
		9	1
		10	1
		15	1

Summary statistics (from untransformed data) are presented in Table 7. Frequency tables for parturition scarring scores for males and females, and the subgroup of parous and non-parous females are presented in Tables 8 and 9. Summary statistics for pubic tubercle height, distance from pubic tubercle apex to pubic symphyseal margin and arcuate angle are also divided into these same subgroups are presented in Tables 10 and 11.

3.1. Population-specific differences

Given the possibility that population-specific differences could affect the results of the statistical analyses carried out, all statistical analyses were also carried out on the Maxwell collection and the Spitalfields collection separately. The full complement of the results of each of these analyses can be found in Appendix C. Prominent differences between the collections included differences in the correlation between certain types of

parturition scarring and individual pelvic measures, as well as differences in the association of pubic tubercle variables to body size and pelvic canal size variables.

Spitalfields females have a larger arcuate angle than Maxwell females. Arcuate angle associated negatively with bi-iliac breadth in Spitalfields females and positively with femoral length in Maxwell females. Spitalfields females presented with significant associations between dorsal pitting, bi-iliac breadth, medio-lateral inlet and outlet, anterior space of the inlet and outlet and pubic length. Amongst Spitalfields females, sclerotic tissue deposition associated with anterior space of the inlet and medio-lateral pelvic outlet. Only pubic length associated with dorsal pitting in Maxwell females. Arcuate angle also associates with bi-iliac breadth and femoral length in Spitalfields males, but there are no significant associations between pubic tubercle, body size and pelvic canal size variables in Maxwell males. Dorsal pitting, sclerotic tissue deposition and pre-auricular sulcus type did not associate with any pelvic measure in Maxwell males, but in Spitalfields males dorsal pitting associated significantly with pubic length, and pre-auricular sulcus type associated with medio-lateral pelvic inlet and the anterior space of the pelvic inlet. These differences in statistical relationships between the collections may highlight population-specific differences, which should be considered in drawing conclusions from these analyses.

3.2. Body size reconstruction

The summary statistics for the reconstruction of male and female body mass and stature are presented below in Tables 12 and 13. Morphometric body mass estimates are consistently higher than the mechanical body mass estimates. The mechanical and morphometric results for body mass estimation were therefore averaged for subsequent analyses.

Table 7. Summary statistics for osteometric variables.

	Females			**Males**		
	N	Mean	S. D.	N	Mean	S. D.
FMLG	133	424.0	28.0	144	456.9	30.7
FBLG	133	423.6	27.1	144	456.1	29.3
FMHD	133	41.9	3.6	144	47.8	3.5
BIIL	120	261.7	21.4	122	270.3	18.3
BIAC	117	119.9	10.7	119	118.0	7.7
INAP	119	108.4	12.8	120	102.6	11.9
INML	120	127.0	10.0	121	121.8	7.9
INPT	119	33.6	6.6	121	26.7	4.9
INAT	118	99.8	7.3	119	100.5	7.7
MDML	120	108.0	9.4	121	93.6	8.8
MDPT	116	66.4	10.1	121	64.7	11.7
OTML	116	123.9	13.7	121	105.6	10.8
OTPT	118	63.8	8.6	121	50.7	6.6
DPPL	138	105.1	7.7	147	109.3	8.1
PBLG	132	87.3	9.6	147	91.0	8.6
PSW	100	7.5	2.1	61	5.4	1.9
PSL	100	28.4	4.8	61	24.6	5.4
Pubic tubercle height	86	5.76	2.48	105	8.80	2.96
Pubic tubercle distance	97	24.97	6.50	121	23.47	3.71
Arcuate angle	84	141.04	7.38	103	139.41	7.58

Table 8. Frequency statistics for dorsal pitting, sclerotic tissue deposition and sulcus type in females and males.

Dorsal pitting	**Males**	**Females**
Score	Frequency	Frequency
0	91	41
1	43	50
2	2	26
3	0	8
Sclerotic tissue deposition		
Score	Frequency	Frequency
0	103	76
1	33	43
Sulcus type		
Type	Frequency	Frequency
0	86	39
1	4	32
2	20	37
3	0	5
4	38	25

Table 9. Frequency statistics for dorsal pitting, sclerotic tissue deposition and sulcus type in parous females and non-parous females.

Dorsal pitting	**Parous females**	**Non-parous females**
Score	Frequency	Frequency
0	5	36
1	14	36
2	12	14
3	3	5
Sclerotic tissue deposition		
Score	Frequency	Frequency
0	21	55
1	12	31
Sulcus type		
Type	Frequency	Frequency
0	7	32
1	13	19
2	9	28
3	2	3
4	8	17

Table 10. Summary statistics for pubic tubercle variables in females and males.

	Males			Females		
	N	Mean	S.D.	N	Mean	S.D.
Pubic tubercle height	105	8.8	3.0	86	5.7	2.5
Pubic tubercle distance	121	23.5	3.7	97	24.9	6.5
Arcuate angle	103	139.4	7.6	84	141	7.4

Table 11. Summary statistics for pubic tubercle variables in non-parous and parous females.

	Non-parous females			Parous females		
	N	Mean	S.D.	N	Mean	S.D.
Pubic tubercle height	61	5.6	2.4	25	6.2	2.6
Pubic tubercle distance	69	24.5	6.9	28	26.2	5.3
Arcuate angle	60	139.9	7.0	24	143.8	7.7

Table 12. Mean estimated body mass (kg) for sample.

		Females	Males
Morph[1]	n	114	117
	Mean (S.D.)	67.3 (12.3)	71.8 (11.6)
Mech[2]	n	131	146
	Mean (S.D.)	57.51 (9.3)	64.5 (11.3)
Average[3]	n	139	150
	Mean	62.3	67.4

[1] Estimates based on Ruff et al.'s (2005) morphometric (bi-iliac breadth-stature) sex-specific formulae.
[2] Estimates based on Ruff et al.'s (2012) mechanical (femoral head) sex-specific formulae.
[3] Average of morphometric and mechanical body mass estimates.

Table 13. Mean estimated stature (cm) for sample.

	Females	Males
n	133	144
Mean	158.9	170.7

3.3. Intra-observer error analysis

Paired t-test results indicate that two osteometric variables are significantly different from 0 with an alpha level of $p < 0.05$: bi-acetabular breadth (t= -2.2, p=0.040), anterior-posterior length of the inlet (t= 2.8, p=0.009), anterior-posterior length of the midplane (t= -3.5, p=0.002), anterior-posterior length of the outlet (t= -3.3, p=0.003), pubic depth (t=2.4, p=0.021) and pubic tubercle distance (t= -2.2, p=0.044). The statistically significant difference in these measurements denotes high error rate, meaning that these measurements were excluded from further analyses. Intra-observer error in parturition scarring scoring was compared using a Wilcoxon signed rank test, with a Monte Carlo resampling method. There were no statistically significant differences between the first and second sets of parturition scarring scoring. This suggests that osteometric data and parturition scarring scores collected in this study are within acceptable margins of accuracy. A summary of the statistical test results for the error analysis can be found in Appendix A.

3.4. Univariate analyses

Independent samples t-tests comparing mean differences between males and females (Table 14) in the sample indicate significant differences ($p < 0.05$) for all variables except for inlet anterior, midplane posterior and arcuate angle. Table 15 presents the descriptive statistics for the independent samples t-test between males and females, demonstrating that on average, males are larger in these measures than females. It is not unexpected that many of the variables differ significantly, as sexual dimorphism influence both shape and size of different planes of the pelvis.

Table 14. Independent samples t-test results for males vs. females.

	p-value*	Mean Difference	S.D.	95% C.I.	
				Lower	Upper
FMLG	*0.000*	32.9	3.5	25.9	39.9
FBLG	*0.000*	32.5	3.4	25.8	39.2
FMHD	*0.000*	6.0	0.4	5.1	6.8
BIIL	*0.001*	8.6	2.6	3.5	13.6
INML	*0.000*	-5.2	1.2	-7.5	-2.9
INPT	*0.000*	-6.9	0.7	-8.4	-5.4
INAT	0.479	0.7	1.0	-1.2	2.6
MDPT	0.227	-1.7	1.4	-4.5	1.1
OTML	*0.000*	-18.3	1.6	-21.4	-15.1
OTPT	*0.000*	-13.1	1.0	-15.1	-11.2
OTAT	*0.085*	-1.4	0.8	-3.0	0.2
PBLG	*0.001*	3.6	1.1	1.5	5.8
Pubic tubercle height	*0.000*	3.0	0.4	2.2	3.8
Arcuate angle	0.141	-1.6	1.1	-3.8	0.5
PSW	*0.000*	-2.1	0.3	-2.8	-1.4
PSL	*0.000*	-3.7	0.8	-5.4	-2.1

* Values in italic are significant at <0.05

Table 15. Descriptive statistics for independent samples t-test comparing mean differences between male and female subsample.

		N	Mean	S.D.	Std. Error Mean
FMLG	M	144	456.9	30.7	2.6
	F	133	424.0	28.0	2.4
FBLG	M	144	456.1	29.3	2.4
	F	133	423.6	27.1	2.3
FMHD	M	144	47.8	3.5	0.3
	F	133	41.9	3.6	0.3
BIIL	M	122	270.3	18.3	1.7
	F	120	261.7	21.4	2.0
INML	M	121	121.8	7.9	0.7
	F	120	127.0	10.0	0.9
INPT	M	121	26.7	4.9	0.4
	F	119	33.6	6.6	0.6
INAT	M	119	100.5	7.7	0.7
	F	118	99.8	7.3	0.7
MDPT	M	121	64.7	11.7	1.1
	F	116	66.4	10.1	0.9
OTML	M	121	105.6	10.8	1.0
	F	116	123.9	13.7	1.3
OTPT	M	121	50.7	6.6	0.6
	F	118	63.8	8.6	0.8
OTAT	M	145	90.2	6.3	0.5
	F	132	91.6	7.1	0.6
PBLG	M	147	91.0	8.6	0.7
	F	132	87.3	9.6	0.8
Pubic tubercle height	M	105	8.8	3.0	0.3
	F	86	5.8	2.5	0.3
Arcuate angle	M	103	139.4	7.6	0.7
	F	84	141.0	7.4	0.8
PSW	M	61	5.4	1.9	0.2
	F	100	7.5	2.1	0.2
PSL	M	61	24.6	5.4	0.7
	F	100	28.4	4.8	0.5

Mean differences between parous and non-parous female subsample are presented in Table 16, with the descriptive statistics of the corresponding independent samples t-test presented in Table 17. Parous females have larger mediolateral inlets, posterior midplanes and posterior sections of the pelvic inlet, which is not surprising as the posterior aspects of the lower planes of the pelvic canal in females are affected by obstetric selection. The significant difference in anterior inlet space is unexpected, as the anterior space of the pelvic inlet has not been reported to vary significantly within sexes in small-bodied samples (Kurki, 2007). Parous females also have significantly larger pubic lengths than non-parous females.

Table 16. Independent samples t-test results for parous vs. non-parous females.

	p-value*	Mean Difference	S.D.	95% C.I.	
				Lower	Upper
FMLG	0.727	1.8	5.1	-8.3	11.9
FBLG	0.880	0.7	4.9	-9.0	10.5
FMHD	0.970	0.0	0.6	-1.3	1.3
BIIL	0.854	-0.8	4.1	-9.0	7.4
INML	*0.004*	-5.5	1.9	-9.2	-1.8
INPT	0.536	0.8	1.3	-1.7	3.3
INAT	*0.007*	-3.8	1.4	-6.5	-1.1
MDPT	*0.030*	-3.2	1.5	-6.1	-0.3
OTML	0.130	-4.1	2.7	-9.4	1.2
OTPT	*0.026*	-3.7	1.6	-6.9	-0.4
OTAT	0.978	0.0	1.3	-2.6	2.5
PBLG	*0.000*	-6.4	1.7	-9.7	-3.1
Pubic tubercle height	0.395	-0.5	0.5	-1.6	0.6
Arcuate angle	*0.005*	-4.6	1.6	-7.7	-1.4
PSW	0.073	-0.8	0.4	-1.6	0.1
PSL	0.501	-0.7	1.0	-2.6	1.3

Values in italics are significant at < 0.05

Table 17. Descriptive statistics for independent samples t-test comparing mean differences between parous and non-parous female subsample.

		N	Mean	S.D.	Std. Error Mean
FMLG	Non-parous	86	424.7	29.2	3.2
	Parous	47	422.9	25.9	3.8
FBLG	Non-parous	86	423.9	28.4	3.1
	Parous	47	423.1	24.8	3.6
FMHD	Non-parous	86	41.9	3.4	0.4
	Parous	47	41.9	3.9	0.6
BIIL	Non-parous	79	261.5	17.4	2.0
	Parous	41	262.2	27.9	4.4
INML	Non-parous	78	125.1	9.8	1.1
	Parous	42	130.5	9.5	1.5
INPT	Non-parous	77	33.9	6.2	0.7
	Parous	42	33.1	7.3	1.1
INAT	Non-parous	76	98.5	7.7	0.9
	Parous	41	102.3	6.0	0.9
MDPT	Non-parous	77	70.7	7.3	0.8
	Parous	41	73.9	8.0	1.2
OTML	Non-parous	78	122.6	12.2	1.4
	Parous	38	126.7	16.2	2.6
OTPT	Non-parous	77	62.5	8.4	1.0
	Parous	41	66.2	8.7	1.4
OTAT	Non-parous	86	91.6	7.1	0.8
	Parous	46	91.7	7.2	1.1
PBLG	Non-parous	85	85.1	9.4	1.0
	Parous	47	91.5	8.6	1.3
Pubic tubercle height	Non-parous	51	5.6	2.5	0.3
	Parous	35	6.0	2.5	0.4
Arcuate angle	Non-parous	51	139.2	6.8	1.0
	Parous	33	143.8	7.4	1.3
PSW	Non-parous	57	7.2	1.9	0.3
	Parous	43	7.9	2.4	0.4
PSL	Non-parous	57	28.1	4.6	0.6
	Parous	43	28.7	5.0	0.8

The Mann-Whitney U tests (Tables 18 and 19) were used to test for differences between subsamples for categorical variables. There are differences between males and females in all three types of parturition scarring. Dorsal pitting is the only type of parturition scarring that is significantly different between both males and females *and* between parous and non-parous females. It should be noted that parous and non-parous females do not show statistically significant differences in two of the three scarring categories.

Table 18. Mann Whitney U test results for females and males.

	Mann-Whitney U	Z	p-value*	Monte Carlo (2-tailed) p	99% C.I. Lower	Upper
Dorsal pitting	4911.5	-6.488	*0.000*	0	0.000	0.000
Sclerotic tissue deposition	7115	-2.097	*0.036*	0.035	0.030	0.040
Sulcus type	8456	-2.654	*0.008*	0.009	0.007	0.011

* values in italic are significant at < 0.05

Table 19. Mann Whitney U test results for parous vs. non-parous females

	Mann-Whitney U	Z	p-value*	Monte Carlo (2-tailed) p	99% C. I. Lower	Upper
Dorsal pitting	1150.000	-3.541	*0.000*	0.001	0.000	0.001
Sclerotic tissue deposition	1648.000	-.013	0.989	1	1.000	1.000
Sulcus type	1921.500	-1.273	0.203	0.209	0.198	0.219

* values in italic are significant at < 0.05

3.5. Bivariate analyses

Bivariate analyses were completed for males and females individually in order to reduce the influence of sexual dimorphism on pelvic components in particular. The female subgroups of parous and non-parous females were pooled into a 'female' sample for bivariate tests.

Pubic tubercle variables were examined alongside pelvic canal size, femoral head diameter, femoral length and bi-iliac breadth to ascertain possible relationships between pelvic canal size, pubic tubercle variables and body size. Results of Pearson's correlation test in males and females are presented in Tables 20 and 21. Pubic tubercle height and pre-auricular sulcus width associate with pelvic canal size in males. Pubic tubercle height associates with femoral head diameter in females.

Table 20. Results of Pearson's product-moment correlation test for pubic tubercle height, arcuate angle, osteometric variables representing body size and mean pelvic canal size in males.

		Arcuate angle	Pubic tubercle height	Pre-auricular sulcus width	Pre-auricular sulcus length
FMLG	r	0.027	0.192	-0.043	-0.113
	p-value*	0.813	0.082	0.763	0.427
	N	82	83	52	52
FMHD	r	-0.171	0.111	-0.022	-0.038
	p-value*	0.124	0.317	0.880	0.789
	N	82	83	52	52
BIIL	r	0.134	0.184	0.062	0.270
	p-value*	0.228	0.093	0.660	0.051
	N	83	84	53	53
Mean pelvic canal size	r	0.128	0.234	0.345	0.175
	p-value*	0.249	*0.032*	*0.011*	0.211
	N	83	84	53	53

* Values in italics are significant at < 0.05

Table 21. Results of Pearson's product-moment correlation test for pubic tubercle height, arcuate angle, osteometric variables representing body size and mean pelvic canal size in females.

		Arcuate angle	Pubic tubercle height	Pre-auricular sulcus width	Pre-auricular sulcus length
FMLG	r	0.149	0.216	-0.090	-0.042
	p-value*	0.273	0.110	0.431	0.711
	N	56	56	79	79
FMHD	r	0.183	0.334	-0.064	0.105
	p-value*	0.177	*0.012*	0.575	0.358
	N	56	56	79	79
BIIL	r	0.065	0.066	0.104	0.024
	p-value*	0.624	0.618	0.352	0.829
	N	59	59	82	82
Mean pelvic canal size	r	0.079	0.203	0.130	-0.060
	p-value*	0.552	0.123	0.246	0.594
	N	59	59	82	82

* Values in italics are significant at < 0.05

Spearman correlation coefficients for dorsal pitting, sclerotic tissue deposition, sulcus type, individual pelvic measures and mean pelvic canal size in males are presented in Table 22. The coefficients do not demonstrate significant correlations between dorsal pitting, sclerotic tissue deposition and any individual pelvic variables amongst males. Mean pelvic canal size does not correlate with dorsal pitting, sclerotic tissue deposition or sulcus type in males. Table 23 presents Spearman correlation coefficients for individual pelvic variables, pelvic canal size and parturition scarring variables in females. Dorsal pitting correlates weakly with mediolateral pelvic inlet and outlet, the anterior portion of the pelvic inlet and pubic length. Pubic length, the anterior inlet and the mediolateral outlet also display weak correlation with sclerotic tissue deposition. Mean pelvic canal size does not associate significantly with any type of parturition scarring in females.

Table 22. Spearman correlation coefficients for osteometric variables representing body size, individual pelvic measurements, mean pelvic canal size and parturition scarring variables in males

	Dorsal pitting			Sclerotic tissue			Sulcus		
	Spearman	p-value*	N	Spearman	p-value*	N	Spearman	p-value*	N
FMLG	-0.107	0.226	130	-0.169	0.055	130	-0.179	*0.034*	141
FMHD	0.011	0.904	130	0.073	0.408	130	-0.060	0.477	141
BIIL	0.009	0.923	119	0.085	0.362	118	-0.078	0.396	121
INML	0.079	0.395	118	0.119	0.201	117	-0.08	0.386	120
MDPT	-0.011	0.909	118	-0.12	0.197	117	-0.003	0.972	120
OTML	0.007	0.939	118	-0.096	0.306	117	-0.116	0.207	120
OTPT	0.006	0.951	118	0.107	0.250	117	-0.111	0.226	120
INPT	0.059	0.522	118	0.038	0.688	117	-0.03	0.747	120
INAT	-0.04	0.666	118	0.012	0.895	117	-0.044	0.635	118
PBLG	0.057	0.511	135	0.101	0.242	135	-0.057	0.494	146
Mean pelvic canal size	-0.121	0.277	83	0.004	0.969	83	-0.066	0.558	82

* values in italic are significant at < 0.05

Table 23. Spearman correlation coefficients for osteometric variables representing body size, individual pelvic measurements, mean pelvic canal size and parturition scarring variables in females.

	Dorsal pitting			Sclerotic tissue			Sulcus		
	Spearman	p-value*	N	Spearman	p-value*	N	Spearman	p-value*	N
FMLG	-0.125	0.173	120	0.093	0.323	114	0.118	0.180	131
FMHD	0.015	0.869	120	0.100	0.289	114	-0.109	0.215	131
BIIL	0.045	0.638	113	0.026	0.788	107	0.078	0.402	119
INML	0.243	*0.009*	114	0.181	0.061	108	-0.019	0.837	119
MDPT	0.04	0.675	110	0.102	0.304	104	-0.107	0.254	115
OTML	0.247	*0.009*	110	0.231	*0.019*	104	0.042	0.658	115
OTPT	0.017	0.856	112	0.127	0.195	106	0.083	0.375	117
INPT	0.062	0.514	114	0.052	0.590	108	-0.063	0.497	119
INAT	0.223	*0.017*	114	0.283	*0.003*	108	0.122	0.189	118
PBLG	0.337	*0.000*	124	0.242	*0.008*	118	-0.005	0.951	132
Mean pelvic canal size	0.140	0.292	59	0.239	0.071	58	-0.048	0.718	59

* values in italic are significant at < 0.05

A comparison of the variation in different parturition scarring categories is illustrated in box-and-whisker plots in Figures 20 to 22. Median pelvic canal size for dorsal pitting scores is lower in males than in females. Sclerotic tissue deposition (Figure 21) shows similar ranges for both males and females, though females have higher median pelvic canal size scores for both presence and absence of sclerotic tissue deposition. Sulcus types are also sexually dimorphic in range when compared to pelvic canal size. The median pelvic canal size measurement is lower amongst males, and sulcus type 3 only appears in females. These box-and-whisker plots demonstrate the sexual dimorphism between pelvic canal size and parturition scarring presence.

