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The Bony Pelvis: Scars of Parturition and Factors Influencing their Manifestation

**Petra Maass
MSSPET003**

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Supervisor: Dr L. J. Friedling

Department of Human Biology
Faculty of Health Sciences
UNIVERSITY OF CAPE TOWN

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DECLARATION

I hereby declare that this thesis is my own, unaided work. It is being submitted in fulfilment for the degree of Master of Science at the University of Cape Town.

It has not been previously submitted for any degree or examination at any other university.

Each significant contribution to and quotation within this thesis, from the work or works of others has been attributed, cited and referenced.

Signed: _____.

Date: _____.

DEDICATION

To my parents, Sanetta and Marius Maass – I am who I am because of you.

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ABSTRACT

The usefulness of “parturition scars” to infer the parity history of skeletal material is still being debated in the literature. Despite numerous studies, the true relationship of parity and scarring has not yet been shown. Skeletal collections with known parity history are rare, thus the best approach would be to examine the relationship of parturition scar features with each other and identify other factors that potentially influence their manifestation.

The aim of this study was to measure and describe the range of variation of several sites on the pelvis reported to display parturition scarring in a skeletal sample of 391 individuals (230 males and 161 females). The scar features, body and pelvic dimensions were compared according to the sex, age and time period of origin of the individuals. Correlation tests were performed to identify potential relationships between scar features, while Principal Component Analysis was used to assess the influence of body and pelvic size on scar manifestation.

Analysis showed that scars occurred more frequently in females, but also in a significant proportion of males. The majority of features did not differ according to the age or time period of origin of individuals. Correlations between scar features suggested that the pubic and sacroiliac ligaments balance each other, while a similar balance exists between the anterior and posterior sacroiliac ligaments. It was shown that despite having smaller body sizes, females had larger pelvic dimensions, especially of the more obstetrically important planes. The pelvic measurements were larger in the modern than the archaeological and historical samples. Only the transverse measurements of the canal appeared to increase with age. Principal Component Analysis showed that body and pelvic sizes were responsible for the majority of variation between individuals, with scars occurring more commonly in those with small body sizes but large pelves or those with both large body and pelvic sizes. The location of scarring on the anterior or posterior of the pelvic girdle was associated with changes to the pelvic dimensions that reduce the overall stability of the pelvic joints. This analysis also showed that females tended to have the body and pelvic sizes associated with scar development, while males tended to have those associated with less scar development.

The results suggest that parturition-related strain is not the primary cause of scarring, but that weight-bearing and pelvic flexibility/ stability may be. Female pelves are more flexible and tend to be relatively large for their body size, increasing the need for ligamentous stabilization of the girdle and causing scar formation. The weight-bearing strain on male pelves may sometimes also be sufficiently large to strain the ligaments, causing similar scar formation.

This study has shown that weight-bearing and pelvic stability are important contributors to scar formation on the bony pelvis. Though the results suggest that parturition is not the primary cause of scar formation, studies of samples of known parity need to be performed to further test this theory.

INTRODUCTION

1.1. “Scars of parturition” and their mechanism of formation

Angel (1969) proposed that pregnancy and childbirth left imprints on the bones of the pelvis in the form of characteristic changes that can be used to determine the parturition history of the individual. The phrase “scars of parturition” was later coined by Stewart (1970) to refer to these characteristic changes. The process by which scar formation occurs is not fully understood, but the generally accepted mechanism relates to the increased secretion of hormones such as relaxin, progesterone and oestrogen during early pregnancy (Abramson *et al.*, 1934; Borg-Stein *et al.*, 2005). These hormones cause the ligaments of the body to become lax, and in the case of the pelvic girdle, slight widening of the joint spaces at the pubic symphysis and sacroiliac joint occurs, widening the birth canal in preparation for the birth process (Lindsey *et al.*, 1988). The increasing weight of the developing foetus, and the increasing lumbar lordosis of the mother to accommodate this weight, places a heavy strain on the weakened ligaments (Monaco, 1996; Ritchie, 2003). To compensate for this strain, the ligaments of the pelvic girdle might become hypertrophic and cause active bone remodelling at the attachment sites of these ligaments (Putschar, 1976). Anterior muscles such as the rectus abdominis, which function in anterior containment of the abdomen, also experience strain in the latter months of pregnancy, which may cause their attachments (in this case the pubic tubercle) to also undergo remodelling (Bergfelder & Herrmann, 1980). Depending on the location and direction of the applied force, the bony interface may develop either pitting or elongation (Andersen, 1986). After parturition, reorganisation and repair slowly return ligaments to their pre-pregnancy state in the weeks that follow. However, the areas of bone remodelling may take many years to disappear (Houghton, 1975) and can thus potentially be used to assess the parturition history of an individual (Angel, 1969). The most commonly reported areas used for such assessments are the dorsal pubic surface, adjacent to the pubic symphysis, the preauricular sulcus and the pubic tubercle (Cox, 2000), and are illustrated in Figure 1.1.

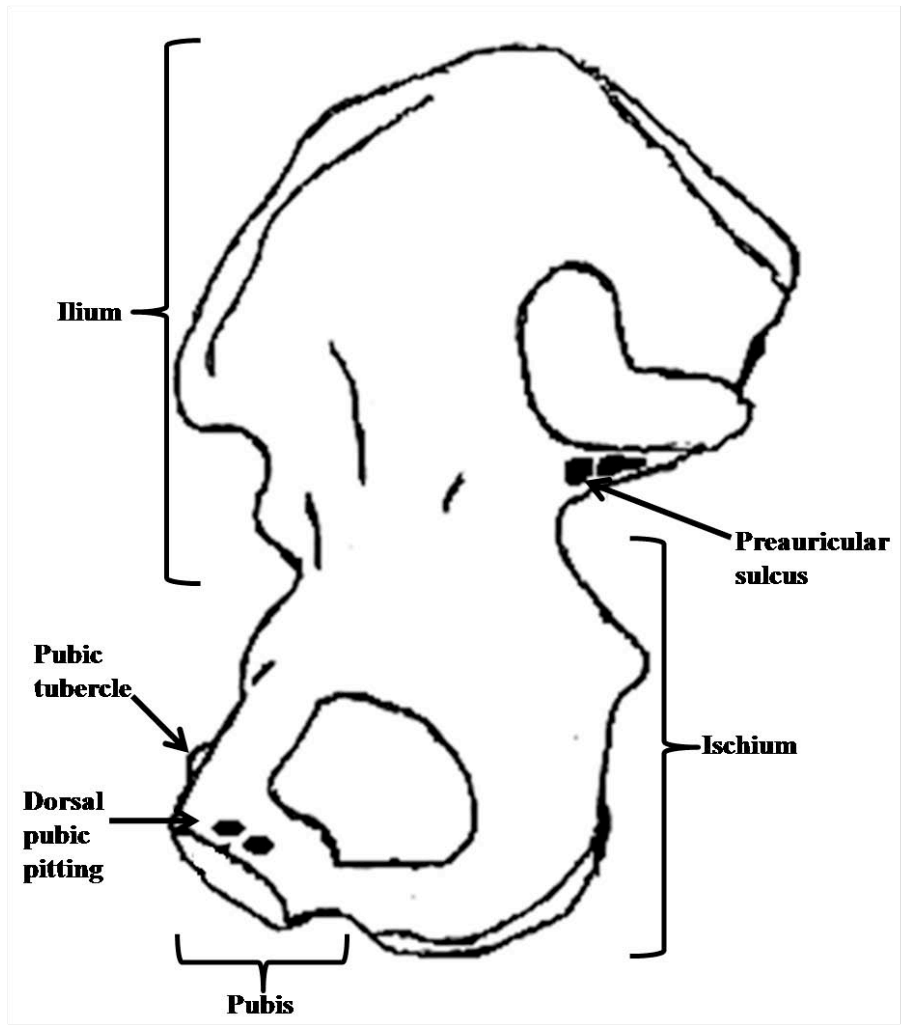


Figure 1.1: Medial view of the right innominate, showing the location of some of the areas of occurrence of “parturition scars”.

1.2. Parturition scarring and estimation of parity history

Angel recognized the potential for determining the parturition history of an individual from their skeletal remains and the potential forensic application of this method. In *The Bases of Paleodemography* (1969), he proposed that not only could one determine whether an individual had given birth, but one could also estimate the number of childbirths from the number and severity of the skeletal alterations. Popularity of Angel's method of using the scars of parturition grew over the next few years, with several studies describing changes that occur at the dorsal pubic surface and the preauricular sulcus (Acsádi & Nemeskéri, 1970; Houghton, 1974 and 1975; Ullrich, 1975). Angel's colleague at the Smithsonian, T. D. Stewart, was the first to caution the use of this method in 1970, stating "probably it will never be possible to associate accurately the degree of scarring with the true number of pregnancies". Stewart further questioned the influence of obstetrical practices on the manifestation of scarring, suggesting that modern medical interventions such as caesarean sections might reduce the trauma to the ligamentous attachment sites and thus reduce the severity of any scarring that may occur. By the late 70's, several studies published evidence contradicting Angel's theory (Gilbert & McKern, 1973; Holt, 1978; El-Najjar & McWilliams, 1978; Suchey *et al.*, 1979) with many of these studies reporting "parturition scars" on some nulliparous females and no scarring on some females who definitely had borne children.

1.3. The importance of the study

Despite the large number of studies cautioning against the use of parturition scars to assess parity history, the method is still widely accepted by anthropologists, archaeologists and palaeopathologists (Andersen, 1986). The availability of a method to assess parity history from skeletal remains holds high value in these fields and also has potential forensic applications. This might explain why, even though the reliability of using this method is being questioned, it is still used by many scientists. It is thus important that the true nature of the relationship of parity history and skeletal markers be investigated. In order to do so, the different forms or morphologies of the areas where scarring is reported to occur need to be described and evaluated for sex or age-related differences. Unfortunately, studies related to parity history face the challenge that there are very few skeletal collections for which parity history is available (Cox, 2000). The alternative approach to the problem is to examine the relationship between parturition scar features and other potential factors such as pelvic and body size that may affect scar manifestation.

1.4. Aims and objectives

The aim of this study is to describe the morphology of the bony pelvis of a large sample of skeletal material in terms of alterations to the bone that relate to changes reported to take place during pregnancy and parturition.

The objectives of this study are to:

1. Measure and describe the range of variation of a series of pelvic features reported in the literature to be altered by pregnancy and/ or parturition (“scars of parturition”) at the dorsal pubic surface, pubic tubercle, preauricular sulcus, interosseous groove, and iliac tuberosity. This data will be used to test for association of these features with the sex, age or time period from which the individuals originate.
2. Perform a Principle Components Analysis to determine the influence of non-parturition-related features such as pelvic dimensions and body size on the manifestation of scarring.

BACKGROUND

Andersen (1986) suggested that the location of parturition scars at the sites of stabilizing ligamentous attachments adjoining the joints of the pelvic girdle indicate that these scars could be the result of excess movement allowed by flexible pelvic architecture. Stability of the pelvic girdle is obtained by the articulation of the wedge-shaped sacrum into the girdle and is supported by soft tissues such as the muscles of the pelvic floor and the connective tissue (Walker, 1992; DonTigny, 1993; Nuger, 2008; Driscoll, 2010). Several studies have shown that male pelvises are more tightly articulated than those of females, which allows less movement of the elements of the girdle (Derry, 1911; Emmons, 1913; İşcan & Derrick, 1984). Female pelvises are more loosely articulated to allow moulding of the pelvis during parturition (Borell & Fernström, 1958; Ohlsén, 1973). Andersen suggested that this increased flexibility created an increased need for stabilization of the girdle by its ligaments in order to allow the weight of the trunk to be transmitted to the lower limbs, resulting in scar formation at the ligamentous attachment sites. During pregnancy, the combination of ligamentous laxity and increasing mechanical strain on the pelvic ligaments due to the increasing weight of both the mother and foetus (and the increasing lumbar lordosis to maintain the centre of gravity over the lower limbs) accentuate the weight-bearing function of the pelvic girdle (Ritchie, 2003; Borg-Stein *et al.*, 2005) and thus cause the formation or enlargement of scars. Andersen's theory is supported by many previous observations. Houghton (1974 and 1975) observed that scarring at the preauricular sulcus was more common and severe than that at the pubic symphysis, suggesting that this might be the result of the sacroiliac ligaments which attach to the preauricular sulcus being under more strain from weight-bearing than the ligaments which cross the pubic symphysis. Molleson *et al.* (1993) showed that the dimensions of the preauricular sulcus and dorsal pubic pitting are associated with larger pelvises and proposed that larger pelvises are less stable in weight transference, causing greater ligamentous stress and associated alterations to the pelvic bones. Andersen further proposed that the reduced frequency of scarring observed in older individuals is the result of decreasing body weight and the higher incidence of arthritic changes such as bony lipping and ankylosis of the joints which reduce the flexibility of the pelvis and thus reduce the strain on its ligaments. This was supported by earlier descriptions of the joints of the girdle by Brooke (1924), Walker (1992) and Prassopoulos *et al.* (1999).

2.1. Joints of the pelvic girdle

The pelvic girdle consists of four bones, namely the two innominates, the sacrum and the coccyx. Posteriorly, the innominates articulate to either side of the sacrum at the sacroiliac joints, and anteriorly to each other at the pubic symphysis. The areas surrounding these joints are commonly investigated for parturition scarring.

2.1.1. The pubic symphyseal joint

The pubic symphysis does not fuse in humans as in some other mammals, possibly to allow some movement and widening during the parturition process (Scheuer & Black, 2000). The symphyseal joint is a secondary cartilaginous joint, with the two pubic bones separated by a fibrocartilagenous disc and strengthened on the borders by ligaments (Figure 2.1). The oval and slightly convex articular surfaces of each of the pubic bones are covered by 1 mm to 3 mm of hyaline cartilage (Becker *et al.*, 2010). The hyaline cartilage becomes thinner with age, causing the roughened, billowing appearance of the articular surfaces to become smoother. Several studies have used these age-related changes to develop methods to estimate age-at-death, including Todd (1920), Meindl *et al.* (1985), and Suchey *et al.* (1986) on which the casts of the Suchey-Brooks pubic ageing method are based. These methods are considered particularly useful because the secondary ossification changes occurring in this region continue long after skeletal maturity, allowing age estimation of older individuals (Scheuer & Black, 2000). The fibrocartilagenous disc joining the two hyaline surfaces functions in resisting tension, shearing and compressive forces (Becker *et al.*, 2010). The disc has a narrow middle portion, but bulges slightly at the superior and inferior ends, and sometimes contains a small cavity. The normal height of the symphysis has been reported as 4.45 cm (Johanson-Unnéus, 1957), while the mean symphysis width reported for non-pregnant females ranges from 0.4 cm to 0.6 cm (Abramson *et al.*, 1934; Williams, 1955; Vix & Ryu, 1971; Garagiola *et al.*, 1989).

The joint is stabilized by four ligaments: the superior, inferior, anterior and posterior pubic ligaments. The superior pubic ligament is a thick fibrous band that attaches to either side of the pubic crest, sometimes as far lateral as the pubic tubercle (Andersen, 1986; Becker *et al.*, 2010). Despite its thickness, the fibres of the ligament are weak and play only a minor role in joint reinforcement (Becker *et al.*, 2010). The inferior pubic ligament is sometimes also referred to as the “subpubic arched” ligament or simply the “arcuate” ligament (Andersen, 1986). The fibres of this ligament are stronger than those of the superior pubic ligament (Abramson *et al.*, 1934), and form the apex of the subpubic arch through attachment of the inferior fibres of the ligament to the inferior

pubic rami (Becker *et al.*, 2010). The superior fibres of the ligament are short and transversely orientated, and blend into the interpubic disc and the posterior pubic ligament. The anterior pubic ligament has very thick fibres that form the anterior border of the joint and is considered the strongest of the pubic ligaments (Andersen, 1986; Lindsey *et al.*, 1988; Becker *et al.*, 2010). The deep fibres of the ligament are transversely orientated and blend with the interpubic disc, while the superficial fibres run more obliquely and interdigitate with the tendons of the rectus abdominis, internal oblique abdominis, pyramidalis and according to some researchers, also with the transverse abdominis, pectineus, adductor longus, adductor brevis and gracilis muscles (Andersen, 1986; Becker *et al.*, 2010). Lastly, the posterior pubic ligament consists of only a few fibres crossing transversely behind the joint. The superior transverse fibres of this ligament blend to those of the superior pubic ligament, while the inferior oblique fibres cross over and merge with the inferior pubic ligament (Becker *et al.*, 2010).

Up until the late 19th century, it was debated whether widening of the pubic symphysis during pregnancy was normal or not, but by 1870 it was generally accepted that hormone-induced relaxation of the ligaments was a normal part of pregnancy (Abramson *et al.*, 1934; Ohlsén, 1973). Studies have shown that serum levels of the hormone relaxin (secreted by the corpus luteum) begin to increase from the 10th to 12th week of pregnancy, decreasing significantly by the 20th week, and then remaining at a stable level until labour (Heckman & Sassard, 1994; Ritchie, 2003; Borg-Stein *et al.*, 2005; Becker *et al.*, 2010). This causes a reduction in the firmness of the symphysis and the tensile strength of the ligaments surrounding it as well as increased vascularisation of the area, resulting in separation of the pubic bones. The degree of separation considered normal varies greatly between reports, but is generally accepted to be less than 10 mm (Young & Ince, 1940; Ritchie, 2003; Borg-Stein *et al.*, 2005). Rupture of the joint is rare (Borg-Stein *et al.*, 2005), and the reported incidence of such events is declining, possibly due to improvements in health care (Lindsey *et al.*, 1988). After pregnancy, relaxin levels decrease and remodelling and repair of the symphyseal ligaments allow them to return to their pre-pregnancy state within a few months (Abramson *et al.*, 1934; Young & Ince, 1940; Houghton, 1975)

2.1.2. The sacroiliac joint

The sacroiliac joint is a more complex structure than the pubic symphysis and because of its location, orientation and morphology, changes to the joint are complex and difficult to examine using techniques such as radiography (Ohlsén, 1973; Walker, 1992). The sacroiliac joint is a synovial joint (Andersen, 1986; Borg-Stein *et al.*, 2005), but has very limited movement due to the action of the strong ligaments crossing it (Scheuer & Black, 2000). The iliac articulation surface is

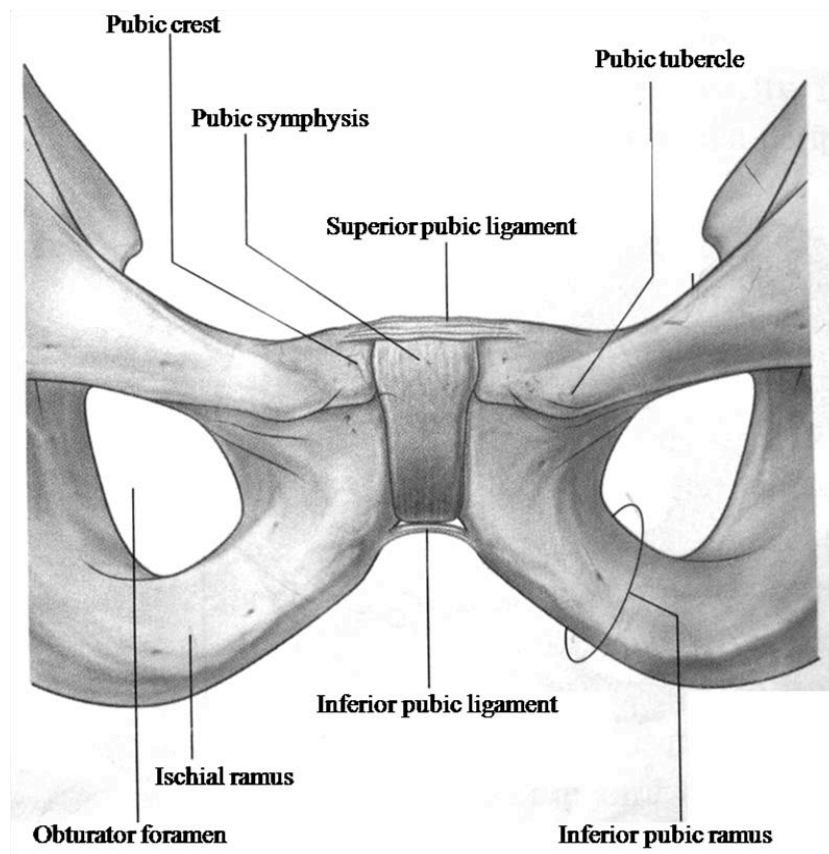


Figure 2.1: The pubic symphyseal joint.