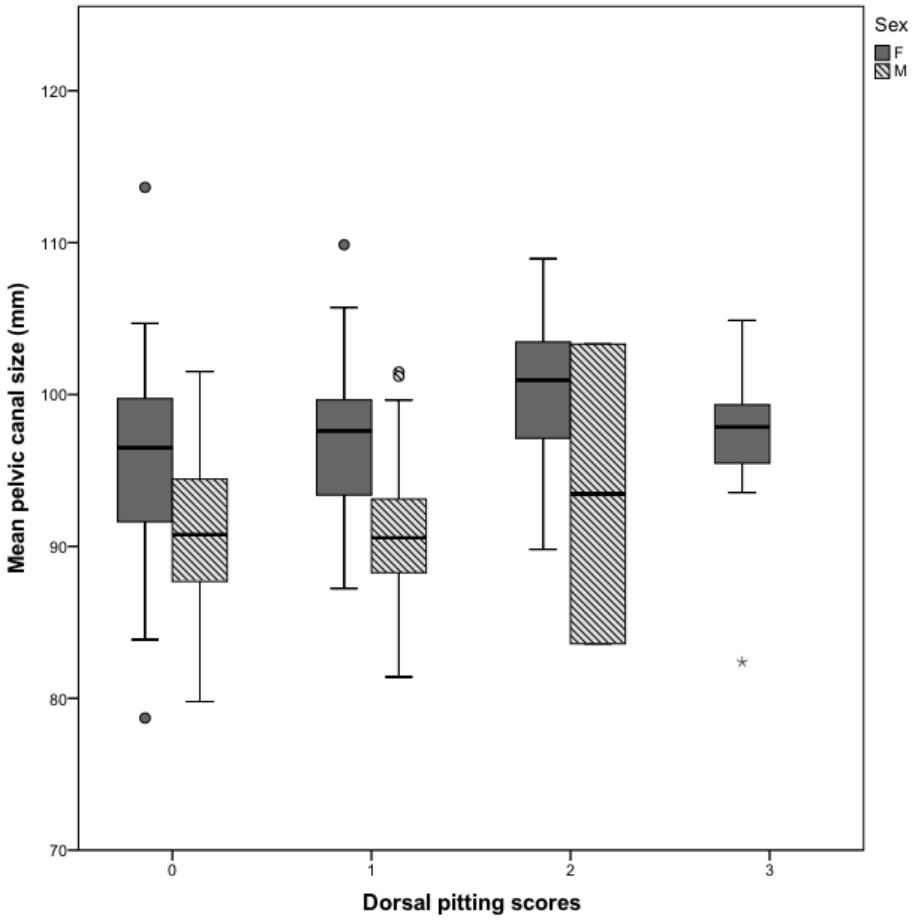


Figure 20. Box-and-whisker plots of dorsal pitting scores and mean pelvic canal size for males and females.

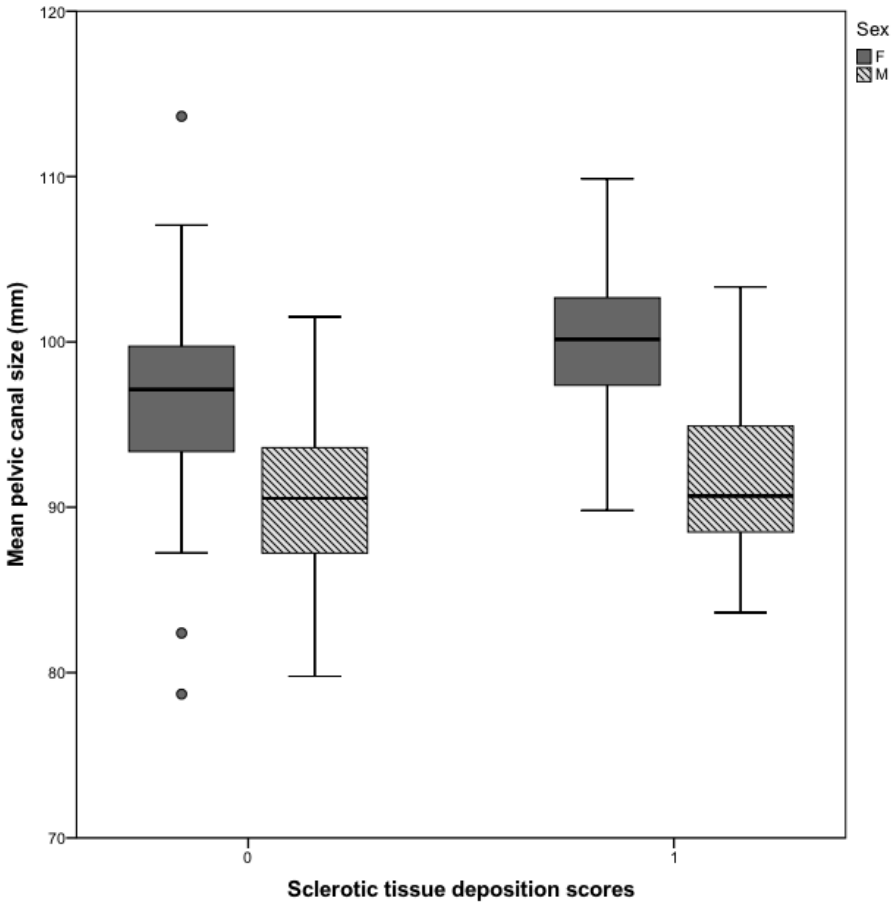


Figure 21. Box-and-whisker plots of sclerotic tissue deposition and mean pelvic canal size for males and females.

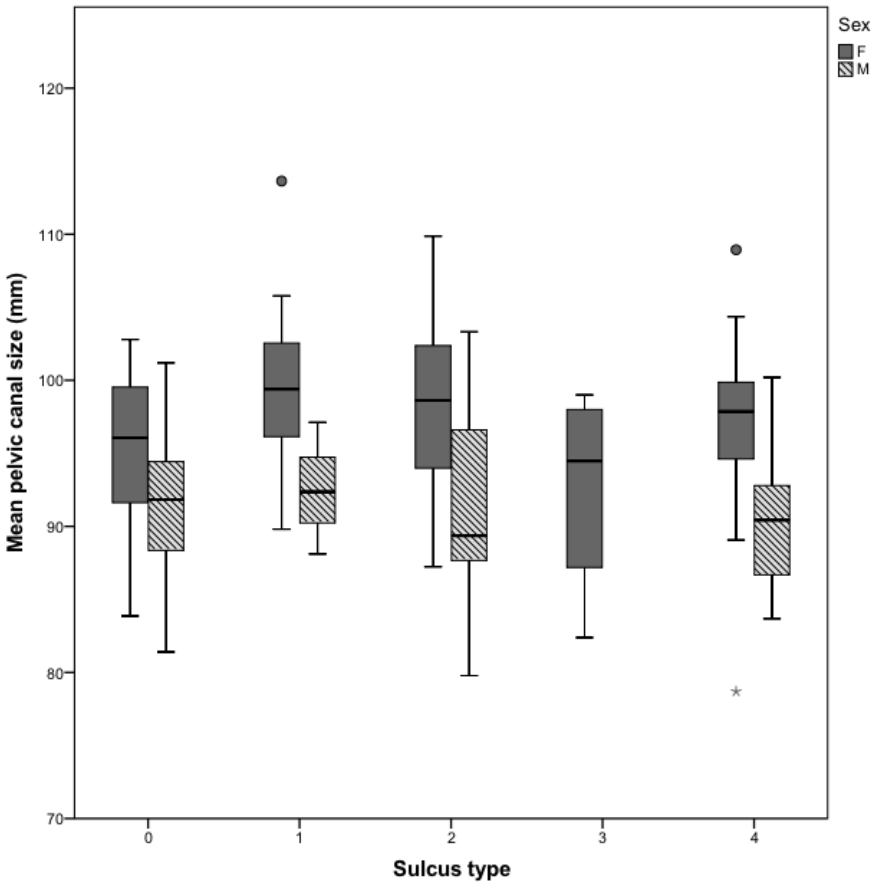


Figure 22. Box-and-whisker plots of sulcus type and mean pelvic canal size for males and females.

Consistent with previous studies (Holt ,1978; Suchey et al., 1979; Snodgrass and Galloway, 2003), there are no significant correlations between parity status (whether a woman has given birth or not) and any of the parturition scarring features (Table 23).

Table 24. Spearman's rank correlation results for parturition scarring types and parity in females.

		Dorsal pitting	Sclerotic tissue deposition	Sulcus type
Parity	Spearman	0.118	-0.106	0.015
	p-value	0.439	0.492	0.918
	N	45	44	50

Pubic tubercle height and pre-auricular sulcus have a statistical relationship with body mass and stature in either males or females, or males and females. The presence of a relationship between these variables signifies the rejection of Null hypothesis 1 and Null Hypothesis 2. Pubic tubercle height has a statistical relationship with mean pelvic canal size in males, which signifies the rejection of Null Hypothesis 3. In females, dorsal pitting has a significant relationship with medio-lateral inlet, medio-lateral outlet, anterior space of the inlet and pubic length. Sclerotic tissue deposition also has a significant relationship with medio-lateral outlet, anterior space of the inlet and pubic length. As these listed individual pelvic measures have a statistical relationship with parturition scarring, Sub-Null Hypothesis 3 is also rejected.

3.6. Multivariate analyses

Principal components analyses (PCA) were utilized to reduce the numerous pelvic variables to a smaller number of components to represent pelvic canal shape. PCA requires that each individual have a value for every variable examined. The sample of females and males used for these tests is consequently reduced to specimens that had recorded values for every pelvic variable. Summary statistics for the reduced sample used for PCA can be found in Appendix B. As with previous statistical analyses, PCA were conducted on males and females separately in order to reduce the influence of sexual dimorphism. The summaries of the eigenvectors for the first three principal components are contained in Table 25, and the full 9 principal components that were extracted in the PCA are detailed in Appendix B. Only the first three principal

components of both the female and male sample were examined as per the Cattell scree test plot (also in Appendix B).

Table 25. Eigenvector coefficients for principal components of log-shape in the test-specific subsample of females and males.

	Females			Males		
	PC1	PC2	PC3	PC1	PC2	PC3
BIIL	0.031	0.032	-0.077	0.036	-0.035	0.005
INML	0.010	0.024	-0.013	-0.003	0.000	0.107
INAT	0.024	0.028	0.007	0.045	-0.017	0.001
INPT	-0.162	-0.008	-0.006	-0.167	-0.037	-0.001
MDPT	0.010	-0.072	0.007	-0.014	0.069	0.000
OTML	0.015	0.005	0.038	0.005	0.038	0.008
OTAT	0.024	0.025	0.013	0.031	-0.020	0.012
OTPT	0.037	-0.097	-0.002	-0.020	0.098	-0.006
PBLG	0.012	0.045	0.049	0.028	-0.032	-0.020
Eigenvalue	0.030	0.020	0.010	0.034	0.020	0.012
% of variance	37.7	24.6	12.8	39.3	23.5	14.2

The first principal component (PC1) accounts for 37% of the female sample variance, and for 39.3% of the male sample variance. Amongst females, PC1 has no significant relationship with log-canal size (log-transformed geometric mean of pelvic canal size) (r=0.078 p= 0.003). PC1 contrasts inlet posterior space, with the posterior spaces of the pelvic canal outlet, the anterior-posterior direction of the outlet, and bi-iliac breadth. This culminates in the first principal component representing posterior outlet and inlet of the canal in females. In males, PC1 has a significant association with log-canal size (r=0.073 p= 0.003). The first principal component in males represents the posterior aspect of the pelvic inlet, midplane and outlet as well as bi-iliac breadth.

In females, the second principal component (PC2) accounts for 24.6% of subsample variance, and PC2 has a significant association with log-canal size (r=0.057 p=0.012). This principal component is loads negatively on the posterior portions of the inlet, midplane and outlet. Bi-iliac breadth, medio-lateral inlet and the anterior spaces of the canal contrast against the posterior space of the inlet and the outlet. This means that individuals with large dimensions of the first set of variables (bi-iliac breadth, medio-lateral breadth etc,) have small of the latter; and vice versa. The second principal component does not associate significantly with log-canal size in males (r=0.022 p= 0.114). PC2 accounts for 23.5% of the total variance in the male subsample, and corresponds to anterior portion of the pelvic canal, bi-iliac breadth and pubic length.

The third principal component (PC3) accounts for 12.8% of the total variance in the female subsample, and 14.2% of the total subsample variance in males. The third principal component associates significantly with log-canal size in females (r=0.039 p= 0.039) and represents the medio-lateral direction of the inlet, bi-iliac breadth and the posterior spaces of the inlet and outlet. Amongst males, PC3 has a significant association with log-canal size (r=-0.130 p= 0.000) and represents the medio-lateral direction of the inlet and outlet.

Figures 23 through to 25 are plots of components scores of individuals in the sample for PC1 and PC2, classified by parturition scarring type. These plots are visualizations of principal shape components that illustrate the variation pelvic shape on these components in relation to degree of parturition scarring. On these plots, individuals clustered close together show similar pelvic shapes, therefore any clustering of individuals with shared scarring type suggests an association with that particular

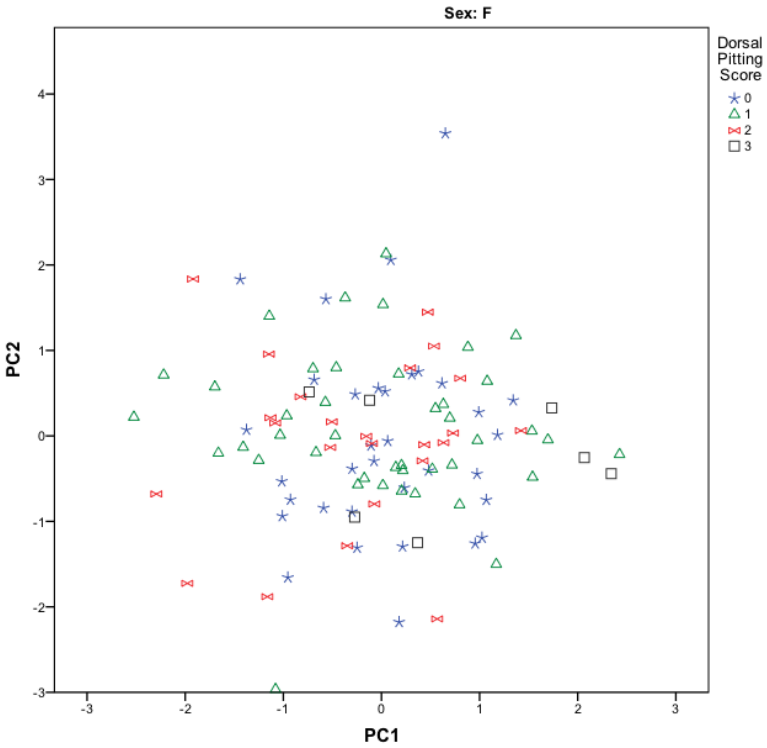
pelvic shape. Given the comparatively small proportion of shape variance represented by PC3 and PC4, examination of patterns in parturition scarring across principal components focuses only on PC1 and PC2.

Amongst females, the plots of trace, medium and large dorsal pitting do not display any clear clustering of scarring scores in specific regions of the graph (Figure 23). This suggests that there is no relationship between degree of dorsal pitting and pelvic canal shape in females. The orientation of dorsal pitting points on the plot differs in males, demonstrating almost equal range of scatter in PC1 and PC2. However similar to females, dorsal pitting scores do not cluster in any specific regions of the graph in males, suggesting that degree of dorsal pitting also does not associate with pelvic canal shape in males.

Figure 24 shows the plots for PC1 and PC2 parturition scarring scores for sclerotic tissue deposition. As exemplified in dorsal pitting scores in PC1 and PC2 in both males and females, there is also no clustering of points in particular areas of the graph. It appears that sclerotic tissue deposition also does not associate with pelvic canal shape in males or in females. Figure 25 shows plots of sulcus types of PC1 and PC2 in females and males. The scatter of points on the plot in males shows greater range in PC2 scores than PC2 scores in females, however once again no discernible cluster groups in specific parts of the graph are evident in males or in females. These plots of first and second principal components suggest that dorsal pitting, sclerotic tissue deposition and pre-auricular sulcus type do not associate with pelvic canal shape in both sexes in the sample.

Figures 26 and 27 are scatterplots of principal component scores for PC1 and PC2 and pubic tubercle variables in both females and males. Similar to the scatterplots showing the scatter of pelvic shape variables and dorsal pitting, sclerotic tissue deposition and sulcus types, pelvic shape variables do not demonstrate any visible relationship with pubic tubercle variables in both sexes. There are no clear clustering groups of shape variables across pubic tubercle height, pubic tubercle distance and arcuate angle values in females or in males.

a)



b)

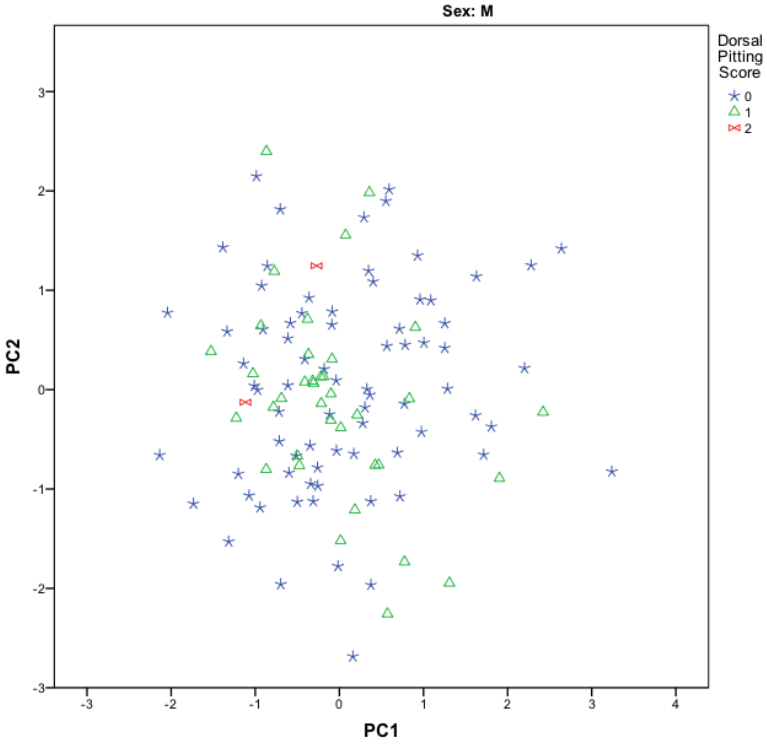
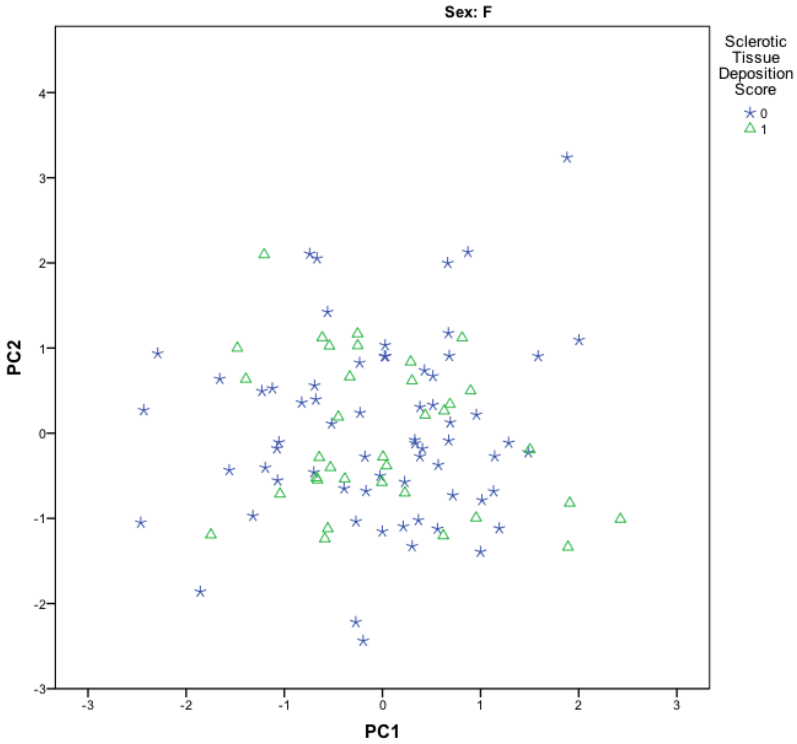


Figure 23. Scatterplots of principal component scores for female **(a)** and male **(b)** dorsal pitting scores log-shape variables: PC1 vs PC2.

a)



b)