[Adapted from Drake *et al.*, 2005]

covered by a thin layer of hyaline cartilage of 1.5 mm to 2 mm thick, while the sacral articulation surface is covered by fibrocartilage of 1 mm to 4 mm thick (Sashin, 1930; Andersen, 1986; Walker, 1992). The articulation surfaces are roughly L- or C-shaped with the longer limb directed dorso-caudally and the shorter limb dorso-cranially (Calvillo *et al.*, 2000; Scheuer & Black, 2000). Like the pubic symphyseal surfaces, the articulation (auricular) surface of the ilium can be used in age-at-death estimations (Lovejoy *et al.*, 1985; Buckberry & Chamberlain, 2002; Igarashi *et al.*, 2005). Many researchers consider the auricular surface more useful for this purpose than the pubic surface, because of the better preservation of the area and the longer period in which changes to the surface occur (Lovejoy *et al.*, 1985; Waldron, 1987; Rabe, 2009). The appearance of the surface is also influenced by sex, with males tending to have wide and flat surfaces and females tending to have narrow and raised surfaces (St Hoyme & İşcan, 1989; Buikstra & Ubelaker, 1994). The surface area of the auricular surface is highly variable and is influenced by factors such as age, sex and body mass (Sashin, 1930; Demir *et al.*, 2007). The width of the joint cavity is also highly variable, even within an individual, with a range of 0.77 mm to 4.39 mm reported by Demir *et al.* (2007). The main function of the joint is to allow weight to be transferred from the trunk to the lower limbs (Sashin, 1930; Brooke, 1924; Wang & Dumas, 1998; Calvillo *et al.*, 2000), but due to the almost vertical orientation of the articulation surfaces, the majority of weight transfer takes place through the ligaments surrounding the joint (Robinson, 1972; DonTigny, 1985 and 1993; Lee, 1999; Scheuer & Black, 2000; Pel *et al.*, 2008).

The sacroiliac joint is stabilized by three ligaments, the interosseous, posterior and anterior sacroiliac ligaments (Figure 2.2). The interosseous sacroiliac ligament is often called the strongest in the body (Walker, 1992; Wang & Dumas, 1998), and is the main restrictor of movement of the joint (Rosatelli *et al.*, 2006). The deep fibres of the ligament form the posterior of the joint cavity and pass from the roughened area immediately posterior and superior to the articular surface on the sacrum to the adjacent area on the ilium where its attachment forms the interosseous groove (Calvillo *et al.*, 2000; Steinke *et al.*, 2010). The superior fibres of the ligament originate from the same area of the sacrum, but the fibres blend with those of the posterior sacroiliac ligament (Sashin, 1930; Rosatelli *et al.*, 2006). The interosseous ligament is prone to become ossified with age and may cause complete ankylosis of the joint which is a common condition in males over 50 years old, but rare in females of any age (Brooke, 1924; Calvillo *et al.*, 2000; Rosatelli *et al.*, 2006). The posterior sacroiliac joint overlies the interosseous ligament, but is separated from it by the posterior rami of the sacral spinal nerves and blood vessels (Rosatelli *et al.*, 2006). The superior part of the ligament originates from the intermediate and lateral sacral crests and attach to the lateral side of the posterior superior iliac spine and the internal lip of the iliac crest (Andersen, 1986; Rosatelli *et al.*,

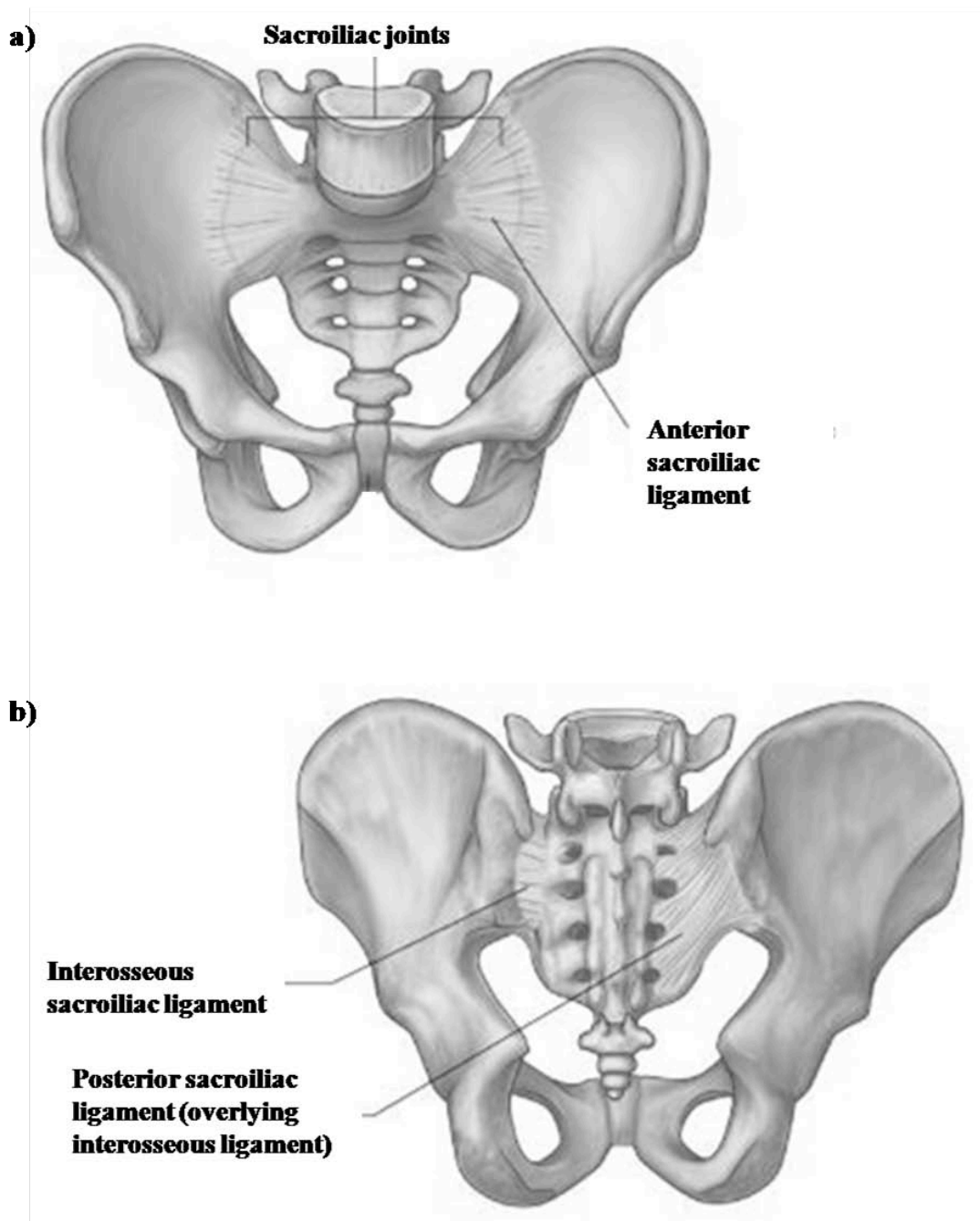


Figure 2.2: Sacroiliac joints and associated ligaments – **a)** anterior and **b)** posterior view.
 [Adapted from Drake *et al.*, 2005]

2006). The inferior fibres of the ligament originate from the S3-S4 region of the sacrum and also insert onto the posterior superior iliac spine and internal lip of the iliac crest. The inferior fibres are also often continuous laterally with part of the sacrotuberous ligament and medially with the thoracolumbar fascia (Andersen, 1986). The anterior sacroiliac ligament is formed by the thickening of the antero-inferior part of the joint capsule (Calvillo *et al.*, 2000; Drake *et al.*, 2005), and is well-developed near the arcuate line and the posterior inferior iliac spine, but thin elsewhere (Rosatelli *et al.*, 2006). The ligament arises from the third sacral vertebra and inserts anterior to the auricular surface of the ilium at the preauricular sulcus (Andersen, 1986). The three ligaments stabilizing the sacroiliac joint are supported by two accessory ligaments, the sacrotuberous and sacrospinous ligaments (Figure 2.3), which restrict movement of the apex of the sacrum (Sashin, 1930). The sacrotuberous ligament passes obliquely from the posterior superior iliac spine, the inferior sacrum and the superior coccyx to the medial margin of the ischial tuberosity. Some of its fibres blend to the inferior fibres of the gluteus maximus and the tendinous portion of the long head of biceps femoris. The sacrospinous ligament is thin and triangular, attaching laterally to the ischial spine and medially to the lateral borders of the sacrum and coccyx, anterior to the sacrotuberous ligament with which its fibres are mixed (Rosatelli *et al.*, 2006). The sacroiliac joint is not crossed by muscles, but it has been shown that training of the muscles in the adjacent areas and those that interdigitate with the sacroiliac ligaments can relieve pain in the joint region (Walker, 1992; Richardson *et al.*, 2002).

The increased secretion of relaxin during pregnancy affects the sacroiliac joint in a similar manner as it does the pubic symphysis (Sashin, 1930; Ohlsén, 1973; Houghton, 1974). The increased laxity of the sacroiliac ligaments allows a forward shift in the position of the uterus, causing increased strain on the back and pelvis (Ritchie, 2003), resulting in a cluster of symptoms clinically referred to as pregnancy-related pelvic girdle pain (Kanakaris *et al.*, 2011). Widening of the joint space occurs in some, but not all pregnant females, with a reported increase of about 4 mm (Ohlsén, 1973; Garagiola *et al.*, 1989). Higher incidence of non-uniform joint thickness has also been reported in females who have had more than three children (Demir *et al.*, 2007). After parturition, the joint returns to its pre-pregnancy state within approximately eight weeks (Brooke, 1924).