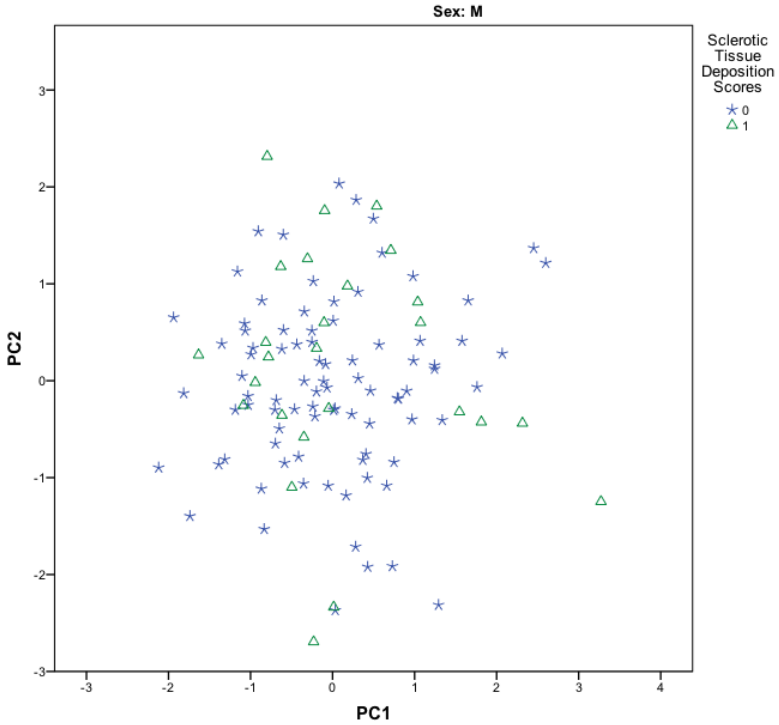
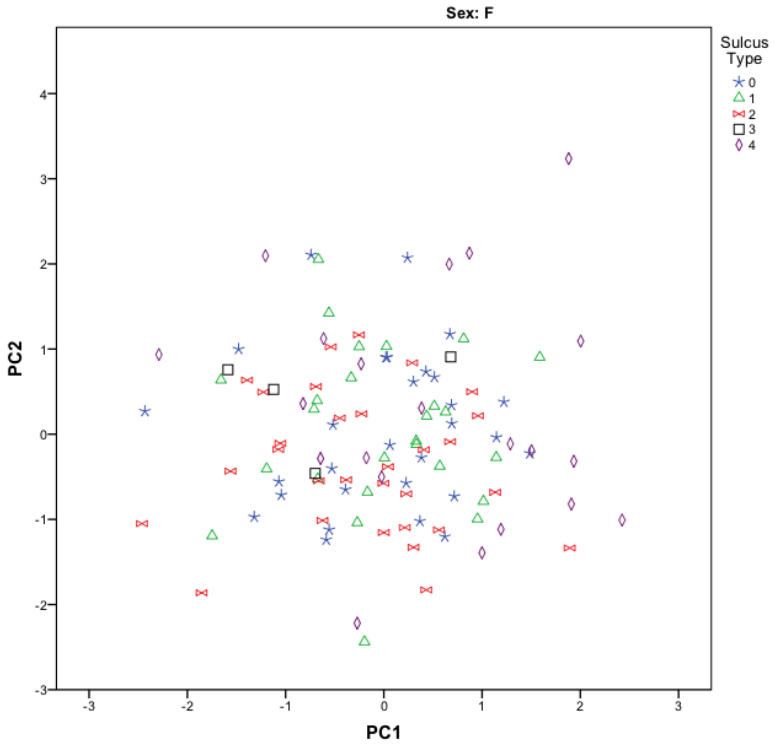


Figure 24. Scatterplots of principal component scores for female (a) and male (b) sclerotic tissue deposition scores log-shape variables: PC1 vs PC2.

a)



b)

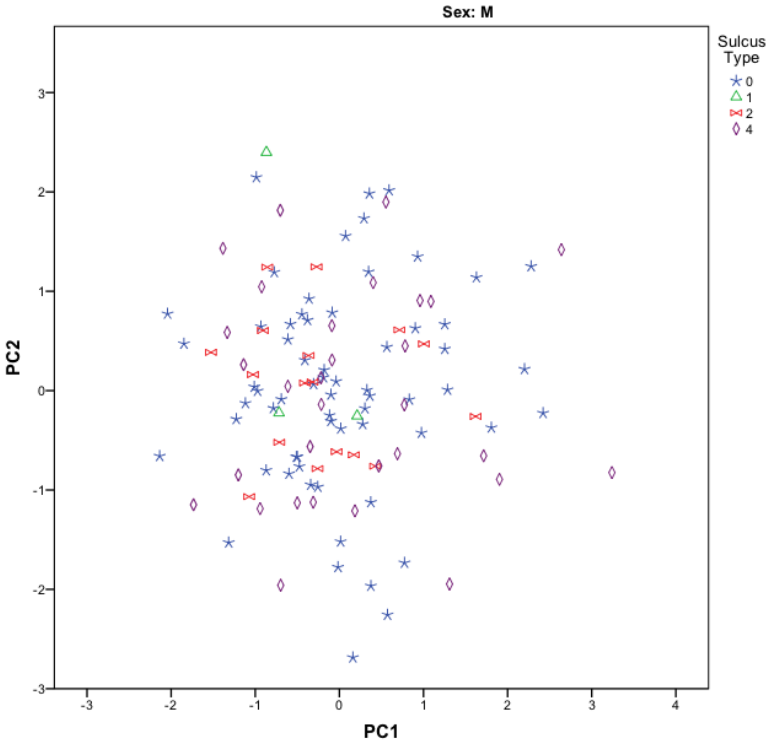
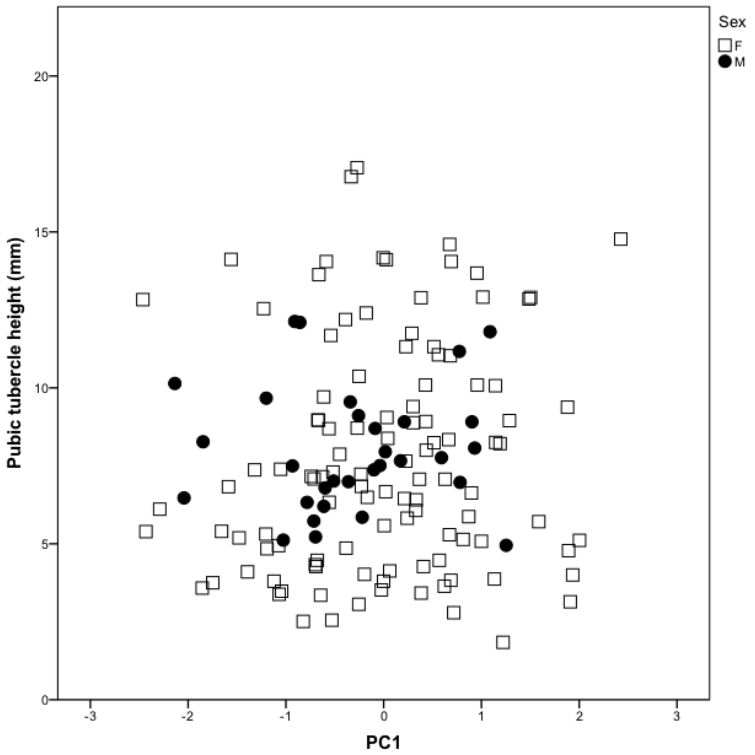


Figure 25. Scatterplots of principal component scores for female (a) and male (b) pre-auricular sulcus types log-shape variables: PC1 vs PC2**.**

a)



b)

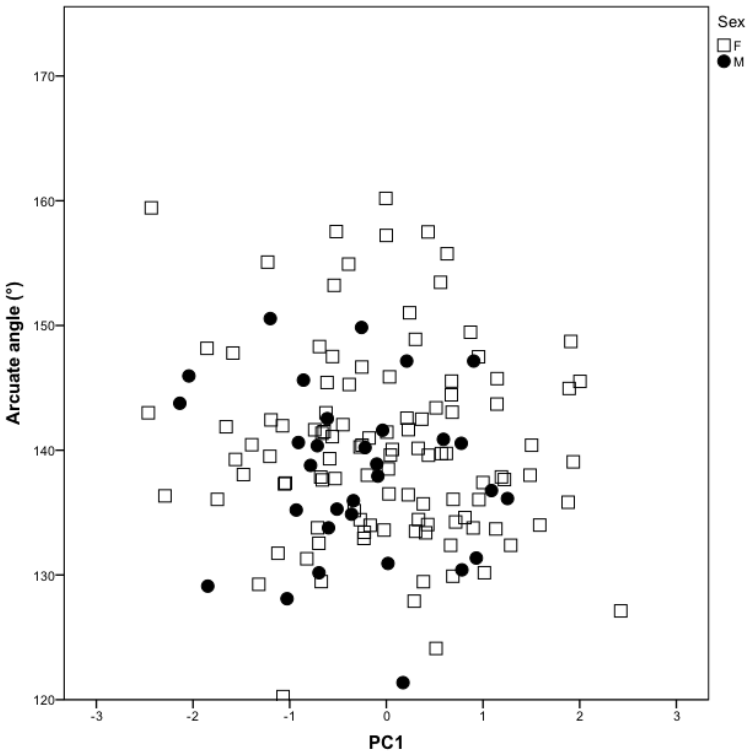
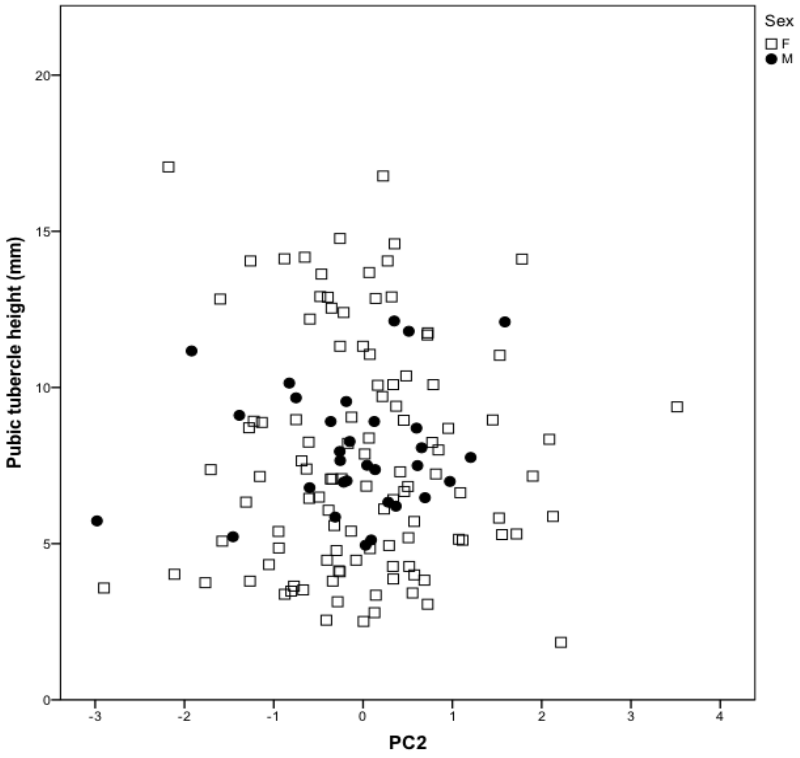


Figure 26. Scatterplots of pubic tubercle distance **(a)**, pubic tubercle height and **(b)** arcuate angle and log-shape variables in males and females: PC1**.**

a)



b)

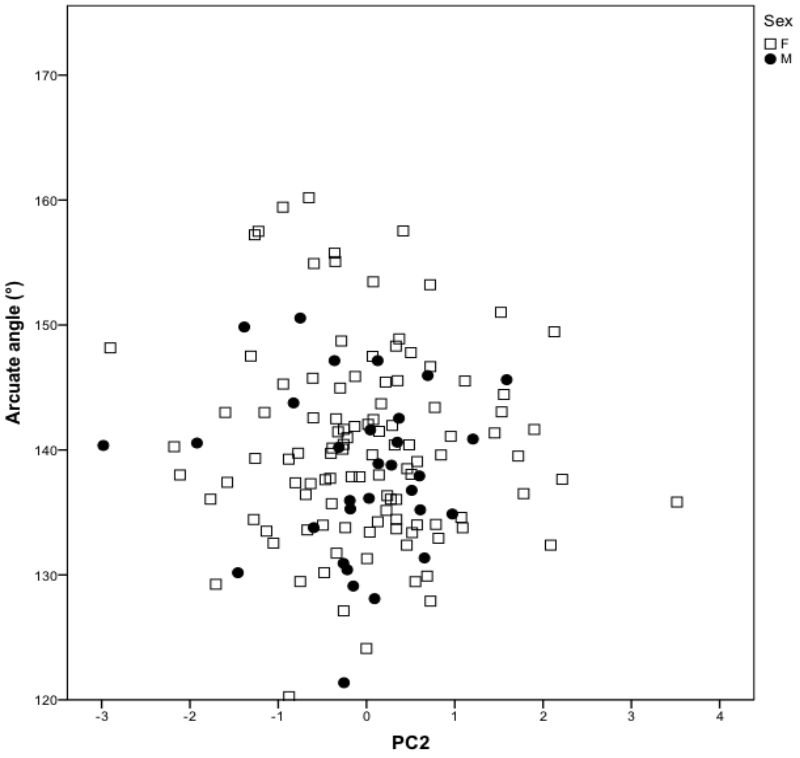


Figure 27. Scatterplots of pubic tubercle distance **(a),** pubic tubercle height and **(b)** arcuate angle and log-shape variables in males and females: PC2.

The PCA did not reveal any significant relationships between any type of parturition scarring and pelvic canal shape in either females or males in the subsample used for PCA analyses. As no relationship was found between these variables in both sexes, Null Hypothesis 4 is accepted.

Chapter 4: Discussion

4.1. Population-specific differences

Population-specific differences that are apparent in statistical analyses carried out on each collection separately indicate influences on the results of the analyses carried out on the collections pooled together. Prominent differences in some variables indicate that some statistical relationships may be present in one population and not the other, affecting conclusions drawn from these relationships. This is particularly important given the complexities of ecogeographic patterning of body size and the variation in pelvic size and shape that is equally population-specific (Kurki, 2013a).

The more plentiful associations between pelvic canal dimensions, dorsal pitting and sclerotic tissue deposition in Spitalfields females compared to Maxwell females suggests that pooled sample results are driven by the Spitalfields collection in particular. Given the association between osteometric indicators of body size and breadth (femoral length and bi-iliac breadth) and arcuate angle in both Spitalfields and Maxwell females, it is likely that any associations between body size and breadth indicators and pubic tubercle variables in the pooled sample is reflective of both collections. The negative relationship between bi-iliac breadth and arcuate angle in Spitalfields females, along with the association between dorsal pitting and bi-iliac breadth, suggests that dorsal pitting appears more frequently in Spitalfields females with a larger bi-iliac breadth and reduced arcuate angle.

Body size and breadth indicators also associated with arcuate angle in Spitalfield males, and not in Maxwell males. Both femoral length and bi-iliac breadth are larger in

Maxwell males than in Spitalfields males. It is likely that arcuate angle associates with femoral length and bi-iliac breadth in males who are overall smaller in body size and breadth, such as those in Spitalfields. Dorsal pitting associated with pubic length in Spitalfields males, and did not associate with any pelvic measures in the Maxwell males. Pubic length is also smaller in Spitalfields males than in Maxwell males. Dorsal pitting likely appears more often amongst males in Spitalfields with a smaller pubic length, and smaller overall body size and breadth. Population-specific differences in statistical relationships between body size, pubic tubercle and parturition scarring variables demonstrate that the Spitalfields collection may drive some of the relationships seen in the pooled sample. This is likely an effect of different temporal and cultural factors, the effect of which on the presence and development of parturition scarring is an important research goal (Ubelaker and De La Paz 2012).

4.2. Body size reconstruction

The reconstructed values for stature and body mass in the sample demonstrate sexual dimorphism in both stature and body mass. Using the averaged values for body mass, females are on average 5.17kg lighter than males. This result is not unexpected, as humans demonstrate increasing sexual dimorphism with increasing body size (Wolfe & Gray 1982; Smith & Cheverud 2002; Kurki 2011a).

4.3. Univariate analyses

A summary of the differences in pelvic canal, non-pelvic canal and parturition scarring variables between female and males are presented in Table 25. Differences in

bi-iliac breadth likely reflect differences in body mass between females and males. Overall, the pelvic canal amongst females is wider than amongst males, with a particular concentration of width in the posterior portions of the canal. This is not unusual, as wider dimensions in the posterior portion of the canal (including throughout the inlet to the outlet) is a sexually dimorphic trait that is associated with obstetric efficiency (Tague, 1992; Kurki 2005; Kurki 2007). Males demonstrate a greater pubic length than females, which is also what is expected (Tague 1992; Kurki 2005; Kurki 2007).

The presence of parturition scarring in males in this sample demonstrates the necessity for different terminology with which to refer to these scars, as they cannot be associated with parturition or pregnancy amongst males. Parturition scarring is present in both males and females, though the presence and development of the scarring type differed between sexes. Generally, females exhibit a greater presence and development of parturition scarring of all types, in the sense that more females exhibited at least the 'presence' of a type of parturition scarring. Sulcus type 1 and above appears more frequently amongst females than amongst males.

Table 26. Pelvic and parturition scarring features of females and males based on results of univariate analyses.

Females	Males
Non-canal pelvic variables	
Small bi-iliac breadth	Large bi-iliac breadth
Wide pre-auricular sulcus	Narrow pre-auricular sulcus
Long pre-auricular sulcus	Short pre-auricular sulcus
Pelvic canal variables	
Wide mediolateral outlet	Long pubic length
Wide mediolateral inlet	Wide anterior inlet
Narrow anterior inlet	
Parturition scarring variables	
Short pubic tubercle	Long pubic tubercle
More dorsal pitting	Less dorsal pitting
More sclerotic tissue deposition	Less sclerotic tissue deposition
Display sulcus type 1+	Absence of specific sulcus type

A summary of the statistically significant differences between parous and non-parous females is presented in Table 26. Parous females show more dorsal pitting than non-parous females, along with a wider arcuate angle. It is surprising that the pelvic midplane is wider in non-parous females in the posterior aspect, as greater space in the posterior pelvic canal is obstetrically advantageous.

Table 27. Pelvic and parturition scarring features of parous females and non-parous females based on results of univariate analyses.

Parous females	Non-parous females
Non-canal pelvic variables	
Short femoral length	Long femoral length
Wide bi-iliac breadth	Narrow bi-iliac breadth
Pelvic canal variables	
Wide inlet mediolaterally	Narrow inlet mediolaterally
Long anterior inlet	Short anterior inlet
Long pubic length	Short pubic length
Wide posterior midplane	Narrow posterior midplane
Wide outlet mediolaterally	Narrow outlet mediolaterally
Wide posterior outlet	Narrow posterior outlet
Parturition scarring variables	
Long pubic tubercle	Short pubic tubercle
Wide arcuate angle	Narrow arcuate angle
More dorsal pitting	Less dorsal pitting

4.4. Bivariate analyses

Different types of parturition scarring were found to associate with body size variables, individual pelvic measurements and mean pelvic canal size in either males or females, or in both sexes. Null hypotheses 1, 2, 3 and Sub-Null Hypothesis 3 were rejected due to these results. The relationship between pubic tubercle variables and body size variables is novel: previous studies on pubic tubercle variables have not identified relationships between pubic tubercle variables and body size in *both* sexes. The association between individual pelvic measurements and dorsal pitting in females may contribute to the difference seen in dorsal pitting in parous and non-parous females.

Pubic tubercle variables were the only type of parturition scarring that associated with pelvic canal size and body size variables in both males and females (Table 28). Pubic tubercle height associates with femoral head diameter in females, suggesting that

pubic tubercle height may be a product of body size variation in females, rather than necessarily pelvic bone changes caused by parturition. Pubic tubercle height associates significantly with pelvic canal size in males alone, demonstrating that pelvic canal size does not influence the development of the pubic tubercle in females. These results suggest that either 1) pubic tubercle height may simply be sexually dimorphic, 2) that there is a relationship between particular pelvic canal sizes and the increase in muscular pressure on the rectus abdominis muscle extends the pubic tubercle or 3) that the pubic tubercle may become more extended in males with weight increase in the upper body particularly in the abdominal region.

Table 28. Correlations between pubic tubercle variables, pelvic canal size and body size variables of females and males based on results of bivariate analyses.

Females		**Males**
	Pubic tubercle height	
Femoral head diameter		Pelvic canal size

Individual pelvic measurements correlated with parturition scarring types in females only, and pre-auricular sulcus type had no associations with any individual pelvic measurements (see Table 29). Dorsal pitting associated positively with mediolateral pelvic inlet and outlet, anterior portion of the inlet and pubic length in females. It is possible that dorsal pitting may appear more frequently in women who have overall wider pelves, however parous females in the sample have narrower pelvic inlet, midplane and outlets than non-parous females do, and dorsal pitting appeared more frequently in parous females than in non-parous females.

Table 29. Parturition scarring variables and individual pelvic variables of females and males based on results of bivariate analyses.

Females	Males
Dorsal pitting	
Mediolateral inlet	
Mediolateral outlet	
Anterior portion of the inlet	
Pubic length	
Sclerotic tissue deposition	
Anterior portion of inlet	
Mediolateral outlet	
Pubic length	

Labour is complicated by contraction at particular parts of the pelvic canal. Specific clinical thresholds have been established for pelvic contraction. Females with pelvic measurements below these thresholds are considered likely to experience complicated labour. However, (Kurki, 2011b) found that the established clinical thresholds for pelvic contraction do not take into account the variation in human body size and shape. Because parturition scarring does not associate with the parity status of females in the sample, parity status *alone* is likely not related to the presence of parturition scarring. It is possible that giving birth may further aggravate dorsal pitting and sclerotic tissue deposition. Both dorsal pitting and sclerotic tissue deposition occur at the anterior portion of the pelvis, concentrated around the pubic symphysis. The pubic symphysis can separate during labour (Harris 1974; Kotwal and Mittal 1996; Kotwal and Mittal 1998; Owens et al. 2002; Usta et al. 2003), but it may also separate due to impact injuries (Teng et al., 2010) and injuries associated with horse-riding (Tomé-Bermejo et al., 2009).

4.5. Multivariate analyses

The aim of principal component analysis in this study was to detect the influence of particular components contributing to overall pelvic canal shape in the sample, and to examine potential patterns in parturition scarring presence on these aspects of canal shape. Clustering of parturition scarring scores in different areas of the principal component plots would indicate the influence of shape components on the presence of parturition scarring. PCA did not reveal any clustering of any type of parturition scarring in both sexes, showing that pelvic canal shape has no relationship with parturition scarring and that Null Hypothesis 4 is summarily accepted.

The first principal component represented the posterior portion of the outlet and inlet in females, and the anterior portion of the pelvic inlet and outlet in males. The second principal component (PC2) represented the bi-iliac region of the pelvis in females, and correlated strongly with log-canal size. Amongst males, PC2 represents the posterior portion of the midplane and outlet of the pelvis. The third principal component represents the anterior-posterior breadth of the inlet and midplane of the pelvic canal in both sexes.

Multivariate analyses did not reveal any relationships between different types of parturition scarring and pelvic canal shape, but bivariate analyses showed some relationships between parturition scarring and *individual* pelvic canal measures eg. in females dorsal pitting is correlated with medio-lateral inlet, anterior-posterior direction of the midplane etc. It is possible that the dominant components of multivariate shape variation among the females are not related to scarring, but to particular dimensions of individual planes. Women with broader inlets, longer and/or wider midplanes or wider

outlets may display greater pitting, whilst women with *wholly different* pelvic canal shapes may not. The limitation of PCA in this type of analysis is that it identifies the most variable components of shape in the multivariate space of *all* the dimensions included in the PCA. PCA focusing solely on the pelvic dimensions that do correlate with different types of parturition scarring may provide a more detailed illustration of possible relationships between pelvic canal shape and parturition scarring.

Chapter 5: Conclusion

This study has demonstrated that parturition scarring is likely not caused by parturition. The presence of parturition scarring in males and in non-parous females indicates that such scarring cannot be caused by childbirth alone. This project has also demonstrated that some types of parturition scars do have a relationship with body size variables, and with pelvic canal variables in *both* sexes. The presence of parturition scarring in males has been reported in some previous investigations (Cox 1989; Ubelaker and De La Paz 2012). This project directly investigated the presence and degree of development of parturition scarring in males in parallel to the presence of parturition scarring in females. Prior studies on parturition scarring have established that it is not statistically associated with parity in females, and similarly in this study parturition scarring did not statistically associate with parity. Dorsal pitting, sclerotic tissue deposition and pre-auricular sulcus type have been more extensively examined in previous studies as examples of parturition scarring (Stewart 1957; Houghton 1974; Suchey et al. 1979; Cox 1989; Cox and Scott 1992) than pubic tubercle variables (Bergfelder and Herrmann 1980; Snodgrass and Galloway 2003). Some of these previous studies have examined the influence of body size and shape variation on the presence of parturition scarring. Unlike the other types of parturition scarring that have been examined in previous studies, in this study pubic tubercle variables were found to associate with body size and pelvic canal size.

Correlation analyses in this study indicate that pubic tubercle distance correlates with stature in males and females, and that arcuate angle associates weakly with body

mass and stature in females. Pubic tubercle distance and pubic tubercle height associates with pelvic canal size in females, whilst only pubic tubercle distance associates with pelvic canal size in males. Individual pelvic canal measures associate with parturition scarring types in females only. Dorsal pitting correlates weakly with bi-acetabular breadth, mediolateral pelvic inlet, anterior-posterior direction of the pelvic midplane, mediolateral pelvic outlet and pubic length amongst females. The results of the principal components analysis (PCA) in this study show that there is no influence of pelvic canal shape on the presence of dorsal pitting, sclerotic tissue deposition or pre-auricular sulcus types in males or in females. Specific types of parturition scarring, such as pubic tubercle variables, associate (though weakly) with variation in body size and pelvic canal size, but are not associated with pelvic canal shape in females and in males.

Given the relationships between some aspects of pelvic dimensions, body size and parturition scarring, broader-bodied individuals may display parturition scarring. The relationship between proportions of limbs to the trunk or pelvis may affect the presence of parturition scarring at the pelvis, or indeed the size of the trunk itself may affect the presence of particular types of parturition scarring. It is possible that size and shape of the abdomen in males and females may affect pubic tubercle variables, as variation in size and shape of the abdomen will affect the area of musculoskeletal interaction of the rectus abdominis muscle.

This study adds to the established literature on parturition scarring and namely identifies the necessity to reconsider the definition of parturition scarring: its presence in both sexes, lack of association with parity in females and lack of association with key

obstetric pelvic canal dimensions suggests that future research on this subject reorients the term ‘parturition scarring’ to a more neutral term that encapsulates its presence in both sexes irrespective of parity.

5.1. Directions for future research

Prior to outlining future project ideas concerning parturition scarring, it is essential to delineate possible improvements to this study. A review of parturition scarring definitions would be beneficial, with a more rigorous photographic protocol to enable more detail-oriented descriptions of parturition scarring types. The definitions used in this study are those used by their original authors. However the differences in types of study samples in previous investigations (eg. sample size, sample origins, bony elements analyzed, etc.,) may affect the interpretation of parturition scarring by different authors who are applying these definitions to another study sample.

Future examinations of parturition scarring should include a focus on alternatives to parturition as causation of parturition scarring, specifically alternatives that examine the effects of musculoskeletal interaction at the pelvis. Studies of sports injuries amongst male athletes have demonstrated that male athletes experience similar pelvic pain to that experienced by women postpartum (Meyers et al., 2000). In designing studies that examine areas of musculoskeletal interaction at the pelvis in both males an females, investigators can expand on the possibility of parturition-like scarring in both sexes.

Detailed anatomical descriptions would be beneficial for a number of aspects of osteological responses to muscle interaction at the pelvis. Future studies should

examine the percentage of pubic area that dorsal pitting covers, which may give further indications as to potential muscle attachment sites in these areas of the pubis that may elicit a bony response through increased muscular force output. Of course the type, severity, spread and physical appearance of scarring will vary among populations, but a concentrated effort to describe these features in as much anatomical detail as possible would contribute to a greater ease in categorizing and identifying these scars within a population.

A more nuanced understanding of the interface between muscle and bone tissue on the *internal* pelvis would also be very constructive in re-evaluating parturition scarring. Without a detailed understanding of the relationship between the muscles that attach in the areas where scarring is present, a more succinct investigation of the musculoskeletal causes of pelvic scarring will not be possible. A more profound understanding of the bone and muscle intersection in the pelvis would also greatly contribute to research on the obstetric dilemma and the obstetric demands of the female pelvis. Whilst it has been established that parturition scarring is not caused by the event of childbirth, it may be *exacerbated* by childbirth. A more accurate musculoskeletal map of the changes in the pelvis during pregnancy and after delivery will provide a view on to the change in the pelvis during this period, including possible changes in parturition scarring appearance.

5.2. Conclusion

This study has strengthened the assertion that parturition scarring is not caused by parturition, as it is present in males. In addition, statistical tests in this study again

show that pelvic scarring does not associate with parity in females. Instead, specific types of parturition scarring that have been under examined (pubic tubercle variables) do associate with body size and pelvic canal size. It is recommended that the term ‘parturition scarring’ be reconsidered in anthropological analyses to reflect its non-connection with parity status, and its association to variations in body size and pelvic canal size. A more neutral term such as ‘pelvic scarring’ or ‘pelvic musculoskeletal scarring’ is proposed as an alternative. Future analyses of parturition scarring should similarly consider the importance of musculoskeletal interactions in creating parturition scarring. This includes the recognition of the potential for childbirth to intensify the presence of pelvic scarring without causing it in females, and for as yet unknown musculoskeletal interactions based on body size and pelvic size variation to affect the presence of such scarring in males.

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Appendix A.

Intra-observer error analyses

Paired sample student's t-test for osteometric variables.

	Mean	S.D.	Std. Error Mean	95% C.I. Lower	95% C.I. Upper	t	df	p-value*
FMLG	0.2	1.7	0.3	-0.4	0.7	0.5	32	0.608
FBLG	0.2	1.3	0.2	-0.3	0.6	0.7	32	0.501
FMHD	0.2	0.5	0.1	0.0	0.3	1.7	32	0.096
BIIL	-4.4	24.4	4.9	-14.4	5.7	-0.9	24	0.381
BIAC	-3.0	6.9	1.4	-5.8	-0.2	-2.2	24	*0.040*
INAP	2.1	3.7	0.7	0.6	3.6	2.8	24	*0.009*
INML	-0.4	2.8	0.6	-1.6	0.8	-0.7	24	0.486
INPT	0.5	3.3	0.7	-0.9	1.8	0.7	24	0.470
INAT	0.0	3.0	0.6	-1.3	1.2	-0.1	24	0.947
MDAP	-3.4	4.9	1.0	-5.4	-1.4	-3.5	24	*0.002*
MDML	-1.7	3.2	0.6	-3.0	-0.3	-2.6	24	*0.016*
MDPT	-1.0	3.4	0.7	-2.4	0.4	-1.5	24	0.156
OTAP	-3.6	5.4	1.1	-5.8	-1.3	-3.3	24	*0.003*
OTML	-0.4	3.8	0.8	-2.1	1.3	-0.5	22	0.630
OTPT	-0.2	3.2	0.6	-1.5	1.1	-0.3	24	0.803
DPPL	0.9	2.1	0.4	0.1	1.6	2.4	33	*0.021*
PBLG	-1.5	7.4	1.3	-4.2	1.3	-1.1	30	0.281
Pubic tubercle height	-0.5	2.0	0.4	-1.4	0.5	-1.0	19	0.311
Arcuate angle	3.5	10.2	2.3	-1.3	8.3	1.5	19	0.147
Pubic tubercle distance	-1.1	2.4	0.5	-2.3	0.0	-2.2	20	*0.044*
PSW	0.4	1.4	0.4	-0.5	1.2	1.0	12	0.337
PSL	1.0	5.3	1.5	-2.2	4.2	0.7	12	0.510

* Values in italics are significant at < 0.05

Wilcoxon Signed Rank test for parturition scarring variables.

			Monte Carlo Sig. (2-tailed)			Monte Carlo Sig. (1-tailed)		
				99% Confidence Interval			99% Confidence Interval	
	Z	Asymp. Sig. (2-tailed)	Sig.	Lower Bound	Upper Bound	Sig.	Lower Bound	Upper Bound
Dorsal pitting	-1.291[b]	0.197	0.305	0.294	0.317	0.152	0.143	0.161
Sclerotic tissue deposition	-1.342[d]	0.180	0.379	0.367	0.392	0.191	0.180	0.201
Sulcus type	-1.048[b]	0.295	0.315	0.303	0.327	0.155	0.145	0.164

Appendix B.

Principal components analyses

PCA male sample (reduced from study sample) descriptive statistics.

	N	Minimum	Maximum	Mean	Std. Deviation
FMLG	115	370.00	566.50	458.15	31.56
FBLG	115	372.00	550.00	456.95	30.07
FMHD	115	25.88	56.89	48.05	3.61
BIIL	118	219.00	321.00	270.55	18.17
BIAC	118	98.00	141.00	118.01	7.70
INAP	118	72.00	132.00	102.65	11.92
INML	118	104.00	144.00	121.91	7.95
INPT	118	14.50	38.50	26.84	4.88
INAT	117	82.50	126.00	100.51	7.70
MDAP	118	95.00	139.00	115.85	9.06
MDML	118	73.28	115.59	93.54	8.85
MDPT	118	45.50	76.50	58.25	6.38
OTAP	118	80.00	125.00	103.31	9.96
OTML	118	75.98	136.69	105.58	10.88
OTPT	118	35.00	66.50	50.49	6.50
DPPL	117	87.09	130.15	109.27	7.82
PBLG	118	72.54	115.17	91.78	8.48
PSW	53	2.63	10.46	5.17	1.73
PSL	53	11.70	34.42	24.86	5.41
Arcuate angle	32	121.37	150.55	137.67	7.21
Pubic tubercle distance	32	16.42	31.56	23.88	3.27
Pubic tubercle height	32	4.95	12.13	8.00	1.97

PCA female sample (reduced from study sample) descriptive statistics.

	N	Minimum	Maximum	Mean	Std. Deviation
FMLG	107	335.00	492.50	422.69	28.83
FBLG	107	336.00	492.00	422.22	27.95
FMHD	107	27.90	50.11	41.82	3.35
BIIL	110	128.00	315.00	262.12	21.77
BIAC	110	90.00	169.00	119.81	10.87
INAP	110	80.00	155.00	108.60	13.00
INML	110	99.00	154.00	127.62	9.78
INPT	110	19.50	53.50	34.08	6.42
INAT	110	77.50	114.00	99.58	7.33
MDAP	110	88.00	149.00	120.40	11.17
MDML	110	82.02	133.14	108.16	9.21
MDPT	110	43.50	99.00	71.62	7.70
OTAP	110	70.00	136.00	108.98	12.84
OTML	110	96.27	155.32	124.48	12.66
OTPT	110	41.50	89.50	63.60	8.39
DPPL	110	81.27	123.30	104.96	7.76
PBLG	110	58.14	106.29	87.05	9.46
PSW	82	2.76	15.04	7.54	2.20
PSL	82	18.21	39.23	28.42	4.71
Arcuate angle	110	120.25	160.19	140.19	7.65
Pubic tubercle distance	110	1.73	35.38	24.30	6.03
Pubic tubercle height	110	1.84	17.06	7.70	3.65

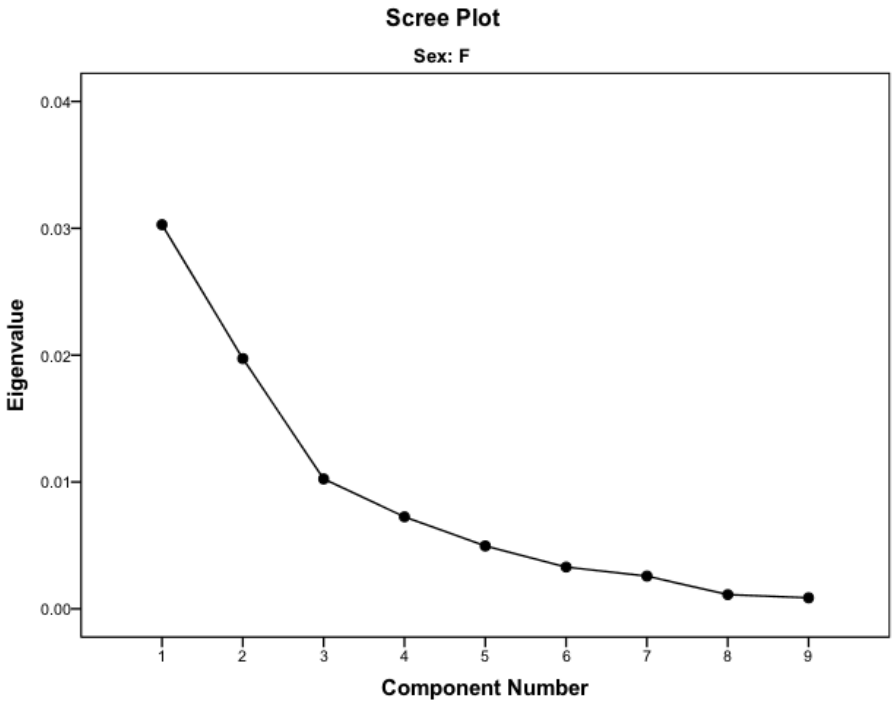
Eigenvalues for all 9 extracted principal components in female sample used for PCA.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
BIIL	0.031	0.032	-0.077	0.006	0.008	0.025	-0.014	-0.001	0.007
INML	0.010	0.024	-0.013	0.006	0.039	-0.017	0.028	0.012	0.010
INAT	0.024	0.028	0.007	-0.016	-0.020	-0.018	0.001	-0.019	0.019
INPT	-0.162	-0.008	-0.006	0.005	-0.001	0.011	0.003	-0.001	0.009
MDPT	0.010	-0.072	0.007	-0.010	0.005	-0.011	-0.027	0.015	0.013
OTML	0.015	0.005	0.038	0.063	0.025	0.008	-0.012	-0.009	0.004
OTAT	0.024	0.025	0.013	0.031	-0.045	0.013	0.011	0.016	0.007
OTPT	0.037	-0.097	-0.002	-0.002	0.001	0.024	0.023	-0.008	0.005
PBLG	0.012	0.045	0.049	-0.043	0.017	0.031	-0.003	0.004	0.005
Eigenvalue	0.030	0.020	0.010	0.007	0.005	0.003	0.003	0.001	0.001
% of variance	37.7	24.6	12.8	9.0	6.2	4.1	3.2	1.4	1.1

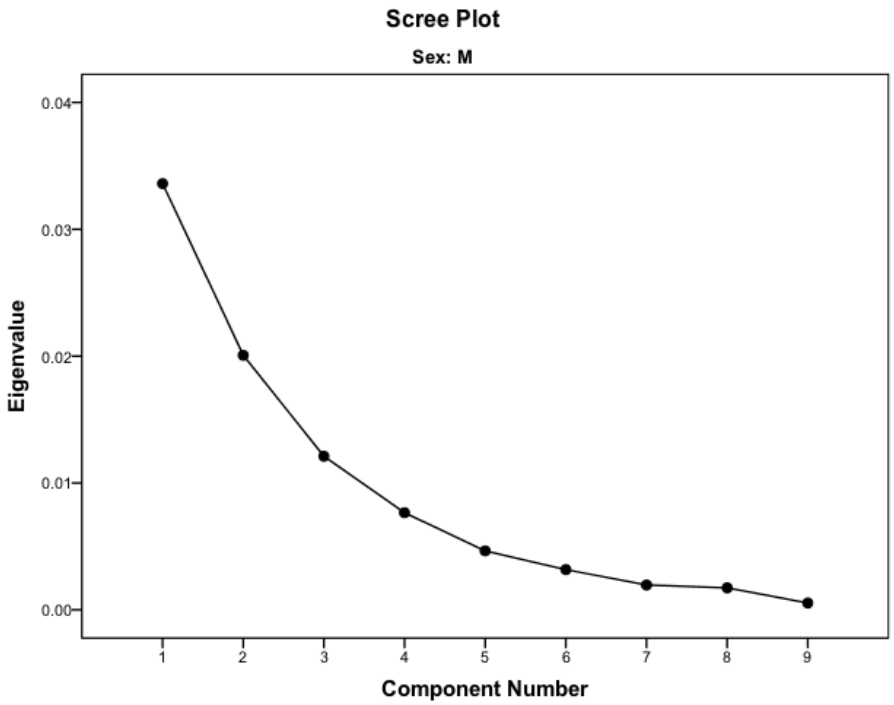
Eigenvalues for all 9 extracted principal components in male sample used for PCA.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
BIIL	0.036	-0.035	0.005	-0.006	-0.010	-0.029	0.024	-0.014	0.010
INML	-0.003	0.000	0.107	-0.008	0.014	0.003	0.000	-0.002	0.000
INAT	0.045	-0.017	0.001	0.000	-0.008	0.018	-0.025	-0.009	0.016
INPT	-0.167	-0.037	-0.001	0.009	0.002	0.000	0.000	0.001	0.007
MDPT	-0.014	0.069	0.000	-0.025	-0.016	0.028	0.022	0.008	0.007
OTML	0.005	0.038	0.008	0.079	-0.002	0.007	0.007	-0.009	0.001
OTAT	0.031	-0.020	0.012	0.022	-0.008	-0.012	0.000	0.036	0.006
OTPT	-0.020	0.098	-0.006	-0.007	0.025	-0.028	-0.010	0.000	0.006
PBLG	0.028	-0.032	-0.020	0.003	0.058	0.015	0.011	0.003	0.004
Eiegenvalue	0.034	0.020	0.012	0.008	0.005	0.003	0.002	0.002	0.001
% of variance	39.3	23.5	14.2	9.0	5.4	3.7	2.3	2.0	0.6

Scree plot for principal components extracted from the female sample used in PCA.



Scree plot for principal components extracted from the male sample used in PCA.



Appendix C.

Descriptive statistics
Descriptive statistics for Maxwell females.