2.2. Areas of occurrence of parturition scars

2.2.1. Dorsal pubic surface

Pitting on the dorsal pubic surface is one of the most researched parturition scars (Ubelaker & De La Paz, 2012). Researchers such as Putschar (1931), Stewart (1957) and Angel (1969) were the first

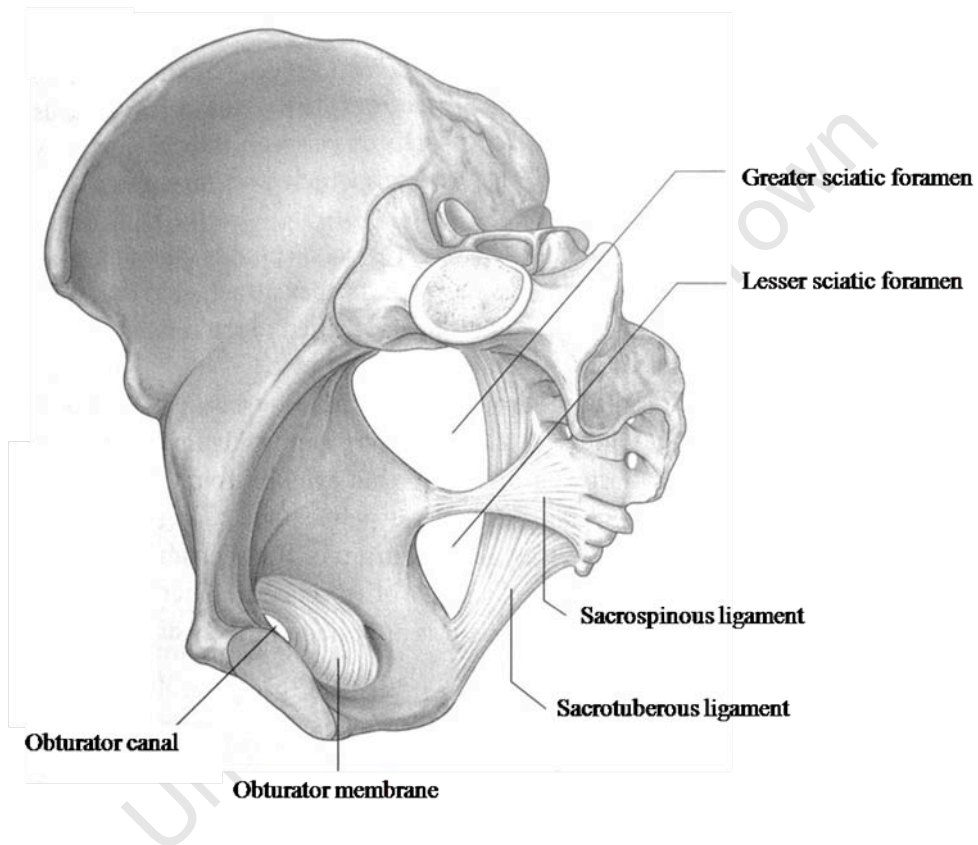


Figure 2.3: Accessory sacroiliac ligaments.

[Adapted from Drake *et al.*, 2005]

pregnancy, as described by Snelling (1870) and Abramson *et al.* (1934). It is suggested that the process of separation of the pubic symphysis under the influence of hormones (such as relaxin) cause the ligaments bridging the symphysis to experience a large amount of strain under the increasing weight of the developing foetus and accompanying increasing lumbar lordosis of the mother (Monaco, 1996; Ritchie, 2003; Borg-Stein *et al.*, 2005; Cunningham *et al.*, 2010). Excessive strain is also placed on these ligaments as the baby moves through the birth canal during labour (Heckman & Sassard, 1994; Borg-Stein *et al.*, 2005). To compensate for this strain, the ligaments become hypertrophic, increasing the size of their insertions onto the bone and causing bone resorption in the area (Putschar, 1931; Stewart, 1957). After several births, the depth and width of the resulting pits increase, eventually fusing to form a large common pit. Later studies by Holt (1978) and Suchey *et al.* (1979) argue that dorsal pubic pitting is not a reliable indicator of parturition.

2.2.2. Pubic tubercle

The extension of the pubic tubercle as an indicator of parity was mentioned in Angel's (1969) original work, but did not receive much attention until the study by Cox (1989). The tubercle, which occurs a few centimetres lateral to the pubic symphysis, is the attachment site of the rectus abdominis muscle and the inguinal ligament, both of which play an important role in containment of the anterior abdomen (Cox & Scott, 1992). In the late stages of pregnancy, the increasing size and weight of the developing foetus place strain on this muscle, causing it to pull at its attachment on the pubic tubercle and extending it (Stewart, 1957; Angel, 1969; Cox, 2000). Cox (1989) reported significant correlation of the number of births with the degree of tubercle extension in the historical Spitalfields sample, but Bergfelder & Herrmann (1980) and Snodgrass & Galloway (2003) could not find similar correlation in modern samples.

2.2.3. Preauricular sulcus

The preauricular sulcus is another widely researched area of parturition scarring, with several studies being performed on dry bone (Derry, 1909; Houghton, 1974 and 1975) and on radiographs (Dee, 1981; Spring *et al.*, 1989). The sulcus appears on the ilium, slightly anterior and inferior to the posterior auricular surface, and is the attachment site of the anterior sacroiliac ligament (Andersen, 1986). During pregnancy, this ligament experiences similar strain as the ligaments at the pubic symphysis and thus the same form of pitting that occurs at the symphysis has been observed in the preauricular region (Houghton, 1974). Several researchers have suggested that pitting in the preauricular sulcus is a more reliable indicator of parity than dorsal pubic pitting (Houghton, 1975;

Kelley, 1979), while others have suggested that it is an indicator of the female sex, rather than of parity history (Dunlap, 1981; Andersen, 1986).

2.2.4. Interosseous groove

The post-auricular sulcus or interosseous groove lies inferior to the iliac tuberosity and superior to the auricular surface on the posterior of the ilium. This groove is formed by the attachment of the interosseous sacroiliac ligament and superficial portions of both the long and short dorsal sacroiliac ligaments (Andersen, 1986). The interosseous ligament plays an important role in the transfer of weight from the trunk to the lower limbs (Brooke, 1924; Andersen, 1986; Scheuer & Black, 2000). Houghton (1974) was the first to notice pitting similar to that at the preauricular sulcus occurring in the interosseous groove, and suggested that the ligaments attached to this area experience the same strain as those of the preauricular sulcus during pregnancy. Only a few studies have examined this region with regard to parturition scarring, mostly because of the difficult position of the area, which makes especially radiographic studies difficult (Walker, 1992), and the fact that the surface is normally roughened to some extent, obscuring many of the potential features of parturition scarring one might want to investigate (Andersen, 1986).

2.2.5. Iliac tuberosity

The iliac tuberosity is a roughened region on the retro-auricular surface of the ilium, and is the attachment site of some of the smaller fibres of the deep accessory sacroiliac, interosseous and dorsal sacroiliac ligaments, as well as some fibres of the iliolumbar ligament (Hadley, 1952; Scheuer & Black, 2000; Pool-Goudzwaard *et al.*, 2001). It is thus expected that the tuberosity may also be modified when the ligaments become lax during pregnancy (Andersen, 1986).

2.2.6. Sacrum

Parturition scarring has also been reported to occur on the sacrum at the attachment sites of the sacroiliac ligaments, but these scars are considered less constant and less reliable than those at other areas of the pelvis (Houghton, 1974; Ullrich, 1975; Andersen, 1986). Pitting is sometimes observed on the smooth anterior surface of the sacrum in the area adjacent to the preauricular sulcus of the ilium, but any possible scars occurring on the posterior of the sacrum are obscured by the naturally rugged appearance of the surface itself (Houghton, 1974; Ullrich, 1975; Kelley, 1979). Ullrich (1975) gave an extensive description of the alterations occurring at the sacrum as a result of pregnancy, providing standard measurements to aid classification of the pitting (Figure 2.4). The

study further provided estimates of the number of obstetric events based on the extent of the sacral pitting. Cox & Scott (1992) found no correlation between parity and the presence of sacral pitting.

2.2.7. Osteitis condensans ilii

Some researchers suggest that the condition osteitis condensans ilii may be a radiographic parturition scar (Wells, 1956; Kurihara *et al.*, 1996). Wells (1956) describes the condition as a “fairly uniform triangular area of increasing density in the lower portion of the iliac bone, adjacent to, but not involving the sacroiliac joint” (Figure 2.5). Wells (1956), Kurihara *et al.* (1996) and Brogdon (1998) reported that the condition is found almost exclusively in parous females, suggesting that it is an indicator of parity. Mitra (2010), however, reported that the correlation between osteitis condensans ilii and parity is not as clear as previously reported, with the condition also being present in several males and nulliparous females. Mitra further refers to other studies that suggest that the condition may be caused by the weight of the gravid uterus compressing the abdominal aorta, resulting in ischemia in the inferior ilium (Hare & Haggart, 1945; Nicholas, 1975). Despite his support of osteitis condensans ilii as a parturition scar, Wells (1956) also reported association of the condition with urinary tract infection and back pain.

2.2.8. Bone microstructure

Mensforth & Lovejoy (1985) noted a reduction of the mid-shaft femoral cortex in females in their third decade of life, with a higher density being restored by the middle of their fourth decade, but gradually decreasing thereafter. These changes are thought to represent calcium stress increased by the increased nutritional demands of pregnancy and lactation (Weaver, 1998; Cox, 2000). Theoretically, changes to bone microstructure may reflect parity, but there are many factors complicating its use. Goldsmith & Johnston (1979) found that certain types of oral contraceptives may lead to increased bone mineralization if used during or following lactation. The relationship between pregnancy, lactation and bone structure is complex and is greatly influenced by dietary or behavioural factors (Weaver, 1998). Studies have shown that an increase in the number of pregnancies leads to increase bone mass, but they also show that prolonged lactation can decrease bone mass (Sowers, 1996). These complicating factors mean that the use of this method to infer parity is restricted to those females who died in the fecund period, but even in such females, the method is not completely diagnostic (Weaver, 1998; Cox, 2000; Ubelaker & De La Paz, 2012).