Maxwell Females							
	N	Range	Minimum	Maximum	Mean	Std. Error	Std. Deviation
FMLG	77	157.5	335.0	492.5	433.1	3.0	25.9
FBLG	77	156.0	336.0	492.0	430.3	2.9	25.7
FMHD	77	21.0	27.9	48.9	41.6	0.5	4.0
Stature	77	42.4	133.7	176.0	160.2	0.8	6.9
Body mass	77	36.9	33.8	70.7	56.6	0.8	6.6
BIIL	68	187.0	128.0	315.0	262.5	3.0	24.5
BIAC	67	79.0	90.0	169.0	117.0	1.4	11.3
INAP	67	63.0	92.0	155.0	114.2	1.3	10.7
INML	67	49.0	99.0	148.0	125.3	1.2	9.5
INAT	66	36.5	77.5	114.0	100.2	1.0	7.9
INPT	66	30.5	23.0	53.5	35.5	0.8	6.8
MDAP	67	61.0	88.0	149.0	120.8	1.4	11.8
MDML	67	50.6	82.0	132.6	106.7	1.1	8.7
MDPT	67	46.0	53.0	99.0	71.8	1.0	7.9
OTAP	67	66.0	70.0	136.0	107.8	1.6	13.2
OTML	66	58.0	96.3	154.2	125.5	1.6	13.4
OTPT	67	44.5	45.0	89.5	62.6	1.0	8.3
OTAT	74	43.2	80.2	123.4	93.2	0.9	7.4
DPPL	76	42.6	81.3	123.9	107.8	0.9	7.7
PBLG	71	57.6	58.1	115.7	87.0	1.3	11.2
Pubic tubercle distance	54	32.4	1.7	34.2	24.4	1.0	7.6
Pubic tubercle height	47	12.9	1.8	14.8	5.7	0.4	2.9
Arcuate angle	46	37.0	120.3	157.2	138.9	1.1	7.2
PSW	47	12.3	2.8	15.0	7.5	0.3	2.3
PSL	47	18.7	18.2	36.9	28.4	0.7	4.7

Descriptive statistics for Maxwell males.

Maxwell Males							
	N	Range	Minimum	Maximum	Mean	Std. Error	Std. Deviation
FMLG	93	163.0	403.5	566.5	466.6	3.0	28.5
FBLG	93	150.0	400.0	550.0	463.7	2.9	27.8
FMHD	93	31.0	25.9	56.9	47.9	0.4	3.8
Stature	93	43.3	152.6	195.9	169.9	0.8	7.7
Body Mass	93	46.0	35.5	81.5	67.0	0.8	7.5
BIIL	82	80.0	241.0	321.0	273.4	2.0	17.8
BIAC	81	43.0	98.0	141.0	118.2	0.9	8.2
INAP	82	52.0	80.0	132.0	106.1	1.2	11.0
INML	82	38.0	106.0	144.0	122.0	0.9	8.3
INAT	82	43.5	82.5	126.0	102.0	0.9	7.8
INPT	82	22.5	16.0	38.5	27.2	0.6	5.1
MDAP	82	44.0	95.0	139.0	116.6	1.1	9.6
MDML	82	36.6	73.3	109.9	93.1	0.9	8.5
MDPT	82	77.5	43.5	121.0	67.8	1.4	12.2
OTAP	82	44.0	81.0	125.0	104.0	1.1	10.1
OTML	82	58.4	76.0	134.4	104.9	1.2	10.5
OTPT	82	30.5	35.0	65.5	50.7	0.7	6.1
OTAT	90	34.8	72.3	107.1	91.2	0.7	6.5
DPPL	92	44.3	93.3	137.6	111.7	0.8	7.7
PBLG	90	42.6	72.5	115.2	92.9	0.9	8.5
Pubic tubercle distance	78	18.4	14.6	33.0	24.0	0.4	3.5
Pubic tubercle height	74	14.0	3.1	17.1	9.4	0.4	3.1
Arcuate angle	72	38.8	121.4	160.2	139.6	0.9	7.8
PSW	33	7.8	2.6	10.5	4.8	0.3	1.7
PSL	33	22.7	11.7	34.4	25.3	1.0	5.6

Descriptive statistics for Spitalfields females.

Spitalfields Females

	N	Range	Minimum	Maximum	Mean	Std. Error	Std. Deviation
FMLG	56	125.0	362.0	487.0	411.6	3.5	26.1
FBLG	56	125.0	364.0	489.0	414.3	3.5	26.4
FMHD	56	13.4	36.7	50.1	42.2	0.4	2.9
Stature	56	36.0	142.4	178.4	157.2	1.0	7.7
Body mass	62	42.7	47.0	89.8	69.3	1.2	9.1
BIIL	52	66.0	234.0	300.0	260.8	2.3	16.8
BIAC	50	36.0	105.0	141.0	123.7	1.2	8.4
INAP	52	55.0	80.0	135.0	100.9	1.6	11.4
INML	53	57.0	97.0	154.0	129.1	1.4	10.3
INAT	52	31.5	82.5	114.0	99.3	0.9	6.6
INPT	53	25.0	19.5	44.5	31.4	0.8	5.5
MDAP	50	50.0	90.0	140.0	119.9	1.5	10.4
MDML	53	48.3	84.9	133.1	109.7	1.4	10.1
MDPT	49	38.5	47.0	85.5	59.0	1.2	8.2
OTAP	50	58.0	78.0	136.0	110.5	1.8	12.9
OTML	50	67.2	88.1	155.3	121.8	2.0	13.9
OTPT	51	45.0	41.5	86.5	65.3	1.2	8.9
OTAT	58	29.0	74.2	103.2	89.6	0.8	6.1
DPPL	62	33.5	86.8	120.3	101.8	0.8	6.5
PBLG	61	35.1	68.6	103.7	87.8	0.9	7.3
Pubic tubercle distance	43	20.5	14.9	35.4	25.7	0.7	4.7
Pubic tubercle height	39	7.5	1.9	9.4	5.8	0.3	1.9
Arcuate angle	38	30.3	129.3	159.6	143.7	1.1	6.8
PSW	53	8.8	4.7	13.6	7.6	0.3	2.0
PSL	53	25.6	18.2	43.8	28.4	0.7	4.9

Descriptive statistics for Spitalfields males.

Spitalfields Males							
	N	Range	Minimum	Maximum	Mean	Std. Error	Std. Deviation
FMLG	51	142.0	370.0	512.0	439.2	3.7	26.6
FBLG	51	146.0	372.0	518.0	442.2	3.8	27.2
FMHD	51	11.8	41.5	53.3	47.6	0.4	2.9
Stature	51	32.2	155.7	187.9	172.2	1.1	7.9
Body mass	57	93.3	40.2	133.5	84.2	1.5	22.9
BIIL	40	76.0	219.0	295.0	264.1	2.8	18.0
BIAC	38	29.0	100.0	129.0	117.6	1.0	6.4
INAP	38	50.0	72.0	122.0	94.8	1.6	10.1
INML	39	34.0	104.0	138.0	121.3	1.1	7.0
INAT	37	28.0	86.0	114.0	97.2	1.0	6.3
INPT	39	18.5	14.5	33.0	25.7	0.7	4.4
MDAP	39	32.0	101.0	133.0	114.2	1.2	7.4
MDML	39	34.7	80.9	115.6	94.7	1.5	9.3
MDPT	39	29.5	47.0	76.5	58.0	1.1	6.9
OTAP	39	45.0	80.0	125.0	102.0	1.6	9.7
OTML	39	53.9	82.8	136.7	107.2	1.8	11.4
OTPT	39	29.0	38.5	67.5	50.6	1.2	7.7
OTAT	55	23.6	77.6	101.2	88.6	0.8	5.6
DPPL	55	36.1	87.1	123.2	105.2	0.9	7.0
PBLG	57	32.3	75.0	107.3	87.9	1.0	7.8
Pubic tubercle distance	43	18.1	11.7	29.8	22.6	0.6	3.9
Pubic tubercle height	31	7.4	3.6	11.0	7.4	0.4	2.0
Arcuate angle	31	27.1	123.5	150.6	138.9	1.3	7.2
PSW	28	8.3	3.3	11.6	6.1	0.4	2.0
PSL	28	18.5	14.0	32.5	23.8	1.0	5.0

Frequency of parturition scarring in females and males Maxwell and Spitalfields collections.

Maxwell

Dorsal pitting	**Males**	**Females**
Score	Frequency	Frequency
0	61	27
1	23	26
2		13
3		4
Sclerotic tissue deposition		
Score	Frequency	Frequency
0	67	40
1	18	25
Sulcus type		
Type	Frequency	Frequency
0	58	28
1	3	17
2	8	12
3		3
4	22	15

Spitalfields

Dorsal pitting	**Males**	**Females**
Score	Frequency	Frequency
0	30	14
1	20	24
2	2	13
3		4
Sclerotic tissue deposition		
Score	Frequency	Frequency
0	36	36
1	15	18
Sulcus type		
Type	Frequency	Frequency
0	28	11
1	1	15
2	12	25
3		2
4	16	10

Frequency of parturition scarring in parous and non-parous females in Maxwell and Spitalfields collections.

Maxwell

Dorsal pitting	**Parous females**	**Non-parous females**
Score	Frequency	Frequency
0	4	23
1	5	21
2	7	6
3	2	2
Sclerotic tissue deposition		
Score	Frequency	Frequency
0	8	32
1	9	16
Sulcus type		
Type	Frequency	Frequency
0	5	23
1	9	8
2	0	10
3	2	3
4	3	12

Spitalfields

Dorsal pitting	**Parous females**	**Non-parous females**
Score	Frequency	Frequency
0	3	11
1	13	11
2	10	3
3	1	3
Sclerotic tissue deposition		
Score	Frequency	Frequency
0	20	16
1	7	11
Sulcus type		
Type	Frequency	Frequency
0	2	9
1	8	7
2	14	11
3	2	0
4	5	4

Descriptive statistics for pubic tubercle variables in males and females, parous and non-parous females in Maxwell and Spitalfields collections.

Maxwell

	Males			Females		
	N	Mean	S.D.	N	Mean	S.D.
Pubic tubercle height	74	9.4	3.1	47	5.7	2.9
Pubic tubercle distance	78	23.9	3.5	54	24.4	7.6
Arcuate angle	72	139.6	7.7	46	138.8	7.2

	Non-parous females			Parous females		
	N	Mean	S.D.	N	Mean	S.D.
Pubic tubercle height	33	5.7	2.7	14	5.8	3.4
Pubic tubercle distance	39	23.8	7.9	15	25.8	6.7
Arcuate angle	33	137.9	6.3	13	141.2	8.9

Spitalfields

	Males			Females		
	N	Mean	S.D.	N	Mean	S.D.
Pubic tubercle height	31	7.4	3.9	39	5.7	1.9
Pubic tubercle distance	43	22.5	3.9	43	25.7	4.7
Arcuate angle	31	138.8	7.2	38	143.6	6.8

	Non-parous females			Parous females		
	N	Mean	S.D.	N	Mean	S.D.
Pubic tubercle height	18	5.3	2.1	21	6.2	1.7
Pubic tubercle distance	20	25.8	4.1	23	25.6	5.2
Arcuate angle	18	141.6	7.3	20	145.5	5.8

Body mass and stature descriptive statistics for males and females in Maxwell and Spitalfields collections.

Maxwell

		Females	Males
Morph[1]	n	67	80
	Mean (S.D.)	58.5 (6.1)	67.5 (10.6)
Mech[2]	n	77	93
	Mean (S.D.)	54.8 (8.6)	65.7 (6.9)
Average[3]	n	77	93
	Mean	56.6 (6.6)	67.0 (7.5)

[1] Estimates based on Ruff et al.'s (2005) morphometric (bi-iliac breadth-stature) sex-specific formulae.
[2] Estimates based on Ruff et al.'s (2012) mechanical (femoral head) sex-specific formulae.
[3] Average of morphometric and mechanical body mass estimates.

	Females	Males
n	77	93
Mean	160.1	169.8

Spitalfields

		Females	Males
Morph[1]	n	47	40
	Mean (S.D.)	79.7 (7.2)	122.7 (26.1)
Mech[2]	n	54	53
	Mean (S.D.)	61.3 (8.8)	59.2 (10.6)
Average[3]	n	62	57
	Mean	69.3 (9.1)	84.2 (22.3)

[1] Estimates based on Ruff et al.'s (2005) morphometric (bi-iliac breadth-stature) sex-specific formulae.
[2] Estimates based on Ruff et al.'s (2012) mechanical (femoral head) sex-specific formulae.
[3] Average of morphometric and mechanical body mass estimates.

	Females	Males
n	56	51
Mean	157.2	172.2

Univariate analyses

Independent sample t-test results for differences between Maxwell males and females.

Maxwell Males and Females

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
FMLG	8.0	168	0.000	33.6	4.2	25.2	41.9
FBLG	8.1	168	0.000	33.4	4.1	25.2	41.6
FMHD	10.6	168	0.000	6.4	0.6	5.2	7.5
BIIL	3.1	148	0.002	10.9	3.5	4.0	17.7
INML	-2.2	147	0.027	-3.3	1.5	-6.2	-0.4
INPT	-8.4	146	0.000	-8.3	1.0	-10.2	-6.3
INAT	1.4	146	0.169	1.8	1.3	-0.8	4.4
MDPT	-2.3	147	0.024	-3.9	1.7	-7.4	-0.5
OTML	-10.5	146	0.000	-20.6	2.0	-24.5	-16.8
OTPT	-10.1	147	0.000	-11.9	1.2	-14.2	-9.6
OTAT	-1.8	162	0.068	-2.0	1.1	-4.2	0.1
PBLG	3.8	159	0.000	6.0	1.6	2.9	9.0
Pubic tubercle height	6.5	119	0.000	3.6	0.6	2.5	4.8
Arcuate angle	0.6	116	0.581	0.8	1.4	-2.0	3.6
PSW	-5.5	78	0.000	-2.6	0.5	-3.6	-1.7
PSL	-2.6	78	0.011	-3.0	1.2	-5.3	-0.7

Descriptive statistics for independent samples t-test between Maxwell males and females.

Maxwell Males and Females

Sex		N	Mean	Std. Deviation	Std. Error Mean
FMLG	M	93	466.6	28.5	3.0
	F	77	433.1	25.9	3.0
FBLG	M	93	463.7	27.8	2.9
	F	77	430.3	25.7	2.9
FMHD	M	93	47.9	3.8	0.4
	F	77	41.6	4.0	0.5
BIIL	M	82	273.4	17.8	2.0
	F	68	262.5	24.5	3.0
INML	M	82	122.0	8.3	0.9
	F	67	125.3	9.5	1.2
INPT	M	82	27.2	5.1	0.6
	F	66	35.5	6.8	0.8
INAT	M	82	102.0	7.8	0.9
	F	66	100.2	7.9	1.0
MDPT	M	82	67.8	12.2	1.4
	F	67	71.8	7.9	1.0
OTML	M	82	104.9	10.5	1.2
	F	66	125.5	13.4	1.6
OTPT	M	82	50.7	6.1	0.7
	F	67	62.6	8.3	1.0
OTAT	M	90	91.2	6.5	0.7
	F	74	93.2	7.4	0.9
PBLG	M	90	92.9	8.5	0.9
	F	71	87.0	11.2	1.3
Pubic tubercle height	M	74	9.4	3.1	0.4
	F	47	5.7	2.9	0.4
Arcuate angle	M	72	139.6	7.8	0.9
	F	46	138.9	7.2	1.1
PSW	M	33	4.8	1.7	0.3
	F	47	7.5	2.3	0.3
PSL	M	33	25.3	5.6	1.0
	F	47	28.4	4.7	0.7

Independent sample t-test results for differences between Maxwell parous and non-parous females.

Maxwell parous and non-parous females							
	t-test for Equality of Means						
						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
FMLG	-.7	75	0.462	-5.1	6.9	-18.8	8.6
FBLG	-.7	75	0.504	-4.6	6.8	-18.2	9.0
FMHD	.4	75	0.689	0.4	1.1	-1.7	2.5
BIIL	.0	66	0.972	-0.2	6.9	-14.1	13.6
INML	-2.7	65	0.008	-6.9	2.6	-12.0	-1.8
INPT	-1.4	64	0.179	-2.6	1.9	-6.4	1.2
INAT	-3.0	63	0.004	-6.3	2.1	-10.5	-2.1
MDPT	-2.4	65	0.020	-5.1	2.1	-9.3	-0.8
OTML	-3.1	64	0.003	-11.2	3.6	-18.4	-4.0
OTPT	-1.3	65	0.204	-3.0	2.3	-7.6	1.7
OTAT	-.8	72	0.402	-1.7	2.0	-5.6	2.3
PBLG	-3.5	69	0.001	-9.8	2.8	-15.5	-4.2
Pubic tubercle height	-.1	45	0.907	-0.1	0.9	-2.0	1.8
Arcuate angle	-1.4	44	0.168	-3.3	2.3	-8.0	1.4
PSW	-3.3	45	0.002	-2.2	0.7	-3.6	-0.9
PSL	-1.1	45	0.260	-1.7	1.5	-4.8	1.3

Descriptive statistics for independent samples t-test between Maxwell parous and non-parous females.

Maxwell parous and non-parous females

Parity		N	Mean	Std. Deviation	Std. Error Mean
FMLG	0	58	431.8	26.8	3.5
	1	19	436.9	23.2	5.3
FBLG	0	58	429.2	26.5	3.5
	1	19	433.8	23.3	5.3
FMHD	0	58	41.7	3.6	0.5
	1	19	41.3	5.0	1.1
BIIL	0	51	262.4	18.2	2.5
	1	17	262.7	38.5	9.3
INML	0	50	123.5	9.4	1.3
	1	17	130.5	8.3	2.0
INPT	0	49	34.8	6.5	0.9
	1	17	37.4	7.7	1.9
INAT	0	48	98.5	8.0	1.2
	1	17	104.9	5.7	1.4
MDPT	0	50	70.5	8.1	1.1
	1	17	75.5	5.7	1.4
OTML	0	50	122.8	12.7	1.8
	1	16	134.0	12.3	3.1
OTPT	0	50	61.8	8.7	1.2
	1	17	64.8	6.7	1.6
OTAT	0	55	92.8	7.6	1.0
	1	19	94.5	7.1	1.6
PBLG	0	53	84.5	10.6	1.5
	1	18	94.3	9.7	2.3
Pubic tubercle height	0	33	5.7	2.7	0.5
	1	14	5.8	3.4	0.9
Arcuate angle	0	33	137.9	6.3	1.1
	1	13	141.2	8.9	2.5
PSW	0	33	6.8	2.0	0.3
	1	14	9.0	2.5	0.7
PSL	0	33	27.9	4.6	0.8
	1	14	29.6	5.0	1.3

Independent sample t-test results for differences between Spitalfields males and females

Spitalfields Males and Females

	t-test for Equality of Means						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
FMLG	5.4	105	0.000	27.6	5.1	17.5	37.7
FBLG	5.4	105	0.000	27.9	5.2	17.6	38.1
FMHD	9.5	105	0.000	5.3	0.6	4.2	6.4
BIIL	0.9	90	0.360	3.4	3.6	-3.9	10.6
INML	-4.1	90	0.000	-7.8	1.9	-11.6	-4.0
INPT	-5.3	90	0.000	-5.7	1.1	-7.8	-3.5
INAT	-1.5	87	0.136	-2.1	1.4	-4.9	0.7
MDPT	-0.6	86	0.526	-1.0	1.6	-4.3	2.2
OTML	-5.3	87	0.000	-14.6	2.7	-20.0	-9.1
OTPT	-8.2	88	0.000	-14.7	1.8	-18.3	-11.2
OTAT	-0.9	111	0.386	-1.0	1.1	-3.1	1.2
PBLG	0.1	116	0.937	0.1	1.4	-2.6	2.9
Pubic tubercle height	3.4	68	0.001	1.6	0.5	0.7	2.5
Arcuate angle	-2.9	67	0.006	-4.8	1.7	-8.2	-1.4
PSW	-3.2	79	0.002	-1.5	0.5	-2.4	-0.6
PSL	-4.0	79	0.000	-4.6	1.1	-6.9	-2.3

Descriptive statistics for independent samples t-test between Spitalfields males and females.

Spitalfields Males and Females

Sex		N	Mean	Std. Deviation	Std. Error Mean
FMLG	M	51	439.2	26.6	3.7
	F	56	411.6	26.1	3.5
FBLG	M	51	442.2	27.2	3.8
	F	56	414.3	26.4	3.5
FMHD	M	51	47.6	2.9	0.4
	F	56	42.2	2.9	0.4
BIIL	M	40	264.1	18.0	2.8
	F	52	260.8	16.8	2.3
INML	M	39	121.3	7.0	1.1
	F	53	129.1	10.3	1.4
INPT	M	39	25.7	4.4	0.7
	F	53	31.4	5.5	0.8
INAT	M	37	97.2	6.3	1.0
	F	52	99.3	6.6	0.9
MDPT	M	39	58.0	6.9	1.1
	F	49	59.0	8.2	1.2
OTML	M	39	107.2	11.4	1.8
	F	50	121.8	13.9	2.0
OTPT	M	39	50.6	7.7	1.2
	F	51	65.3	8.9	1.2
OTAT	M	55	88.6	5.6	0.8
	F	58	89.6	6.1	0.8
PBLG	M	57	87.9	7.8	1.0
	F	61	87.8	7.3	0.9
Pubic tubercle height	M	31	7.4	2.0	0.4
	F	39	5.8	1.9	0.3
Arcuate angle	M	31	138.9	7.2	1.3
	F	38	143.7	6.8	1.1
PSW	M	28	6.1	2.0	0.4
	F	53	7.6	2.0	0.3
PSL	M	28	23.8	5.0	1.0
	F	53	28.4	4.9	0.7

Independent sample t-test results for differences between Spitalfields parous and non-parous females.

Spitalfields parous and non-parous females							
	t-test for Equality of Means						
						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
FMLG	-.5	54	0.621	-3.5	7.0	-17.6	10.6
FBLG	-.4	54	0.666	-3.1	7.1	-17.3	11.2
FMHD	-.1	54	0.898	-0.1	0.8	-1.7	1.5
BIIL	-.5	50	0.644	-2.2	4.7	-11.6	7.3
INML	-1.0	51	0.331	-2.8	2.8	-8.5	2.9
INPT	1.4	51	0.159	2.2	1.5	-0.9	5.2
INAT	-1.1	50	0.266	-2.1	1.8	-5.7	1.6
MDPT	-.8	49	0.444	-1.6	2.1	-5.9	2.6
OTML	.2	48	0.843	0.8	4.0	-7.2	8.8
OTPT	-1.4	49	0.169	-3.4	2.5	-8.4	1.5
OTAT	-.1	56	0.928	-0.1	1.6	-3.4	3.1
PBLG	-2.0	59	0.052	-3.7	1.8	-7.3	0.0
Pubic tubercle height	-1.4	37	0.161	-0.9	0.6	-2.1	0.4
Arcuate angle	-1.8	36	0.082	-3.8	2.1	-8.2	0.5
PSW	.5	51	0.627	0.3	0.5	-0.8	1.4
PSL	.0	51	0.964	0.1	1.4	-2.7	2.8

Descriptive statistics for independent samples t-test between Spitalfields parous and non-parous females.

Spitalfields parous and non-parous females

		N	Mean	Std. Deviation	Std. Error Mean
FMLG	0	28	409.9	28.9	5.5
	1	28	413.4	23.5	4.4
FBLG	0	28	412.8	29.3	5.5
	1	28	415.9	23.6	4.5
FMHD	0	28	42.2	2.8	0.5
	1	28	42.3	3.0	0.6
BIIL	0	28	259.8	15.9	3.0
	1	24	261.9	18.0	3.7
INML	0	28	127.8	10.2	1.9
	1	25	130.6	10.4	2.1
INPT	0	28	32.4	5.3	1.0
	1	25	30.2	5.6	1.1
INAT	0	28	98.4	7.2	1.4
	1	24	100.4	5.7	1.2
MDPT	0	27	71.1	5.7	1.1
	1	24	72.7	9.2	1.9
OTML	0	28	122.1	11.5	2.2
	1	22	121.3	16.8	3.6
OTPT	0	27	63.7	7.7	1.5
	1	24	67.2	9.9	2.0
OTAT	0	31	89.5	5.6	1.0
	1	27	89.7	6.7	1.3
PBLG	0	32	86.0	6.9	1.2
	1	29	89.7	7.5	1.4
Pubic tubercle height	0	18	5.3	2.1	0.5
	1	21	6.2	1.7	0.4
Arcuate angle	0	18	141.7	7.3	1.7
	1	20	145.5	5.9	1.3
PSW	0	24	7.7	1.7	0.3
	1	29	7.4	2.2	0.4
PSL	0	24	28.4	4.8	1.0
	1	29	28.3	5.0	0.9

Results of Mann-Whitney U tests for statistical differences between Maxwell and Spitalfields males and females, and parous and non-parous females.

Maxwell Males and Females

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Dorsal pitting	1743.5	5313.5	-4.9	0.000
Sclerotic tissue deposition	2276.0	5931.0	-2.4	0.019
Sulcus	2814.5	7000.5	-2.1	0.035

Maxwell parous and non-parous females

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Dorsal pitting	291.5	1669.5	-2.5	0.012
Sclerotic tissue deposition	332.5	1508.5	-1.3	0.183
Sulcus	522.5	712.5	-0.1	0.904

Spitalfields Males and Females

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Dorsal pitting	819.0	2197.0	-4.1	0.000
Sclerotic tissue deposition	1323.0	2649.0	-0.4	0.667
Sulcus	1562.5	3215.5	-1.3	0.203

Spitalfields parous and non-parous females

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Dorsal pitting	263.5	669.5	-2.0	0.041
Sclerotic tissue deposition	310.5	688.5	-1.1	0.253
Sulcus	380.5	908.5	-1.7	0.097

Bivariate analyses

Results of Pearson's product moment correlation for pubic tubercle variables, osteometric body size and breadth indicators and mean pelvic canal size.

Maxwell Females

		AA	PTH	PSW	PSL
FMLG	Pearson Correlation	.314*	0.247	-0.277	-0.164
	Sig. (2-tailed)	0.033	0.097	0.072	0.292
	N	46	46	43	43
FMHD	Pearson Correlation	0.230	.353*	-0.176	-0.122
	Sig. (2-tailed)	0.125	0.016	0.260	0.436
	N	46	46	43	43
BIIL	Pearson Correlation	0.124	0.115	0.108	-0.026
	Sig. (2-tailed)	0.411	0.448	0.490	0.868
	N	46	46	43	43
Mean pelvic canal size	Pearson Correlation	.371*	0.182	0.220	-0.069
	Sig. (2-tailed)	0.011	0.227	0.157	0.659
	N	46	46	43	43

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Maxwell Males

		AA	PTH	PSW	PSL
FMLG	Pearson Correlation	-0.012	0.118	-0.067	-0.211
	Sig. (2-tailed)	0.920	0.329	0.720	0.255
	N	69	70	31	31
FMHD	Pearson Correlation	-0.188	0.097	-0.182	-0.273
	Sig. (2-tailed)	0.121	0.426	0.327	0.138
	N	69	70	31	31
BIIL	Pearson Correlation	0.085	0.129	-0.132	0.111
	Sig. (2-tailed)	0.487	0.288	0.478	0.553
	N	69	70	31	31
Mean pelvic canal size	Pearson Correlation	0.081	0.188	0.245	0.073
	Sig. (2-tailed)	0.509	0.119	0.183	0.698
	N	69	70	31	31

**. Correlation is significant at the 0.01 level (2-tailed).

Spitalfields Females

		AA	PTH	PSW	PSL
FMLG	Pearson Correlation	-0.228	0.297	0.223	0.121
	Sig. (2-tailed)	0.477	0.348	0.192	0.483
	N	12	12	36	36
FMHD	Pearson Correlation	0.183	0.315	0.118	.433**
	Sig. (2-tailed)	0.570	0.319	0.493	0.008
	N	12	12	36	36
BIIL	Pearson Correlation	-.690**	0.053	0.127	0.093
	Sig. (2-tailed)	0.009	0.864	0.441	0.574
	N	13	13	39	39
Mean pelvic canal size	Pearson Correlation	-.709**	0.319	.316*	0.014
	Sig. (2-tailed)	0.007	0.288	0.050	0.931
	N	13	13	39	39

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Spitalfields Males

		AA	PTH	PSW	PSL
FMLG	Pearson Correlation	.608*	0.315	0.311	-0.094
	Sig. (2-tailed)	0.027	0.294	0.170	0.684
	N	13	13	21	21
FMHD	Pearson Correlation	-0.007	0.310	0.349	0.356
	Sig. (2-tailed)	0.983	0.302	0.121	0.113
	N	13	13	21	21
BIIL	Pearson Correlation	.590*	0.274	0.361	.467*
	Sig. (2-tailed)	0.026	0.343	0.099	0.028
	N	14	14	22	22
Mean pelvic canal	Pearson Correlation	.572*	0.198	.762**	0.261
	Sig. (2-tailed)	0.032	0.498	0.000	0.241
	N	14	14	22	22

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Results of Spearman's correlation test for parturition scarring variables and individual pelvic canal measures.

		Dorsal Pitting			Sclerotic tissue			Sulcus		
		Correlation Coefficient	Sig. (2-tailed)	N	Correlation Coefficient	Sig. (2-tailed)	N	Correlation Coefficient	Sig. (2-tailed)	N
Maxwell Females	FMLG	-0.008	0.951	70	0.014	0.911	65	0.233*	0.045	75
	FMHD	0.031	0.797	70	0.074	0.559	65	-0.014	0.906	75
	BIIL	-0.112	0.380	64	-0.001	0.997	59	0.233	0.058	67
	INML	0.152	0.230	64	0.252	0.054	59	-0.042	0.739	66
	INPT	0.087	0.492	64	-0.020	0.879	59	0.067	0.591	66
	INAT	0.203	0.108	64	0.222	0.091	59	0.224	0.071	66
	MDPT	0.108	0.396	64	0.072	0.589	59	0.000	0.998	66
	OTML	0.192	0.133	63	0.171	0.200	58	0.107	0.396	65
	OTPT	-0.176	0.164	64	0.120	0.365	59	0.022	0.861	66
	OTAT	0.020	0.867	70	0.030	0.811	65	0.135	0.254	73
	DPPL	0.005	0.964	70	0.002	0.985	65	0.155	0.183	75
	PBLG	.325**	0.007	69	0.165	0.194	64	0.142	0.237	71

		Dorsal Pitting			Sclerotic tissue			Sulcus		
		Correlation Coefficient	Sig. (2-tailed)	N	Correlation Coefficient	Sig. (2-tailed)	N	Correlation Coefficient	Sig. (2-tailed)	N
Maxwell Males	FMLG	-0.037	0.739	84	-0.134	0.220	85	-0.140	0.186	91
	FMHD	-0.042	0.702	84	0.079	0.474	85	-0.008	0.941	91
	BIIL	0.063	0.578	81	0.005	0.964	81	-0.145	0.195	81
	INML	0.048	0.670	81	0.058	0.608	81	-.277*	0.012	81
	INPT	0.085	0.451	81	0.036	0.748	81	0.087	0.442	81
	INAT	0.014	0.901	81	-0.050	0.660	81	-0.142	0.206	81
	MDPT	0.187	0.095	81	-0.171	0.127	81	0.192	0.087	81
	OTML	-0.002	0.983	81	-0.169	0.132	81	-0.125	0.266	81
	OTPT	0.096	0.393	81	0.063	0.577	81	-0.039	0.732	81
	OTAT	0.034	0.762	84	-0.041	0.709	85	-0.167	0.119	89
	DPPL	-0.072	0.518	83	-0.054	0.627	84	-0.029	0.788	90
	PBLG	0.012	0.912	83	0.127	0.248	84	0.114	0.288	89

		Dorsal Pitting			Sclerotic tissue			Sulcus		
		Correlation Coefficient	Sig. (2-tailed)	N	Correlation Coefficient	Sig. (2-tailed)	N	Correlation Coefficient	Sig. (2-tailed)	N
	FMLG	-0.050	0.731	50	0.114	0.436	49	0.200	0.140	56
	FMHD	0.050	0.729	50	0.160	0.272	49	-0.229	0.089	56
Spitalfields Females	BIIL	.324*	0.023	49	0.042	0.776	48	-0.059	0.676	52
	INML	.313*	0.027	50	0.151	0.302	49	-0.046	0.744	53
	INPT	0.163	0.258	50	0.119	0.415	49	-0.160	0.252	53
	INAT	.297*	0.036	50	.375**	0.008	49	0.002	0.991	52
	MDPT	0.190	0.205	46	0.136	0.372	45	0.045	0.758	49
	OTML	.391**	0.007	47	.309*	0.037	46	-0.043	0.768	50
	OTPT	0.254	0.082	48	0.150	0.315	47	0.170	0.234	51
	OTAT	.373**	0.006	53	0.234	0.095	52	-0.050	0.711	58
	DPPL	0.073	0.602	53	0.100	0.482	52	0.015	0.908	61
	PBLG	.351**	0.009	55	.358**	0.008	54	-.288*	0.025	61

		Dorsal Pitting			Sclerotic tissue			Sulcus		
		Correlation Coefficient	Sig. (2-tailed)	N	Correlation Coefficient	Sig. (2-tailed)	N	Correlation Coefficient	Sig. (2-tailed)	N
Spitalfields Males	FMLG	-0.077	0.611	46	-0.062	0.684	45	-0.041	0.778	50
	FMHD	0.186	0.216	46	0.096	0.529	45	-0.135	0.351	50
	BIIL	0.022	0.894	38	0.307	0.064	37	0.120	0.462	40
	INML	0.138	0.417	37	0.270	0.111	36	.486**	0.002	39
	INPT	0.126	0.456	37	0.015	0.929	36	-0.177	0.281	39
	INAT	-0.016	0.923	37	0.164	0.339	36	.387*	0.018	37
	MDPT	-0.117	0.490	37	-0.059	0.734	36	-0.181	0.270	39
	OTML	-0.039	0.819	37	0.083	0.629	36	-0.143	0.386	39
	OTPT	-0.076	0.654	37	0.155	0.368	36	-0.219	0.181	39
	OTAT	0.108	0.451	51	0.104	0.471	50	-0.072	0.599	55
	DPPL	-0.016	0.912	50	0.168	0.250	49	-0.031	0.825	54
	PBLG	.276*	0.047	52	0.167	0.243	51	-0.228	0.089	57

Results of Spearman's correlation test for parity and parturition scarring in parous females.

Maxwell Parous Females

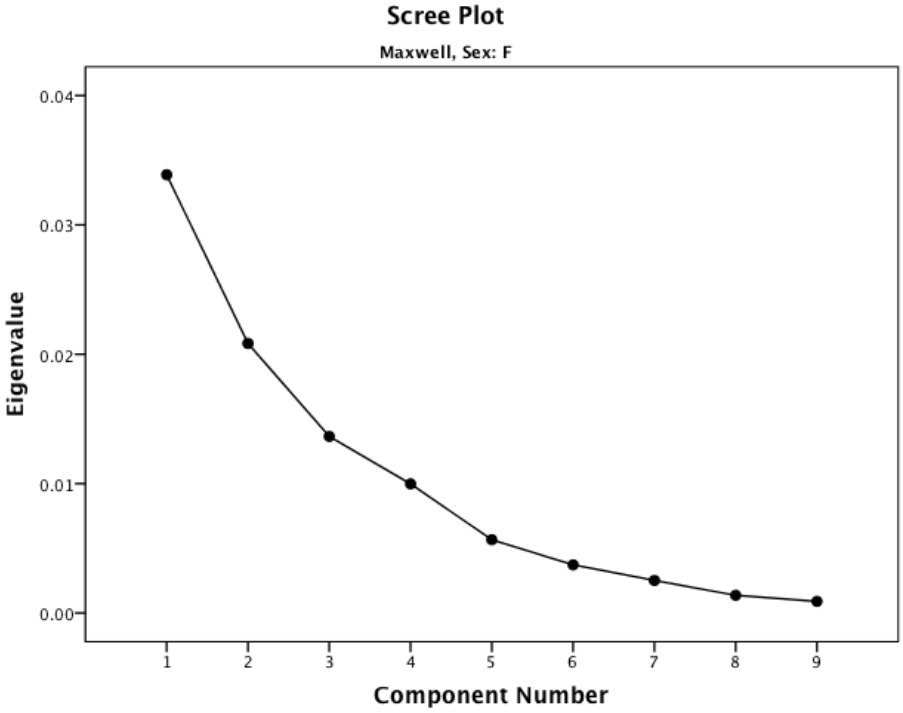
		Sclerotic tissue	Sulcus	Dorsal pitting
Parity	Correlation Coefficient	0.137	-0.396	0.281
	Sig. (2-tailed)	0.601	0.093	0.259
	N	17	19	18

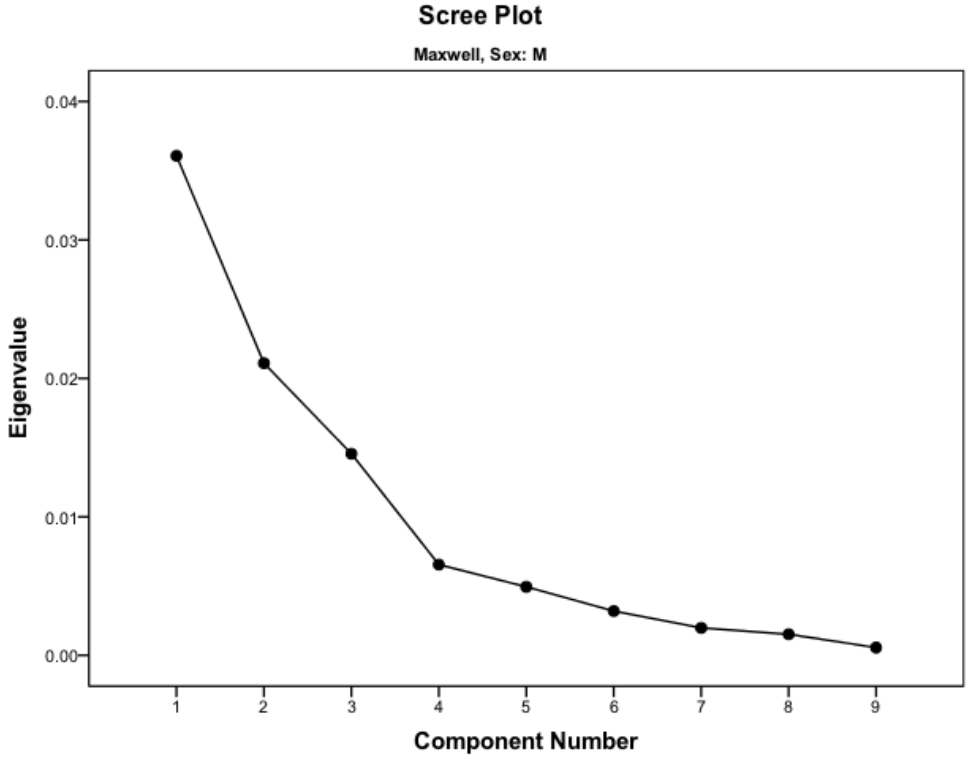
Spitalfields Parous Females

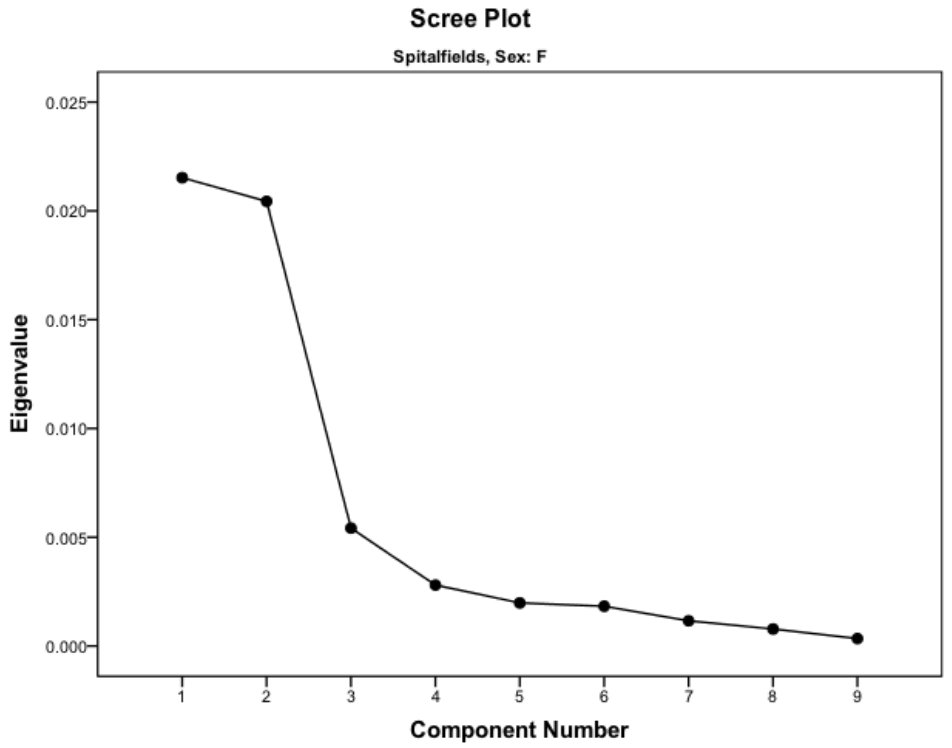
		Sclerotic tissue	Sulcus	Dorsal pitting
Parity	Correlation Coefficient	-0.188	0.190	0.050
	Sig. (2-tailed)	0.349	0.306	0.805
	N	27	31	27

Multivariate analyses

Scree plots for principal components analysis for males and females of Maxwell and Spitalfields collections.