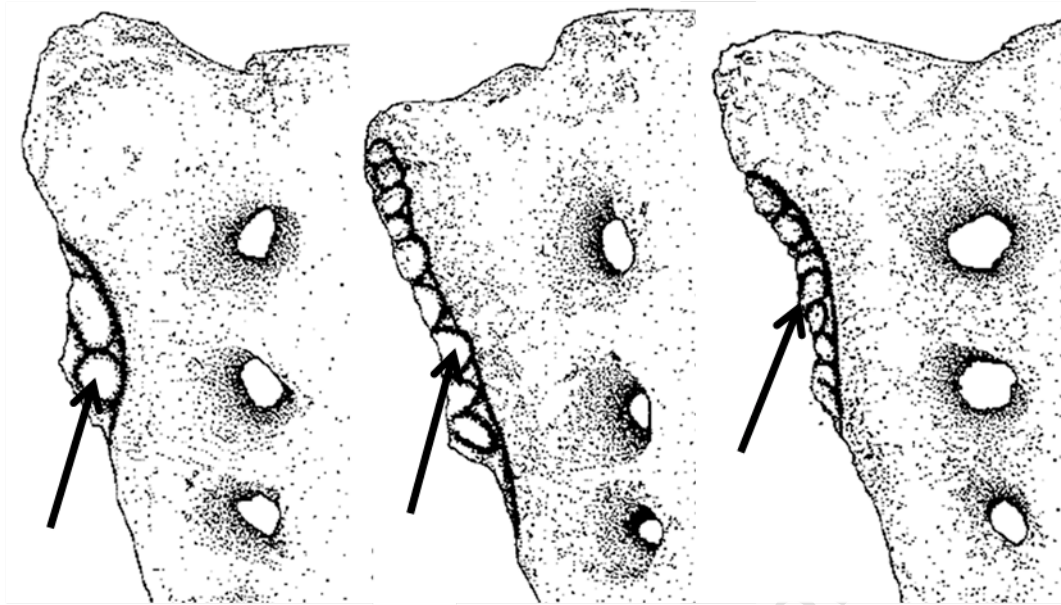


Figure 2.4: Anterior view of the right hemisection of the sacrum, showing three of Ullrich's (1975) stages of classification of parturition scarring at the lateral sacral borders (indicated by arrows).

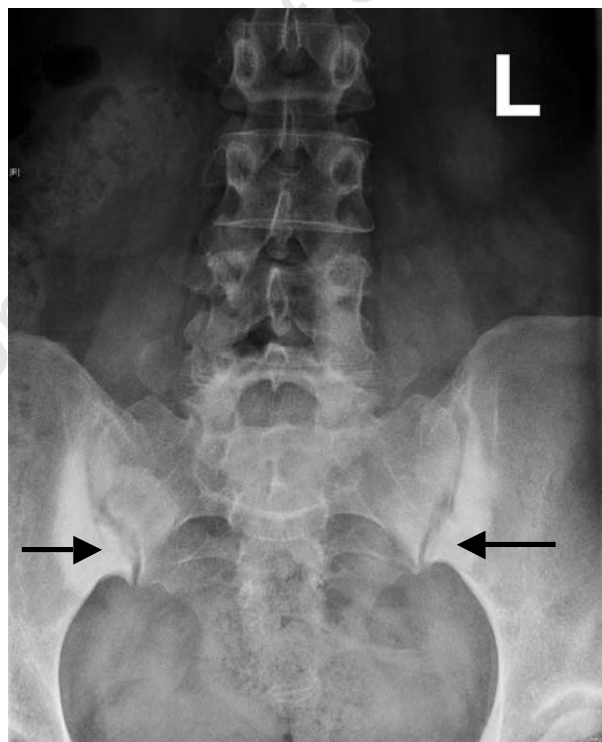


Figure 2.5: Characteristic triangular appearance of bilateral osteitis condensans ilii (indicated by arrows). [Adapted from Mitra, 2010]

2.3. Previous studies

2.3.1. Early studies (Pre-1969)

As early as 1909, Derry noted that the preauricular sulcus of females showed pitting and sharp overhanging edges, compared to the sulcus of males which tended to be small and smooth. Derry proposed parturition as a possible explanation for this difference between the sexes. Though the concept was not new, previous studies attributed the variation in pelvic features to racial differences and thus went mostly unnoticed (Ubelaker & De La Paz, 2012). In 1957, while examining age estimations based on the pubic symphysis, Stewart found that female ages tended to be overestimated. He attributed this to parturition-related changes to the anterior pubic surface due to reinforcement of muscle attachments, and the posterior pubic surface along the symphyseal margin due to reinforcement of ligamentous attachments. Stewart's theory was supported by the work of Snelling (1870), Sashin (1930) and Abramson *et al.* (1934), which have shown increased ligamentous laxity with increased levels of secretion of the hormone relaxin during pregnancy. Although the studies of Derry and Stewart suggested a connection between parity history and the alterations observed on the pelvic girdle, the concept remained unnoticed until 1969, when Angel published *The Bases of Paleodemography*.

2.3.2. Angel (1969)

Angel's *The Bases of Paleodemography* (1969) did not specifically focus on parturition scarring, as it was only one of several demographic indicators discussed in the article. Angel did, however, claim that parity history could be estimated "from pelvic bony changes resulting from childbirth". He suggested that changes are most clearly seen around the pubic symphysis due to stresses to the muscle and tendinous attachments of anterior abdominal muscles such as rectus abdominis, and the stretching and tearing of the arcuate and interpubic ligaments during birth. Using Stewart's (1957) skeletal data of Eskimo females of known parity, he further claimed that the number of children that an individual had could be estimated from the extent of scarring, but provided no supporting evidence for this claim. One of the females examined, reported to have had only two children, showed more severe scarring on the dorsal pubic surface than Angel's method would suggest. Angel's explanation for this observation was that this individual "clearly has had more actual births than stated or else is pathological". Despite the lack of evidence of direct association between parity history and parturition scarring, the forensic potential of the method appealed to many scientists. One such example is seen in *The Fisherman from Barum – Mother of Several Children!* (Gejvall, 1970). Gejvall had consulted Angel regarding estimation of the sex of a 9000 year old skeleton, by

sending him several photographs of the individual. Angel's deduction was that this skeleton, originally thought to be male, was actually that of a female and according to the presence of parturition scarring, had given birth to between ten and twelve children (Gejvall, 1970). In the years that followed, several studies were published aiming to simplify Angel's method. One such study was that of Acsádi & Nemeskéri (1970), which described five stages of classification of alterations, each associated with an estimated number of births.

2.3.3. Stewart (1970)

Stewart (1970) examined the pubic symphysis of 205 female skeletons from the Terry collection (see Appendix D for a brief description of this collection) in order to evaluate the possible influence of modern gynaecological practices on the severity of parturition scars. He classified dorsal pubic scars as either "trace to small" or "medium to large". The results of the study showed that some females who have had children showed little or no scarring but some who have not had children do show scarring. Stewart strongly cautioned the use of scars to assess parity history, stating that "probably it will never be possible to associate accurately the degree of scarring with the true number of complete pregnancies". He further suggested that obstetric practices and age at first delivery may play an important role in scar formation. Despite these criticisms, Stewart proposed that instead of discarding the method entirely, it simply required further investigation. Ignoring Stewart's cautions, Angel continued to use parturition scarring as an indicator of childbirth, describing such alterations in some of his later work on archaeological skeletons from Greece (1971).

2.3.4. Gilbert & McKern (1973)

Though the study by Gilbert & McKern (1973) focussed on age-related changes to the female pubis, it also provided evidence supporting Stewart's (1970) cautions against the use of parturition scars. The skeletal material used in this study consisted of a large sample of modern females (n= 140) from the Hamann-Todd Collection (see Appendix D for a brief description of this collection), and like Stewart's study, the authors reported several cases where scarring was more severe in females with only one child than others with many more children. Unlike Stewart, Gilbert & McKern more expressly rejected the possibility that the number of pregnancies could be determined from parturition scars alone. The study further pointed out that other factors such as the size of the foetus, size and shape of the pelvis and obstetrical practices may also influence scar manifestation.

2.3.5. Houghton (1974 and 1975)

Up until the mid 70s, most studies focussed on alterations at the pubic region. Houghton (1974) was the first to provide a detailed description of the alterations occurring at the preauricular surface. He described two forms of the sulcus: the groove of the ligament (GL) and the groove of pregnancy (GP). Houghton reported that the GP form was found only in females and must thus be indicative of parity. The study also examined the alterations at the pubis, but claimed that these were not as definitive as those at the preauricular sulcus, possibly due to the sulcus being more in the direct line of weight-bearing. Houghton pointed out several other important concepts in his two publications. He was the first to mention the possibility of similar changes occurring at the attachment site of ligaments at the interosseous groove and on the sacrum, but stated that these alterations are harder to detect due to the normal ruggedness of these sites. He further mentioned that age-related changes to the bone may obscure parturition scars and make classification of the features difficult, and noted that pitting on the dorsal pubic surface is less conspicuous in modern populations, possibly due to improved health care and reduced physical activity during pregnancy.

2.3.6. Ullrich (1975)

Ullrich (1975) combined the work of Angel (1969), Acsádi & Nemeskéri (1970) and Houghton (1975) by using the parturition scarring occurring at the anterior and posterior pubic surfaces, ilium and sacrum to estimate the number of children borne by an individual. The study provided detailed descriptions of alterations to each of these areas in 77 female skeletons from the Slavic cemetery of Sanzkow in Germany, with a classification system for the different appearances of the sites and an associated estimate of the number of births. Ullrich's study was, however, very flawed. The study proposes a classification system to help in the estimation of number of births, yet the sample used in the study was of unknown parity history and included "several" juveniles. Despite providing estimates of number of births and claiming that these alterations "can be diagnosed with adequate certainty", Ullrich concludes the study by stating "for the time being, the association of a certain number of childbirths with the respective stages must, however, remain largely hypothetical".

2.3.7. Holt (1978)

Holt's (1978) examination of 68 females of known parity history from the Hamann-Todd collection (Appendix D) was the first systematic evaluation of the usefulness of parturition scars on the dorsal pubis as indicators of parity history. A large percentage of nulliparous females in this study presented with some form of dorsal pubic scarring, yet no statistically significant difference was detected between the parous and nulliparous groups in terms of frequency, size or shape of the

scars. Holt noted that the nulliparous females who did show scarring had high incidences of pathological conditions and obesity, and thus proposed that these factors may be more important in scar formation than pregnancy itself.

2.3.8. Suchey et al. (1979)

Suchey *et al.* (1979) examined the remains of 486 modern American females from the Los Angeles County Department of Chief Medical Examiner-Coroner's office, for whom parity history was known, using Stewart's (1970) classification of dorsal pubic pitting. The study evaluated the relationship between the degree of scarring and the number of full-term pregnancies, interval since last pregnancy, and age of descent. The association between the number of pregnancies and the size of pubic pitting was significant but not strong ($r= 0.38$), with several nulliparous females showing pitting and several parous females showing no pitting. Scarring was also found to increase with age, but decrease with the interval since pregnancy. The authors present the conclusion that the morphology of pitting cannot be used to estimate the number of pregnancies, due to the large influence of other factors such as age.