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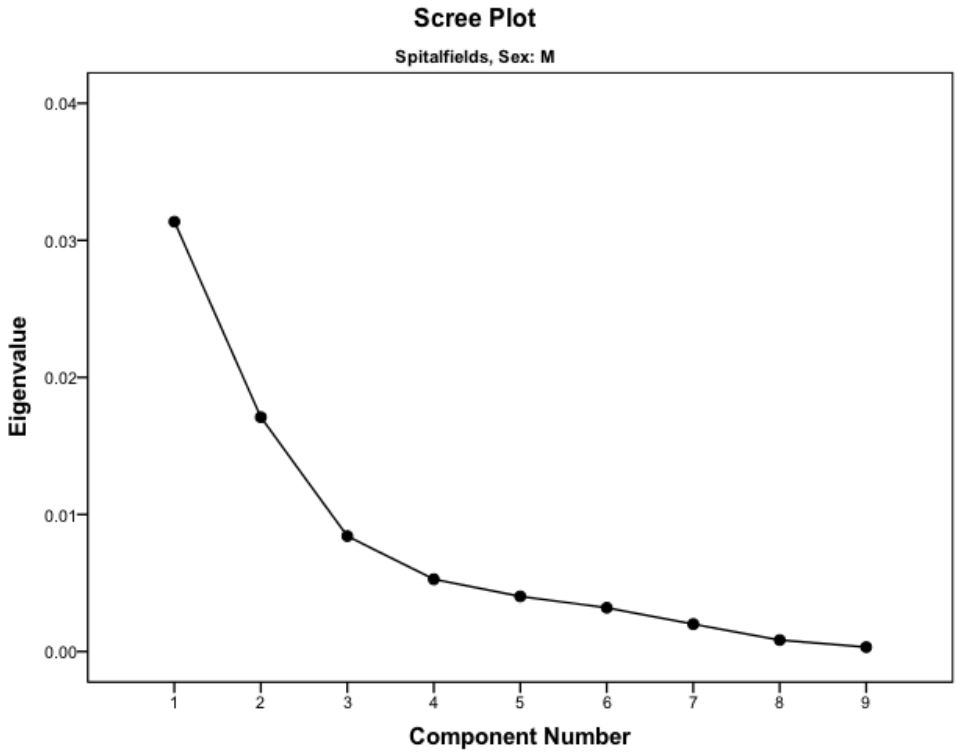
9
Component Number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0.01
0.00
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2
3
4
5
6
7
8
9
Component Number

Extracted principal components for principal components analysis of males and females in Maxwell and Spitalfields collections.

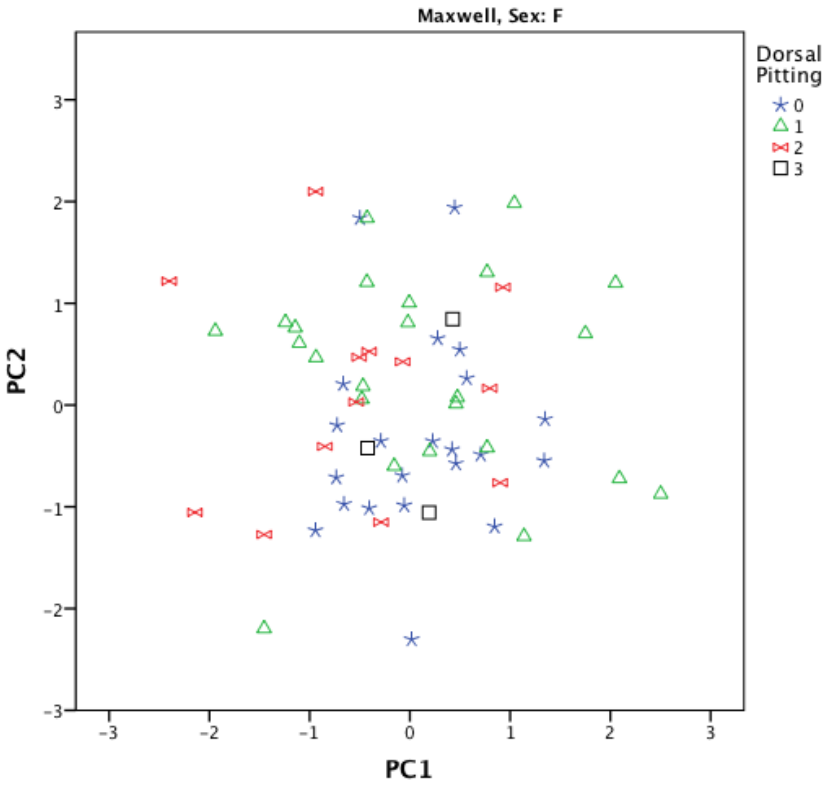
Maxwell Females	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
BIIL	0.046	0.010	-0.096	-0.016	-0.001	0.021	-0.012	0.005	0.006
INML	0.003	0.023	-0.021	0.017	-0.029	-0.018	0.028	-0.006	0.017
INPT	-0.168	-0.012	-0.018	0.006	0.013	0.009	0.000	0.006	0.007
INAT	0.028	0.024	0.018	-0.014	0.018	-0.020	0.001	0.031	0.007
MDPT	0.008	-0.068	0.024	-0.009	-0.016	-0.008	-0.029	-0.004	0.017
OTML	0.011	0.027	0.019	0.074	-0.025	0.023	-0.010	0.011	0.001
OTPT	0.037	-0.093	0.014	-0.001	0.009	0.029	0.025	0.007	0.003
OTAT	0.033	0.026	0.007	0.034	0.057	0.004	-0.003	-0.012	0.011
PBLG	-0.005	0.069	0.045	-0.050	-0.009	0.032	0.001	-0.003	0.008
Eigenvalue	0.034	0.021	0.014	0.010	0.006	0.004	0.003	0.001	0.001
% of variance	36.6	22.5	14.7	10.7	6.1	4	2.7	1.4	0.996

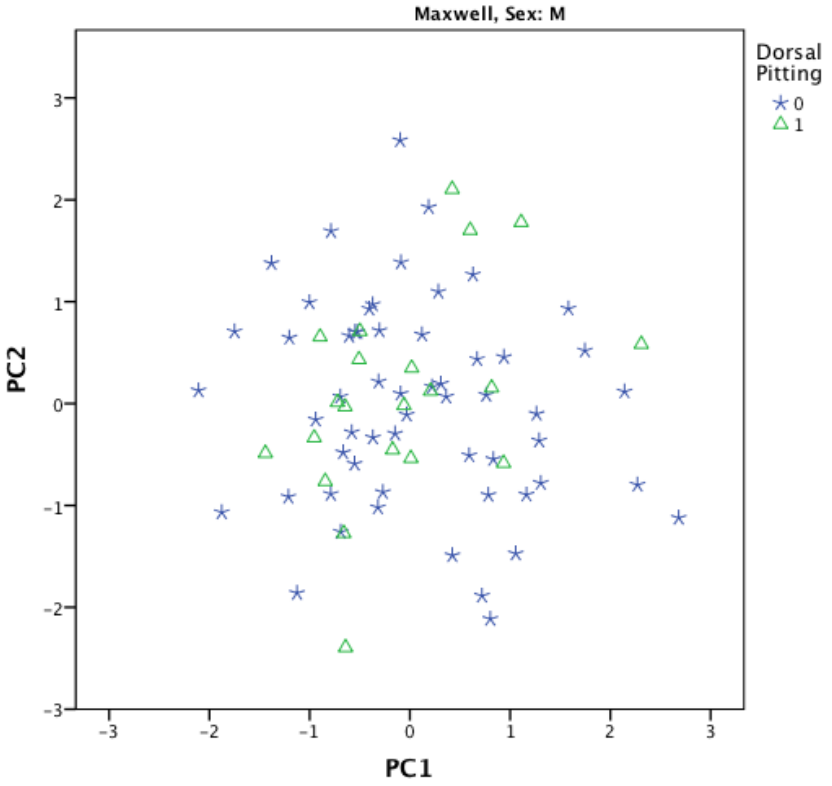
Maxwell Males	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
BIIL	0.029	0.036	0.000	-0.017	-0.018	0.033	0.021	-0.007	0.011
INML	-0.006	0.026	0.116	0.001	0.014	0.000	0.002	-0.002	0.000
INPT	-0.177	0.023	-0.007	0.004	0.004	0.000	-0.001	0.001	0.007
INAT	0.044	0.022	-0.001	0.007	-0.005	-0.024	-0.018	-0.016	0.015
MDPT	-0.005	-0.074	0.014	-0.020	-0.007	-0.028	0.023	0.009	0.007
OTML	0.003	-0.024	0.003	0.075	-0.008	0.002	0.014	-0.004	0.001
OTPT	-0.001	-0.101	0.010	0.000	0.021	0.026	-0.016	-0.001	0.007
OTAT	0.031	0.030	0.008	0.015	-0.010	0.003	-0.010	0.033	0.007
PBLG	0.030	0.033	-0.027	0.005	0.061	-0.004	0.012	0.003	0.004
Eigenvalue	0.036	0.021	0.015	0.007	0.005	0.003	0.002	0.002	0.001
% of variance	39.8	23.3	16	7.3	5.4	3.5	2.1	1.6	0.6

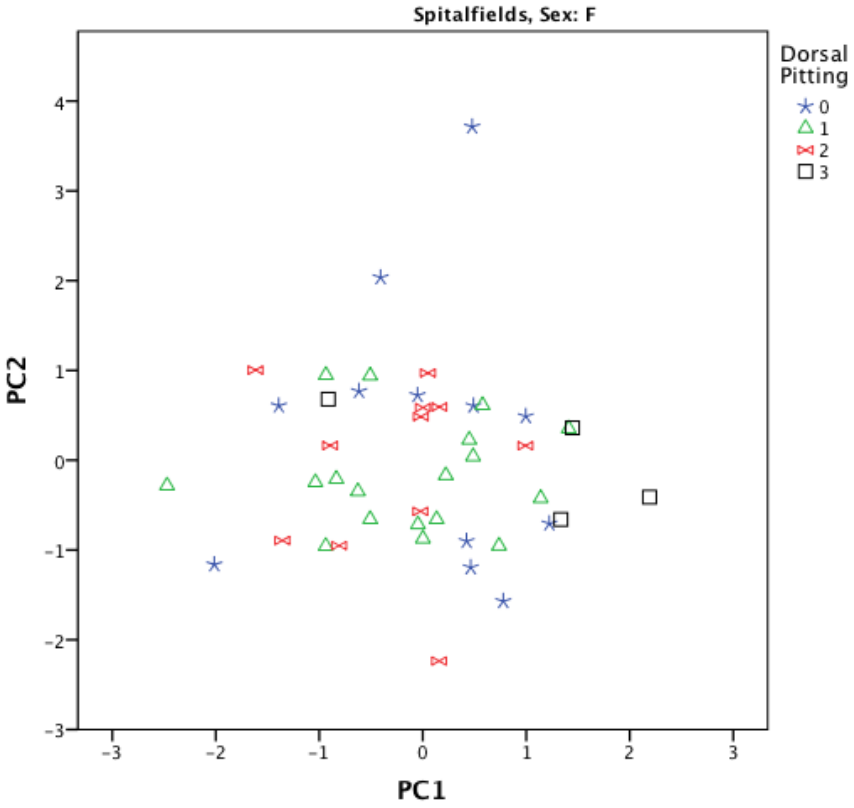
Spitalfields Females	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
BIIL	-0.004	0.043	-0.025	0.031	0.010	0.008	0.019	-0.005	0.004
INML	-0.009	0.024	-0.011	0.010	0.009	0.024	-0.018	0.014	0.001
INPT	-0.121	-0.062	0.011	0.000	0.004	0.004	0.004	0.001	0.005
INAT	0.003	0.042	-0.013	-0.011	-0.015	-0.005	-0.008	-0.003	0.015
MDPT	0.040	-0.062	-0.010	0.004	-0.024	0.008	0.012	0.014	0.002
OTML	0.028	-0.008	0.055	0.029	-0.007	0.002	-0.006	-0.004	0.003
OTPT	0.064	-0.083	-0.011	-0.004	0.024	0.003	-0.003	-0.006	0.006
OTAT	0.014	0.029	0.023	-0.006	0.019	-0.017	0.008	0.017	0.005
PBLG	0.013	0.029	0.027	-0.027	0.003	0.027	0.012	-0.004	0.001
Eiegenvalue	0.022	0.02	0.005	0.003	0.002	0.002	0.001	0.001	0
% of variance	38.2	36.3	9.6	4.9	3.5	3.2	2	1.3	0.6

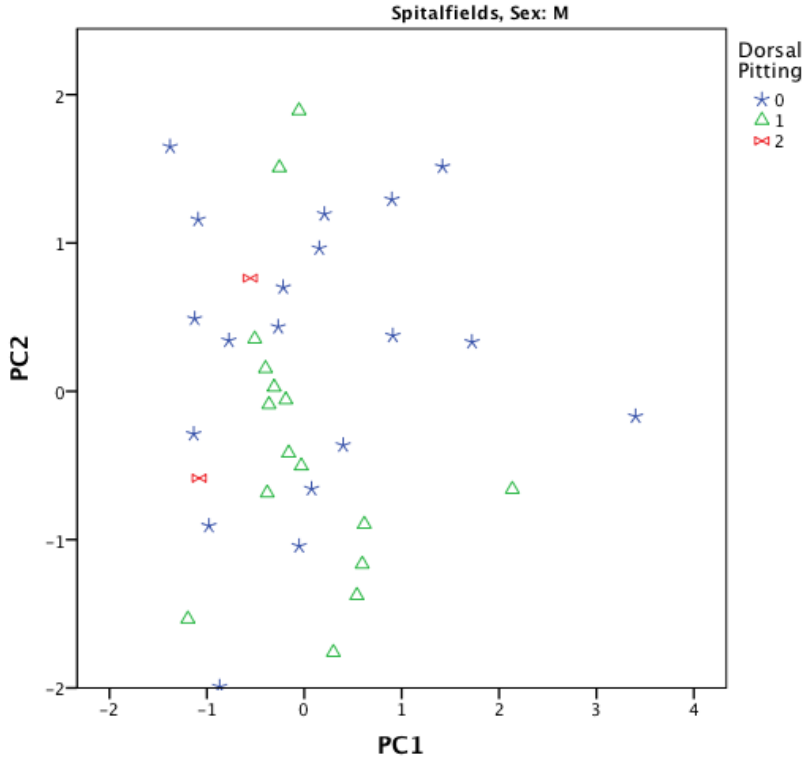
Spitalfields Males	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
BIIL	0.052	-0.029	0.006	0.011	0.005	-0.014	0.004	0.025	0.001
INML	-0.006	0.010	-0.018	0.069	-0.006	0.011	0.000	-0.001	0.000
INPT	-0.143	-0.056	0.023	0.004	-0.007	0.002	-0.002	0.004	0.004
INAT	0.046	-0.003	-0.011	-0.003	-0.012	0.002	-0.022	-0.001	0.014
MDPT	-0.031	0.046	-0.037	-0.016	-0.024	0.021	0.021	0.009	0.003
OTML	0.005	0.068	0.068	0.003	-0.009	0.017	-0.008	0.005	-0.001
OTPT	-0.061	0.076	-0.012	0.004	0.033	-0.025	-0.001	0.002	0.004
OTAT	0.028	-0.001	0.033	0.010	-0.015	-0.024	0.028	-0.008	0.006
PBLG	0.023	-0.023	0.012	0.000	0.043	0.030	0.015	-0.002	0.005
Eigenvalues	0.031	0.017	0.008	0.005	0.004	0.003	0.002	0.001	0
% of variance	43.2	23.5	11.6	7.2	5.5	4.4	2.7	1.1	0.4

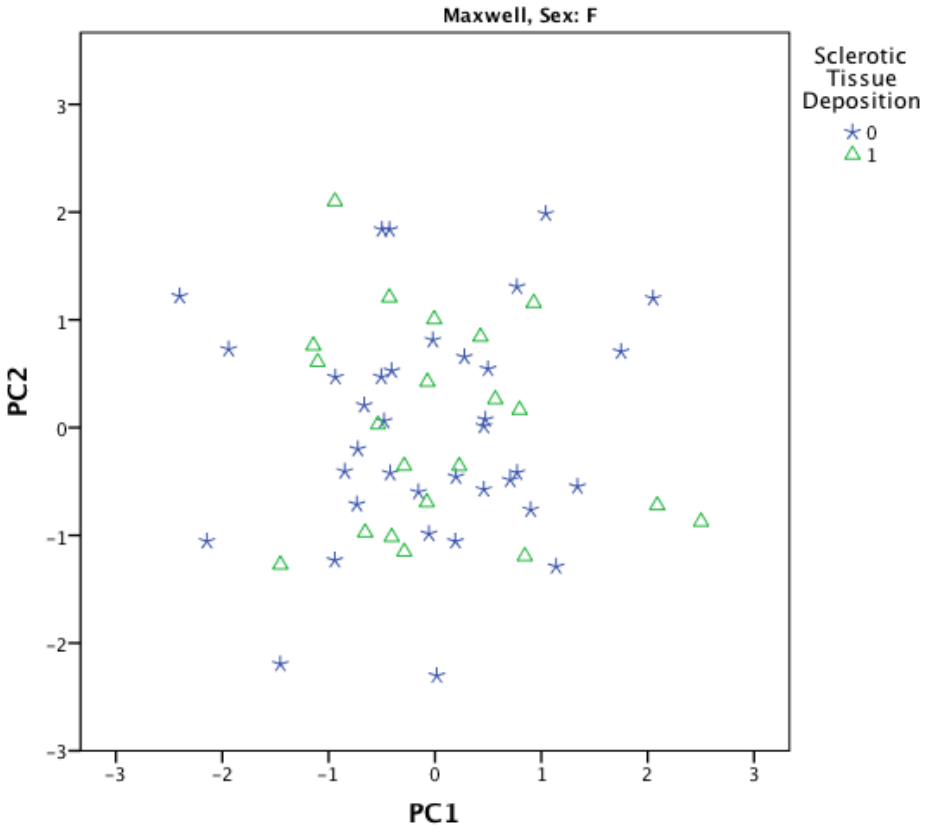
Scatterplots of PC1 and PC2 by parturition scarring type in Maxwell and Spitalfields males and females.

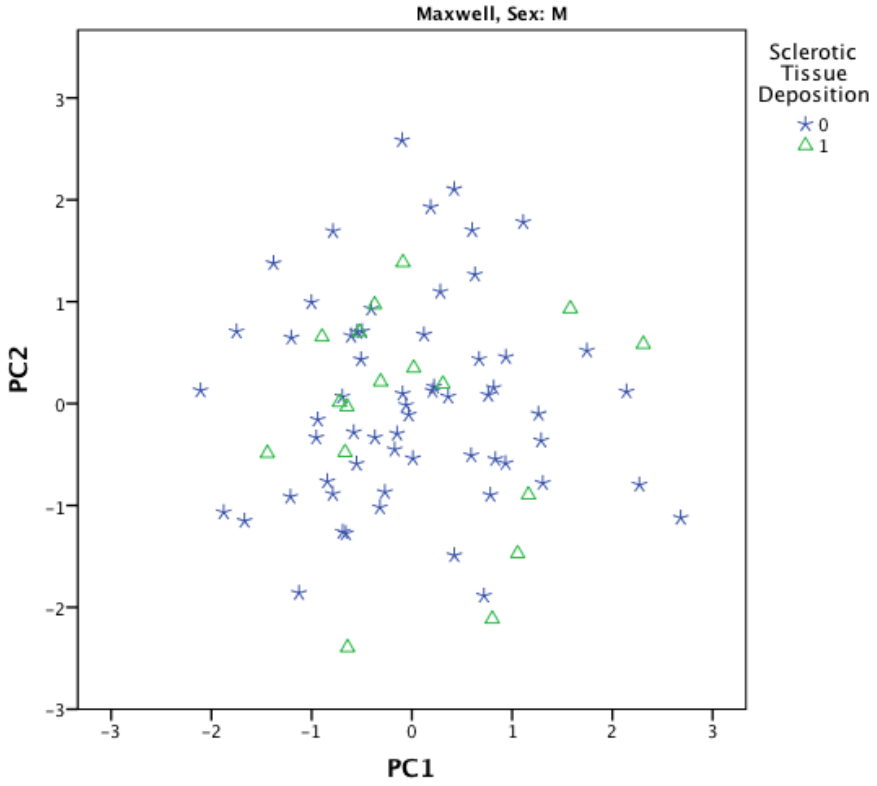


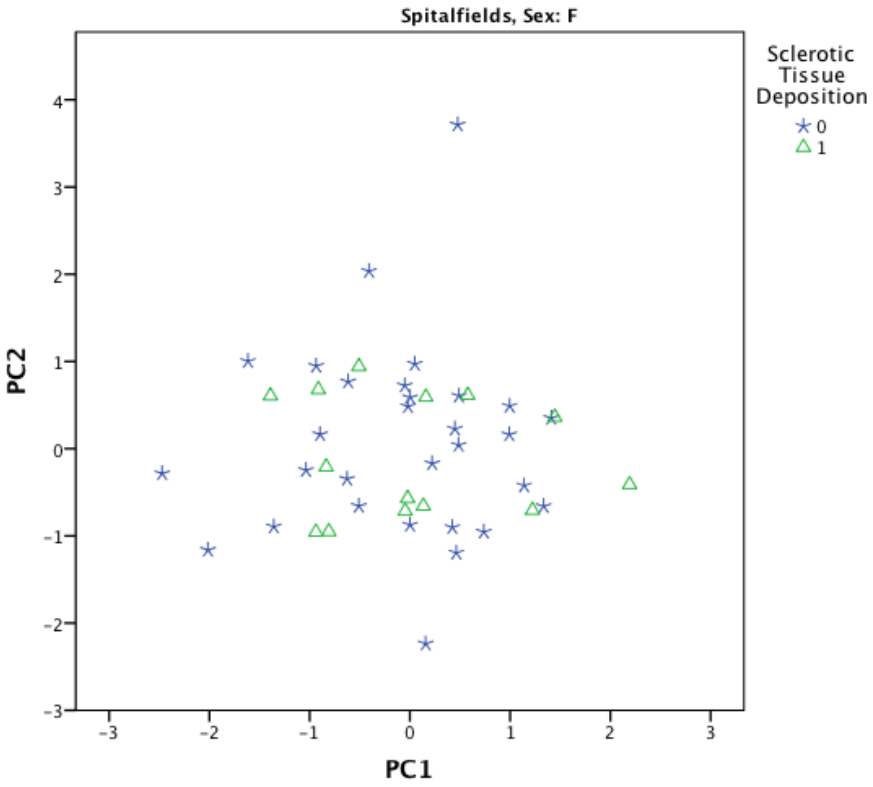


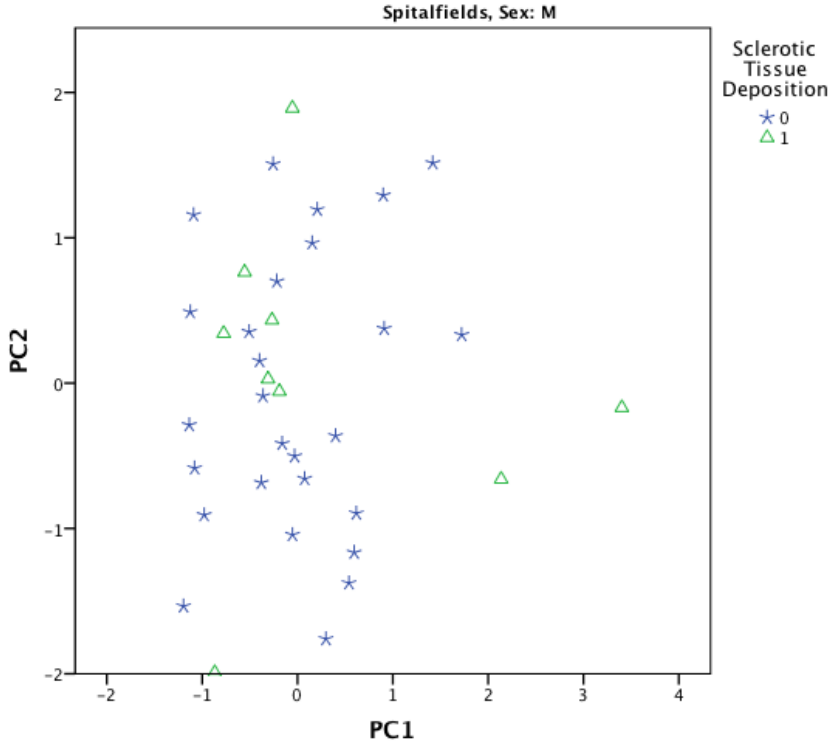

Spitalfields, Sex: F
Dorsal Pitting
0
1
2
3
PC2
PC1
4
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