2.3.9. Kelley (1979)

Kelley (1979) attempted to improve on the Holt (1978) study by examining 198 females from the Hamann-Todd collection (Appendix D) with known parity history. The study examined dorsal pubic pitting, the preauricular sulcus and the interosseous groove. The results show that although dorsal pubic pitting is uncommon in both parous and nulliparous females, the percentage of parous females presenting with pitting was larger than that of nulliparous females. Kelley used Houghton's (1974) GL or GP classification of the preauricular sulcus and found that the GP form was more common in parous than nulliparous females, but still not completely diagnostic of parity status. The results of the interosseous groove were similar, with larger percentages of parous females showing the developed form of the groove than the nulliparous females did. Kelley suggested that combining the assessment of these three areas increased the reliability of assessment, though still not making it completely diagnostic. He further emphasised that other factors such as hormone levels and age may affect the appearance of scarring. Kelley concludes that the scarring cannot be used to determine parity history, and that judgement other than "parturition" or "no parturition" is unjustified.

2.3.10. Bergfelder & Herrmann (1980)

Bergfelder & Herrmann (1980) performed a study on 49 pairs of pubic bones of modern European females, of which parity history was known, to test the classification system of parturition scars proposed by Ullrich (1975). The results of this study disagreed with Ullrich's claims at almost every area of scarring. Ullrich claimed that larger number of births led to increased development of exostoses and protrusions (including the pubic tubercle) on the anterior surface of the pubis. This study found no connection between the appearance of the surface and number of births. On the posterior pubis, Ullrich claimed that every parturition event will produce small cavities which will eventually fuse into one large cavity, but Bergfelder and Herrmann showed that while the size of the cavities on this surface increase with increasing number of births, the changes were not consistent. Scarring often differed between the left and right pubis of the same individual and was sometimes present on nulliparous females or absent in multiparous females. An interesting observation made by the authors of this study, which was only alluded to in previous studies, was that scarring was also present in cases of miscarriage, thus scarring was not necessarily from the birth event itself, but also from the stresses occurring in the months leading up to it. The authors agreed with previous studies that age and pelvic structure may greatly influence scar manifestation. Similar to Kelley (1979), they proposed that the absence of scarring should be interpreted as zero to few births, moderate scarring as several births and severe scarring as many births. The study again emphasised that the exact number of births could not be estimated from parturition scars.

2.3.11. Owsley & Bradtmiller (1983)

In 1983, Owsley & Bradtmiller published a study on female mortality in skeletons of historic Native Americans. The authors assessed the parity history of the two females described in this study by examining alterations to the pubis and preauricular sulcus. They also recorded the presence of Schmorl's nodes which are depressions or erosions that form as a result of the protrusion of the nucleus pulposus of an intervertebral disc (usually caused by trauma) onto the adjacent vertebral body. Schmorl's nodes were observed on the vertebrae of both females, but without any signs of trauma or arthritic changes the surrounding area of the vertebral column. The authors interpreted this as a possible indicator that Schmorl's nodes (in the absence of other modifications to the area) may be a parturition scar itself. It is suggested that the continued stress of pregnancy, possibly combined with lactation from a previous pregnancy, may have weakened the vertebral bodies of these individuals to such an extent that their daily activities may have been enough to cause node formation. While the authors found this observation "most tentative", they were also careful to caution the use of nodes alone to infer parity history. They note that the increased lumbar lordosis and thoracic kyphosis in a pregnant individual may predispose vertebrae to node formation, and

suggested that nodes be used in combination with parturition scars on the pelvis. Their cautions were supported by Weinreb *et al.* (1989), which demonstrated that herniations of the intervertebral disc are normal in all females of childbearing age, not only pregnant ones, thus nodes cannot be used as indicative of parity history.

2.3.12. Tague (1985 and 1988)

Tague examined bone resorption at the preauricular sulcus and dorsal pubis. Both studies showed that dorsal pubic pitting was correlated to parity, but not to age, and that pitting in the two regions is independent. Unfortunately, like Ullrich (1975), Tague used an archaeological sample for which no parity data is available, thus true correlation of scarring to parity cannot be determined from this sample.

2.3.13. Andersen (1986)

To test the reliability of parity determination from skeletal remains, Andersen (1986) examined parturition scarring at several sites of the pelvic girdle in 151 females of known parity, as well as a control sample of 87 males from the Hamann-Todd collection (Appendix D). The alterations were described both in terms of categorical descriptions from the literature and using metric observations. Andersen found that scarring at the dorsal pubis, preauricular sulcus and interosseous groove were not reliable indicators of parity, especially as male individuals often also showed similar alterations in these areas, and that scarring may be age-related. Like many studies before, Andersen observed that scarring may be present in nulliparous females or absent in parous females. She suggested that pelvic flexibility may be a better explanation for scar formation, demonstrating that female pelvises are more flexible than those of males. This might indicate that female pelvic girdle ligaments have larger attachment sites to prevent excess movement and provide stability of the girdle. Lastly, she discussed several other factors such as occupational stresses, obesity and trauma which may affect scar manifestation. Andersen's study was very important as it was the first to examine scarring in a large sample of known parity and also the first to test for correlation between scars and pelvic flexibility.

In the year following Andersen's study, an article by Angel *et al.* (1987) did not use scars to estimate the number of births as part of their analysis of a historic sample from Philadelphia, as Angel had done in many of his previous studies. The study did, however, suggest that increased number of births were detected through the observations discussed in Angel's previous publications.

2.3.14. Spring et al. (1989)

Spring *et al.* (1989) took a different approach to examining alterations at the preauricular sulcus by examining radiographs of the sulcus area before and after parturition in a small sample of six female patients of the Kaiser Permanente Medical Center in the United States of America. Comparison of the radiographs showed no change in the appearance of the sulcus. The rest of the study followed the traditional design of comparing nulliparous females to parous females and to males. The results show that while deep sulci were strongly correlated to the female sex, the appearance of the sulcus was not correlated to past parity.

2.3.15. Cox (1989) and Cox & Scott (1992)

In her doctoral dissertation and a later journal article, Cox described alterations to the preauricular sulcus, dorsal pubic surface, pubic tubercle and sacrum of 94 females of known parity from the 18th century Christ Church, Spitalfields collection (see Appendix D for a brief description of this collection). The results of the study showed that scarring at the preauricular sulcus and sacrum were independent of obstetric events, and while a few females with either dorsal pubic pitting or extension of the pubic tubercle were parous, the absence of these features was found in both parous and nulliparous females. Cox also noted that alterations were found more frequently in larger pelves, contrary to the expectation that smaller pelves would exhibit more scarring due to the increased expectation of trauma during childbirth.

2.3.16. Galloway (1995) and Galloway et al. (1998)

Galloway (1995) strongly cautioned the use of parturition scars for forensic applications, pointing out that many other cultural and temporal changes such as birth rates and obstetric care may influence scarring. A few years later, Galloway *et al.* (1998) examined some of the factors that may affect scar manifestation in a modern sample from the Los Angeles County Coroner's Office with known age, stature, weight and parity information. The study included measurements of the height and width of the pubic symphyseal area, height and width of the pubic tubercle and the retropubic angle, while pitting on the dorsal pubis was classified according to Ullrich's (1975) method. The results of the study showed that dorsal pubic pitting increased with reported births, but also with longer pubic bones. Pitting was also negatively correlated to stature. This study was significant because it was the first to test the effect of difference in body size on scar manifestation, rather than just stating it as a contributing factor.

2.3.17. Snodgrass & Galloway (2003)

Snodgrass & Galloway (2003) examined dorsal pubic pitting and pubic tubercle height and distance from the symphyseal margin in a sample of 148 modern females of known parity status, obtained from the Los Angeles County Coroner's Office. They found that the number of births was not correlated to the height of the tubercle, but that the tubercle height and distance were significantly correlated to each other. The degree of dorsal pubic pitting was also found to be correlated to the number of births, but was strongly influenced by age and body size. Despite the observed correlations, the authors claimed that the significance of these correlations was not sufficient for forensic application. Lastly, the authors also mentioned the possible influence of hormone levels, infant and maternal size, obstetric practices and activity levels during pregnancy on scar formation.

2.4. Factors possibly influencing or associated with parturition scar manifestation

The pelvic girdle is a complex structure with many dimensions and functions. It is possible that factors other than parturition (especially those affecting pelvic morphology) may cause or alter the manifestation of parturition scars (Holt, 1978; Suchey *et al.*, 1989). Thus it is important for any study examining parturition scars to take such possible factors into consideration.

2.4.1. Age

Several studies have reported that the age of a woman at the time of her first pregnancy may affect parturition scarring (Kelly, 1979; Suchey *et al.*, 1979; Bergfelder & Herrmann, 1980; Tague, 1988; Snodgrass & Galloway, 2003). Early pregnancy may affect the shape of the pelvis if the epiphyses of the pelvic girdle have not yet sufficiently fused (Ashworth *et al.*, 1976; Abitbol, 1987; Driscoll, 2010). An increased risk of complications such as cephalopelvic disproportion is also reported for young females (McKenry *et al.*, 1979; Van Bogaert, 1999). Both of these factors may cause trauma-related parturition scarring on the bones of the pelvis. Many studies also report that age-related remodelling of the bone may obliterate existing scarring over time (Houghton, 1974 and 1975; Kelley, 1979; Bergfelder & Herrmann, 1980). Other studies report that structural changes to the pelvic girdle, such as decreasing pubic angle (Tague, 1989; Galloway *et al.*, 1998) or increased joint rigidity (Putschar, 1931 and 1976; Walker, 1992; Rosatelli *et al.*, 2006), may either cause or enlarge scarring. The most commonly affected parturition scar appears to be dorsal pubic pitting (McKern & Stewart, 1957; Acsádi & Nemeskéri, 1970). Suchey *et al.* (1979) found that nulliparous females

older than 30 years more frequently exhibit pitting than those that are younger. Andersen's (1986) study suggested that age may especially influence the formation of dorsal pubic pitting in males, but could not test this statistically due to small sample sizes. Cox (1989) and O'Connell (2004) demonstrated that pelvic size increases with age. Cox (1989) further found correlation of both parturition scars and age to larger pelves, i.e. older individuals tend to have larger pelves with more scarring. Snodgrass & Galloway (2003) showed that dorsal pubic pitting and pubic tubercle height were strongly correlated to age and body mass index, proposing that these changes are related to changes in hormone levels which may influence the stability of the girdle and in turn parturition scarring.

2.4.2. Body and pelvic size

Many of the studies examining the manifestation of parturition scars point out that body size may be an important contributor to scar formation (Gilbert & McKern, 1973; Wells, 1975; MacLaughlin & Cox, 1989; Snodgrass & Galloway, 2003), though very few studies have tested this possible relationship. It is suggested that if scarring is related to obstetrical events, one would expect more severe scarring on smaller pelves due to their reduced capacity and associated increased risk of obstruction (Cox, 1989). Measurements such as pelvic diameters, stature and body mass have been used as a means to predict pelvic capaciousness (Caldwell & Moloy, 1933 and 1938; Van Bogaert, 1999; Kurki, 2007).

Measurement of pelvic dimensions is the most direct way to predict pelvic capaciousness. The birth canal is often divided into the inlet plane, the midplane and the outlet plane. The pelvic inlet plane is bound by the superior borders of the pubic symphysis and pubic rami, the sacral promontory and alae, and the iliopectineal lines and eminences (Cunningham *et al.*, 2010). This plane is the most obstetrically important, as it is the site where the foetal head normally engages with the pelvis. The anteroposterior diameter of the inlet is especially important as it is the plane through which the biparietal diameter of the foetal head has to pass (Correia *et al.*, 2005). The biparietal diameter of the foetal head is smaller than its fronto-occipital diameter, but deformation of the fronto-occipital diameter is less harmful to the neonate than that of the biparietal diameter (Borell & Fernström, 1958). The transverse diameter of the inlet is not as important as the anteroposterior, but still plays a role in the determination of the birth canal shape and accommodates the fronto-occipital diameter of the foetal head during labour (Correia *et al.*, 2005; Basavanthappa, 2006). The midplane of the pelvis is bound by the pubic bones, sacral hollow, bodies of the ischium and part of the ilium, greater sciatic notches and the obturator foramen (Cunningham *et al.*, 2010). In this plane, the interspinous diameter of the pelvis occurs. This diameter is the most obstetrically significant

measurement of the pelvis, as it is usually the smallest and therefore the most common site of obstruction during labour (Correia *et al.*, 2005; Basavanthappa, 2006). The foetus thus has to rotate in its progress from the inlet to the midplane, so that the fronto-occipital diameter of its head aligns with the widest diameter of the midplane, which is at a right angle to that of the inlet (Walrath, 2003; Correia *et al.*, 2005; Driscoll, 2010). The outlet plane of the pelvis is difficult to describe because of its irregular outline (Emmons, 1913), and is anatomically bound by the coccyx, sacrotuberous ligaments, ischial tuberosities and the inferior border of the pubic symphysis (Cunningham *et al.*, 2010). The diameters of this plane are not as important as those of the inlet and midplanes, as no rotation of the foetus is required (Correia *et al.*, 2005). The fronto-occipital diameter of the foetal head passes through the anteroposterior diameter of the outlet plane, with the fragile biparietal diameter of the foetal head passing through the transverse diameter (Correia *et al.*, 2005; Driscoll, 2010). Caldwell & Moloy (1933 and 1938) and several other researchers (Turner, 1885; Thoms, 1937) used measurements of the pelvic inlet to classify the shape of the pelvic canal. They suggested that each of the four pelvic shapes had its own inadequacies and required its own obstetric approach. Measurement of the pelvic dimensions in living patients, however, was found to be problematic (De Souza, 1913), and thus focus shifted to using maternal stature as an indicator of pelvic capaciousness.

Measurement of stature is considered a simple and objective method commonly used by maternal care practitioners as a means to assess pelvic capaciousness (Thomson, 1959; Awonuga *et al.*, 2007). The correlation between stature and pelvic dimensions makes it a practical alternative to direct pelvic measurements, especially in living patients (Bernard, 1952; Basavanthappa, 2006; Ridgeway *et al.*, 2011). The relationship between stature and labour complications such as cephalopelvic disproportion has been well-documented (Thomson, 1959; Van Bogaert, 1999; Kurki, 2007), with taller individuals reported as less likely to require medical intervention during labour (Bernard, 1952; Savona-Ventura *et al.*, 2008). Tague (2000) suggested that within a population there may be a threshold stature below which adequate pelvic size is difficult to achieve, regardless of the size of the mother or foetus. Generally, females shorter than about 150 cm are considered as having the highest risk of complications (Bernard, 1952; Van Bogaert, 1999; Basavanthappa, 2006), but as Van Bogaert (1999), Awonuga *et al.* (2007) and Benjamin *et al.* (2011) argue, a single standard may not be applicable to all populations and thus stature may not be sufficiently reliable for diagnosis. Kurki (2007) also demonstrated that pelvic dimensions may be protected in populations such as Later Stone Age foragers to ensure pelvic adequacy, i.e. the pelvic dimensions of smaller-bodied populations are proportionately larger in relation to their body size to allow the birth canal to be large enough for the mature foetus to pass through.

Similar to stature, maternal weight is considered a good indicator of pelvic capaciousness and is one of the measurements commonly made by maternal care practitioners (Awonuga *et al.*, 2007). Tague (2000) demonstrated that femoral length (as a proxy for stature) has limited association with pelvic capacity, but that proxies for body mass such as clavicular length and femoral head diameter show higher correlation to pelvic capacity. This suggests that body mass may be a more suitable predictor of capaciousness. Similar correlations of body mass to pelvic dimensions have been shown by Rosenberg (1988), while Savona-Ventura *et al.* (2008) reported higher incidence of medical intervention required in obese individuals.

Few studies have examined the relationship between parturition scarring and body size, but the results tend to suggest that body size indeed influences scar manifestation. Galloway *et al.* (1998) found that dorsal pubic pitting is positively correlated with larger pubic bones, but negatively correlated to stature. She further noted correlation between the height of the pubic tubercle and the size of the arcuate angle, which may also be influenced by the length of the pubic bones. Snodgrass & Galloway (2003) found significant correlation between stature and the distance of the pubic tubercle from the symphyseal margin, and between dorsal pubic pitting and the body mass index of older females. Cox (1989) found that scarring was generally associated with larger pelves, contrary to the expectation that scarring would be more common in smaller pelves. This suggests that something other than parturition may be responsible for scar formation. A major drawback of body size estimates is that they are subject to strong environmental influences (Zuckerman *et al.*, 1983; Sibley *et al.*, 1992; Nuger, 2008).

2.4.3. Other potential influences

There are many environmental and genetic factors that affect the shape of the pelvis and thus potentially also parturition scar formation. Studies have shown the effect of diseases such as scoliosis, tuberculosis, rickets, polymyelitis, congenital hip dislocation and spondylolisthesis, which can cause pelvic asymmetry or reduction of certain pelvic dimensions (Emmons, 1913; Wells, 1975; Scheuer & Black, 2000; Basavanthappa, 2006). Poor nutrition, especially in the foetal and early childhood periods, is often also cited for flattening of the pelvic inlet (Emmons, 1913; Allbrook, 1962; Angel, 1978; Cook, 1984; Driscoll, 2010). Obstetric practices may also affect the manifestation of scarring, as the higher frequency of caesarean sections in recent years may reduce the incidence of birth-related trauma to the pelvis (Stewart, 1957; Andersen, 1986; Schemmer *et al.*, 1995; Driscoll, 2010). A recent study by Nuger (2008) shows that climate may influence pelvic shape, with females living in colder climates being larger than those living in warmer climates, and thus having larger pelves and larger infants. Genetics and ancestry may affect pelvic shape, with

several studies reporting smaller pelves in American Black individuals than American White individuals (İşcan, 1983; İşcan & Cotton, 1985; Baragi *et al.*, 2002; Tague, 2007; Giroux & Wescott, 2008; Driscoll, 2010). Activity patterns involving hard labour, prolonged crouching or sitting are also reported to reduce certain pelvic dimensions (Emmons, 1913; Sibley *et al.*, 1992; Schemmer *et al.*, 1995; Abitbol, 1996; Driscoll, 2010).

2.5. Summary

Andersen (1986) suggested that, contrary to the widely accepted belief that parturition causes scarring on the pelvic bones, these scars are actually the result of variable pelvic flexibility. The ligaments of the pubic symphyseal and sacroiliac joints of the pelvis play an important role in maintaining stability of the pelvic girdle to allow weight transfer from the trunk to the lower limbs (Calvillo *et al.*, 2000; Scheuer & Black, 2000). Hormones such as relaxin cause these ligaments to become increasingly lax during pregnancy, resulting in the widening of the joint spaces (Ohlsén, 1973; Houghton, 1974; Borg-Stein *et al.*, 2005). It is this widening and the accompanying remodelling of the ligaments to accommodate the increased strains of pregnancy that are presumed to be the cause of parturition scarring on the bones of the pelvic girdle. Some researchers have proposed that these bone alterations can be used to assess the parity history of an individual (Angel, 1969; Houghton, 1974 and 1975; Ullrich, 1975; Kelley, 1979). Although these alterations have been shown to be associated with parturition and other related events, other factors such as age, body size and physical activity have also been shown to contribute to similar changes (Gilbert & McKern, 1973; Cox, 1989; Sibley *et al.*, 1992; Snodgrass & Galloway, 2003; Driscoll, 2010). Despite the extensive literature regarding parturition scars, none of the proposed scar features have yet been shown to be indisputably diagnostic of pregnancy or parturition. Many studies that have investigated parturition scarring showed little, if any, evidence for their conclusions. Only a few studies have used individuals of known parity history, and these often report on scarring in one or two areas of the pelvis only or do not investigate the influence of other factors that may affect scar manifestation. Despite the cautions of the reliability of scars as indicators of parity, several anthropologists, archaeologists, palaeopathologists and palaeodemographers still continue to use this method, possibly because of the great potential value of being able to assess parity history from skeletal remains only (Andersen, 1986; Ubelaker & De La Paz, 2012). The possibility still remains that accurate predictive methodology could be developed through research on remains of known parity history, using an approach that combines observation of features such as pelvic size and morphology, with consideration of both cultural and temporal factors (Ubelaker & De La Paz, 2012).