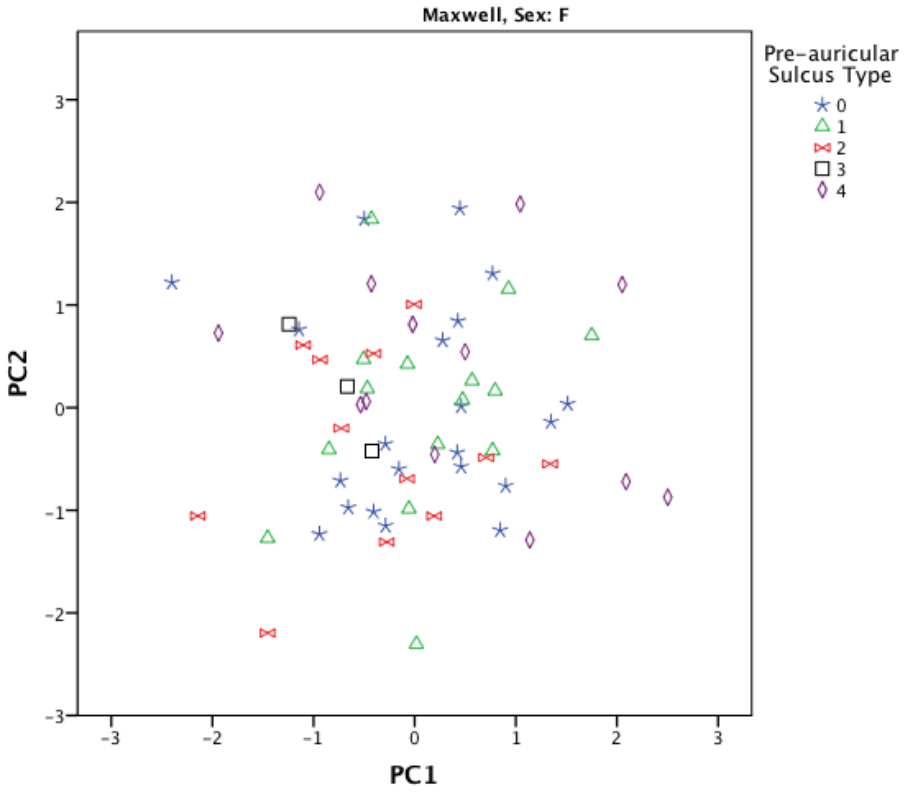

Spitalfields, Sex: M
Dorsal Pitting
0
1
2
PC2
PC1
2
1
0
-1
-2
-2
-1
0
1
2
3
4

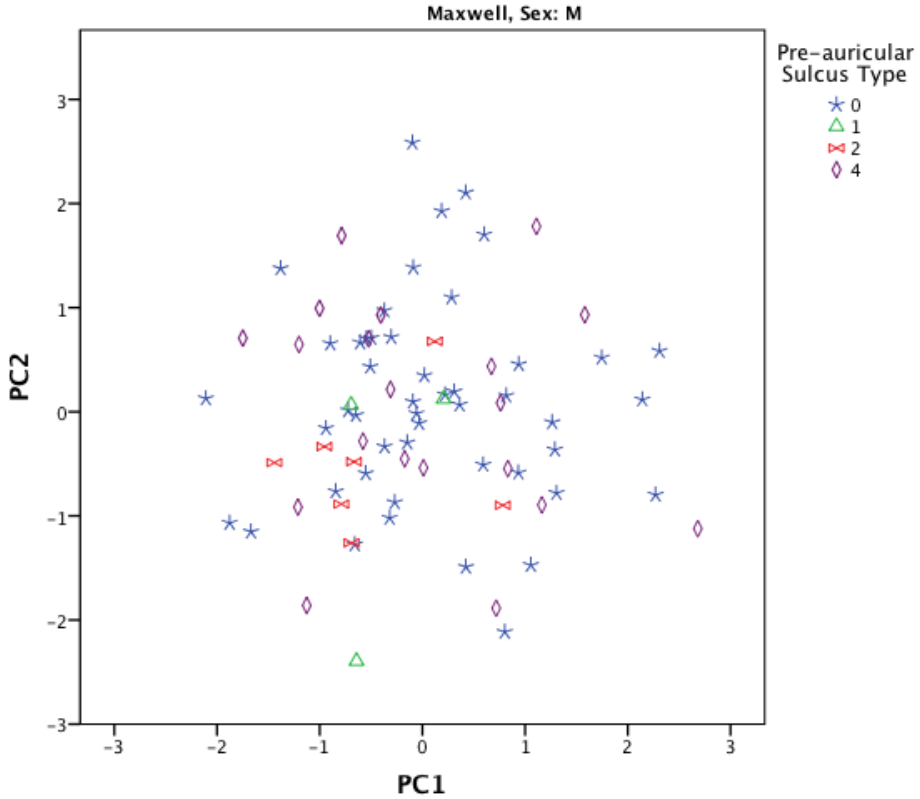

Maxwell, Sex: F
Sclerotic Tissue Deposition
0
1
PC2
PC1
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

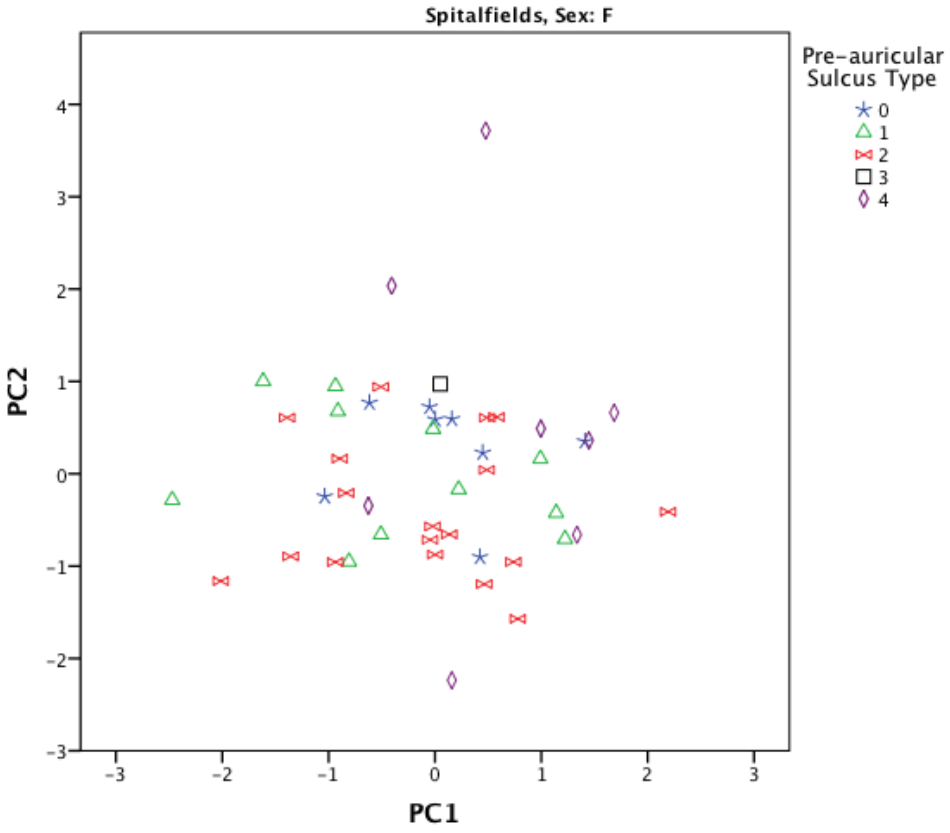

Maxwell, Sex: M
Sclerotic Tissue Deposition
0
1
PC2
PC1
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

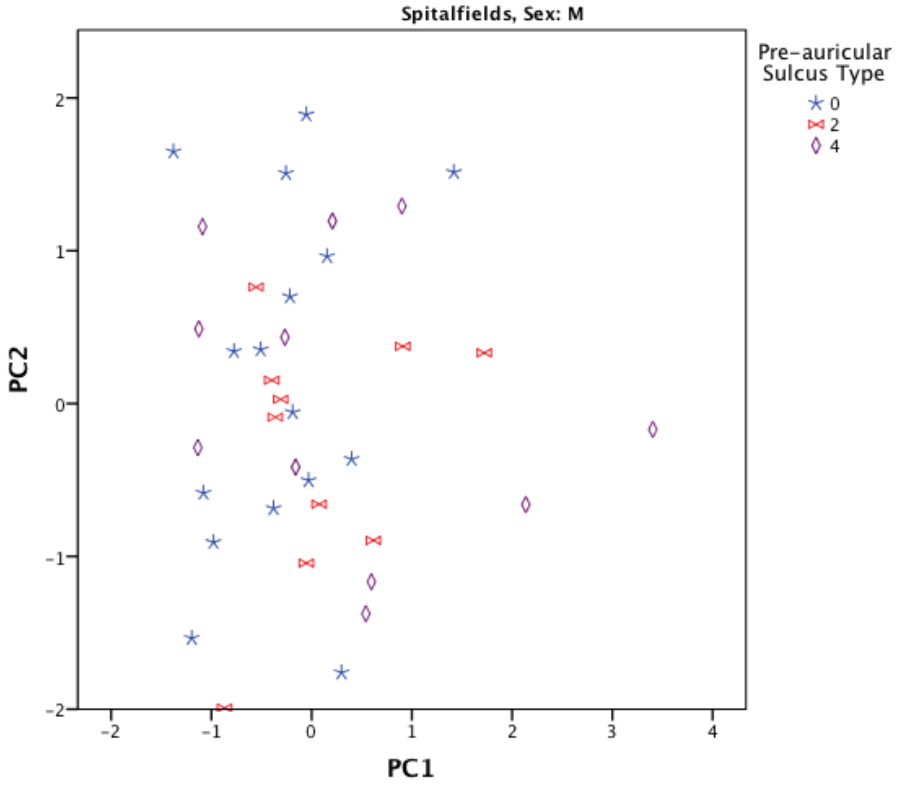

Spitalfields, Sex: F
Sclerotic Tissue Deposition
0
1
PC2
PC1
4
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3


Spitalfields, Sex: M
Sclerotic Tissue Deposition
0
1
PC2
PC1
2
1
0
-1
-2
-2
-1
0
1
2
3
4

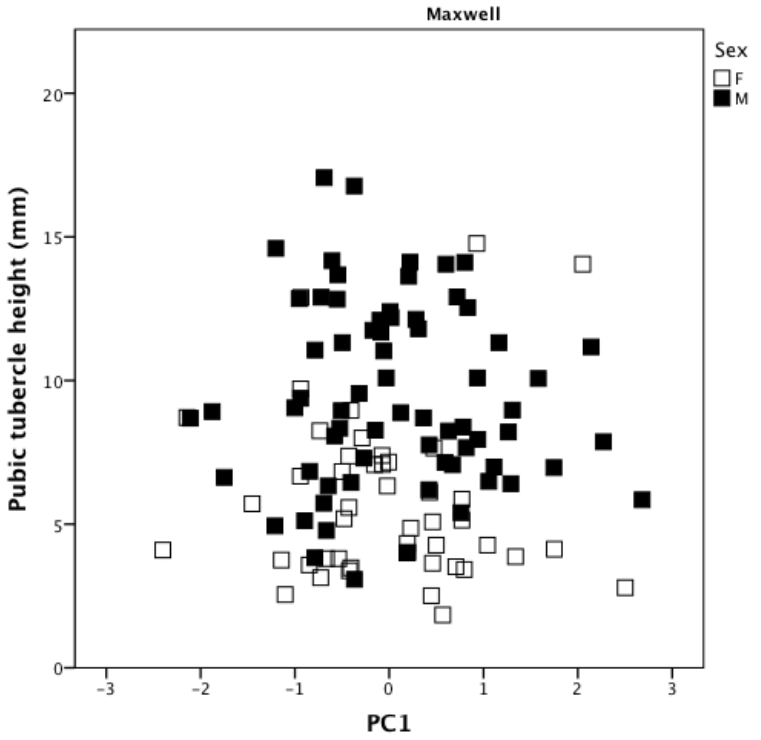

Maxwell, Sex: F
Pre-auricular Sulcus Type
0
1
2
3
4
PC2
PC1
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

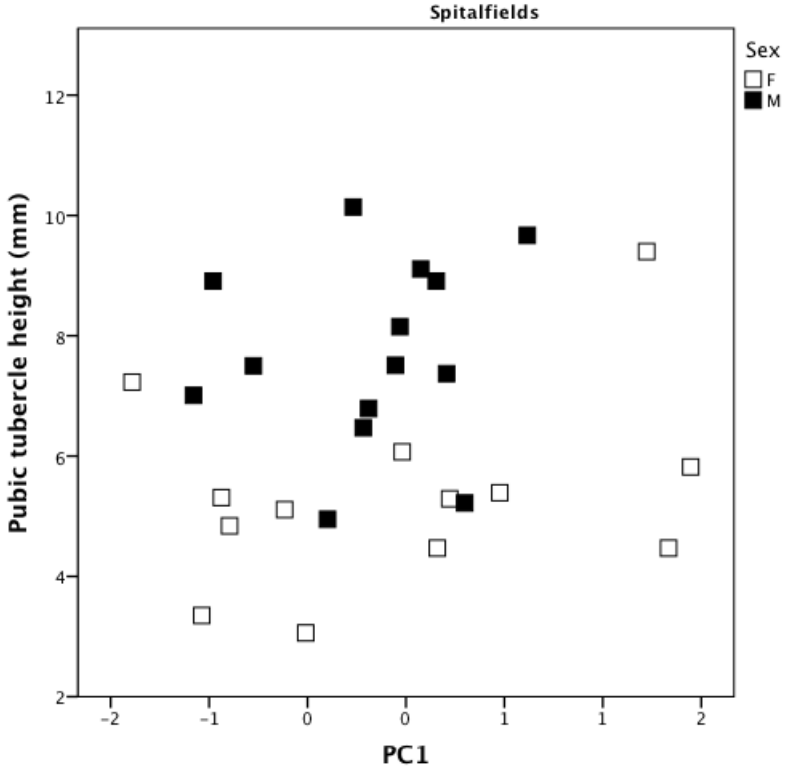

Maxwell, Sex: M
Pre-auricular Sulcus Type
0
1
2
4
PC2
PC1
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

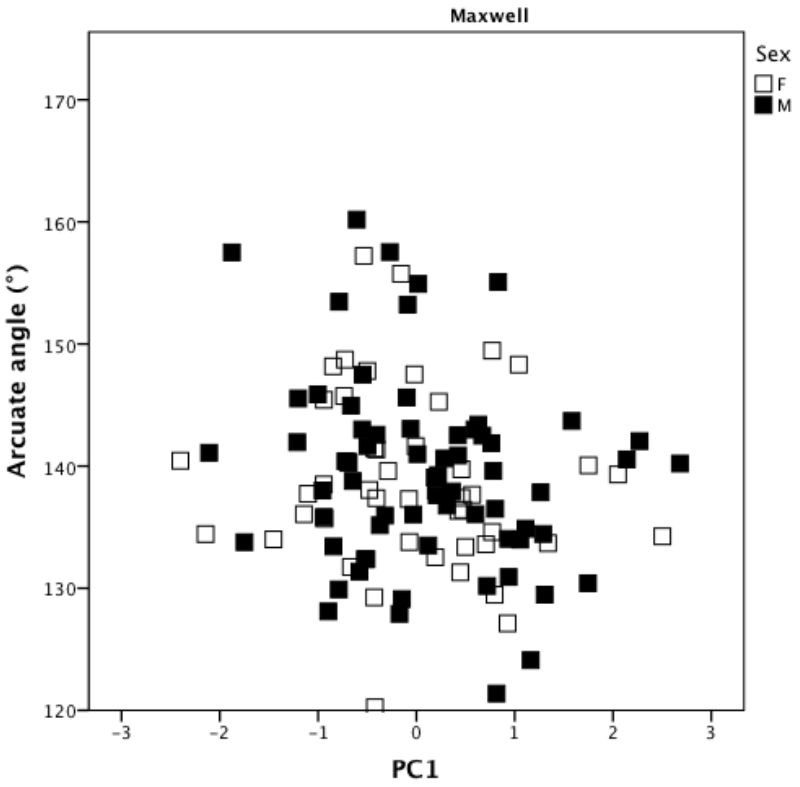

Spitalfields, Sex: F
Pre-auricular Sulcus Type
0
1
2
3
4
PC2
PC1
4
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

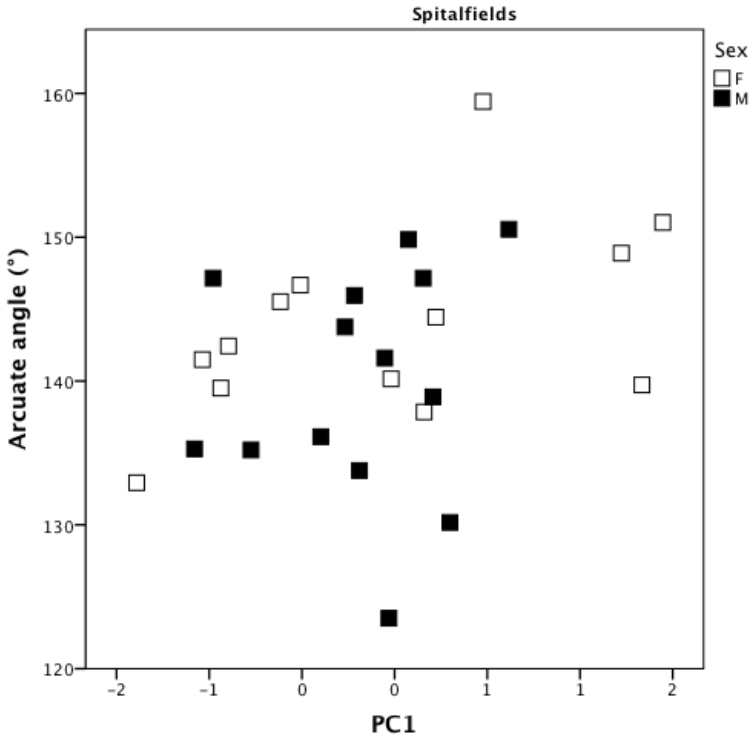

Spitalfields, Sex: M
Pre-auricular Sulcus Type
0
2
4
PC2
PC1
2
1
0
-1
-2
-2
-1
0
1
2
3
4

Scatterplots of PC1 and pubic tubercle variables (pubic tubercle height and arcuate angle) in males and females from Maxwell and Spitalfields collections.






Maxwell
Sex
F
M
Arcuate angle (°)
170
160
150
140
130
120
-3
-2
-1
0
1
2
3
PC1


Spitalfields
Sex
F
M
Arcuate angle (°)
160
150
140
130
120
-2
-1
0
0
1
1
2
PC1