MATERIAL AND METHODS

3.1. Study sample

Skeletal remains from the Universities of Cape Town and of Stellenbosch skeletal collections were examined. The combined sample consisted of 391 individuals (230 males and 161 females). Selection criteria for these individuals were skeletal maturity and relative completeness of the innominates (i.e. most areas under investigation being present). Individuals showing pathology in any of the areas of interest were excluded from this study. Individuals were divided into broad age groups similar to those suggested by Buikstra & Ubelaker (1994), namely “young adult” (20-35 years), “middle adult” (36-50 years) and “old adult” (older than 50 years). The only modification made was that the latter group was divided into “old adult” (51-65 years) and “very old adult” (older than 65 years). A cut-off of 20 years was used as the point of skeletal maturity, and thus all individuals younger than 20 years were excluded. Individuals were also divided into three comparative groups based on the period in which they lived, namely archaeological, historical and modern (described in more detail below). A summary of the age and sex group distribution of the sample is given in Table 3.1.

3.1.1. Archaeological sample

The archaeological sample of this study consists of the remains of Later Stone Age (LSA) foragers, dating over one million years BP, that were accidentally discovered in the southern and western coastal regions of South Africa and excavated by the South African Heritage Resources Agency (SAHRA) or other appointed teams. The Universities of Cape Town and Stellenbosch often serve as a storage facility for these remains. Data regarding the age and sex of the individuals examined in the present study were gathered from work by Morris (1992), and Sealy & Pfeiffer (2000). In the cases where this data had not been previously recorded, standard age and sex estimation techniques, based on pelvic and cranial morphology, were used (Suchey *et al.*, 1986; İşcan *et al.*, 1993; Buikstra & Ubelaker, 1994; Igarashi *et al.*, 2005).

3.1.2. Historical sample

The historical sample of this study consists of skeletal remains from the Cobern Street and Marina Residence burial sites that were accidentally discovered as a result of recent urban development in the Green Point area in Cape Town (Friedling, 2007). Both sites date from the 18th and 19th centuries and reflect the poorer groups of the Cape society at the time. The Archaeology Contracts

Office of the University of Cape Town oversaw both excavations and the skeletal material is currently housed in the Department of Human Biology at the University of Cape Town. Data regarding the age and sex estimates of these individuals were obtained from Friedling (2007) and Manyapelo (2007).

3.1.3. Modern sample

The modern sample consisted mostly of the skeletal remains of individuals that have donated their bodies to the Faculties of Health Sciences of the University of Cape Town and Stellenbosch. Unclaimed skeletal remains of forensic cases brought to the Department of Human Biology at the University of Cape Town by the South African Police Service for analysis were also included in the sample. The individuals included in the sample (of either cadaveric or forensic origin) are mostly from individuals that have lived in the Western Cape Province of South Africa within the past 40 years, while a small proportion of the sample consisted of individuals from other areas of South Africa. Data regarding the age and sex of the individuals of cadaveric origin were obtained from the accession registers of the collections where they are housed, while standard age and sex estimation techniques (Suchey *et al.*, 1986; İşcan *et al.*, 1993; Buikstra & Ubelaker, 1994; Igarashi *et al.*, 2005) were used for individuals of forensic origin.

Table 3.1: Summary of the study sample composition according to time period and age group classifications.

Time period	Archaeological		Historical		Modern		TOTAL
	Males	Females	Males	Females	Males	Females	
Age group							
Young adult	13	11	5	5	28	20	82
Middle adult	12	7	12	7	36	35	109
Old adult	2	1	2	1	55	27	88
Very old adult	0	0	0	1	65	46	112
TOTAL	27	19	19	14	184	128	391

3.2. Data collection

A data collection form (Appendix A) was completed for each individual. The measurements used are described in more detail below. All measurements were made by the author alone, using the same digital sliding caliper (with a depth gauge) and osteometric board. Older studies, such as those of Stewart (1970), Ullrich (1975), Holt (1978) and Kelley (1979) tend to have used a morphological approach when examining the degree of scarring, while more recent studies prefer a metric approach (Andersen, 1986; Snodgrass & Galloway, 2003). In the present study it was decided to use

a combination of the two methods by first measuring the features of interest and then using these measurements to classify individuals into defined categories, thus providing both improved accuracy of classification and sufficient descriptive information regarding the appearance of the features as discussed by Ebrahim & Sullivan (1995) and Eufinger *et al.* (1997). Individuals were examined in exactly the same manner, irrespective of age and sex. Where applicable, measurements were taken from both left and right sides and statistically analysed to determine whether there was a significant difference between the two sides. This was found not to be the case, and thus, according to convention (Buikstra & Ubelaker, 1994), only the measurements of the left side were used for further analysis.

3.2.1. Dorsal pubic surface

An example of typical pitting on the dorsal pubic surface is shown in Figure 3.1. The maximum diameter of the pitted area was measured and each individual was then classified according to the standards of Stewart (1970):

- Absent
- Trace to small: pits or depressions not exceeding 2.0 mm in diameter.
- Medium to large: well-defined pits with a diameter exceeding 2.0 mm.

3.2.2. Pubic tubercle

The height of the pubic tubercle, defined by Snodgrass & Galloway (2003) as the maximum height that the tubercle protrudes from the bone on the ventral side of the pubis, was measured (Figure 3.2). This measurement was then used to classify the extension of the tubercle into one of the following categories for tubercle height:

- Small: < 1.0 mm
- Medium: 1.0 mm – 3.0 mm
- Large: > 3.0 mm

3.2.3. Preauricular sulcus

The location of the preauricular sulcus is shown in Figure 3.3. The maximum depth and maximum width of the preauricular sulcus was measured and used to classify the appearance of the sulcus into one of the following categories (Figure 3.4):

- Absent/ Broad-shallow: < 3.0 mm deep
- Narrow-shallow: 3.0 mm – 5.0 mm deep
- Defined: > 5.0 mm deep, but < 10.0 mm wide
- Complex: > 5.0 mm deep and > 10.0 mm wide

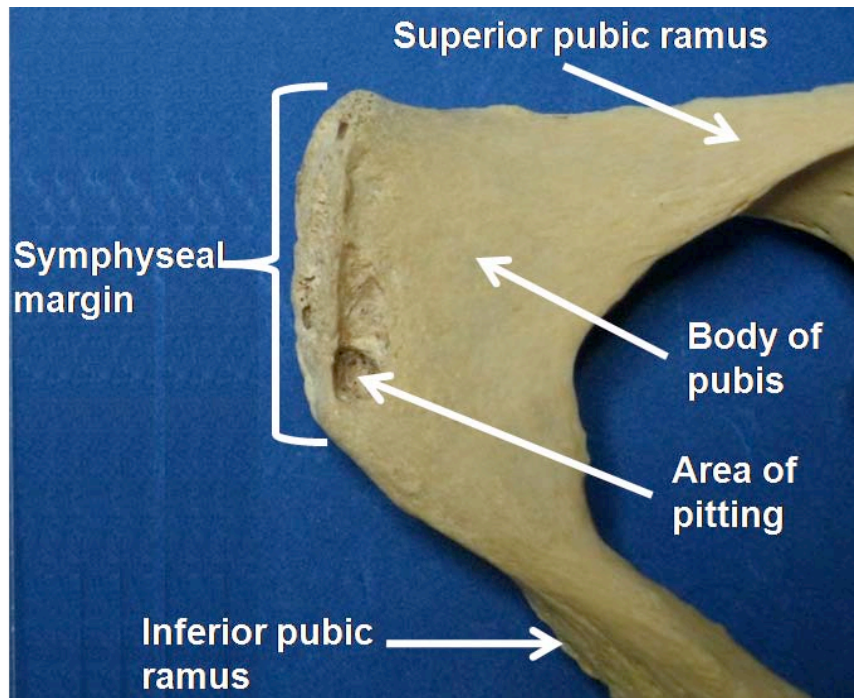


Figure 3.1: Dorsal view of the right pubis of a 42 year old female (AN402), showing pitting near the symphyseal margin.

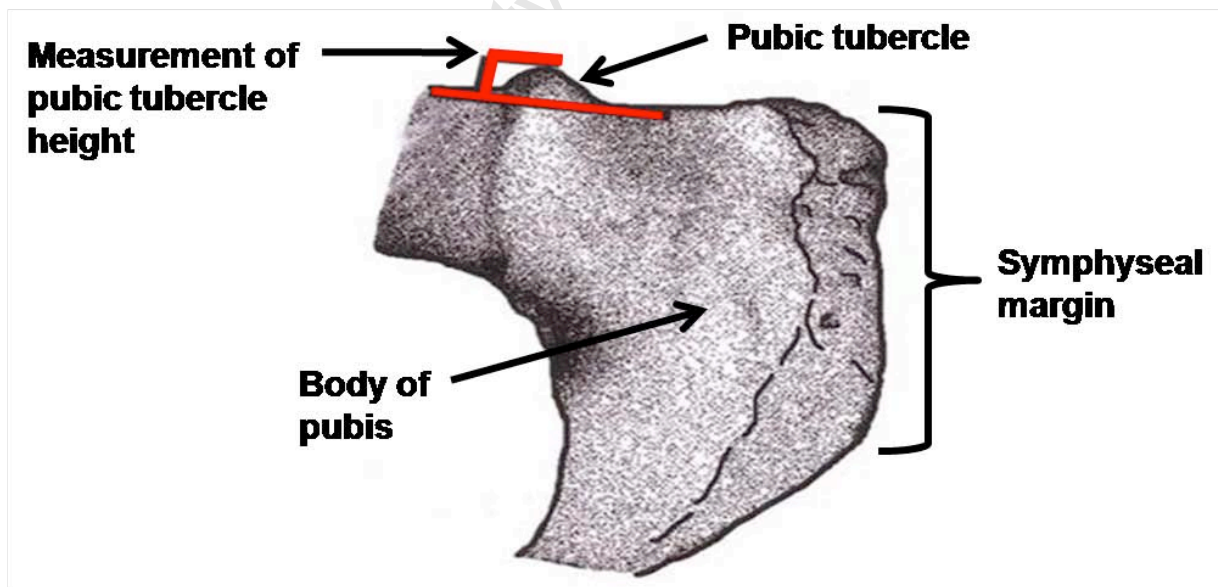


Figure 3.2: Anterior view of the right pubis, showing the measurement of the height of the pubic tubercle. [Adapted from Snodgrass & Galloway, 2003]

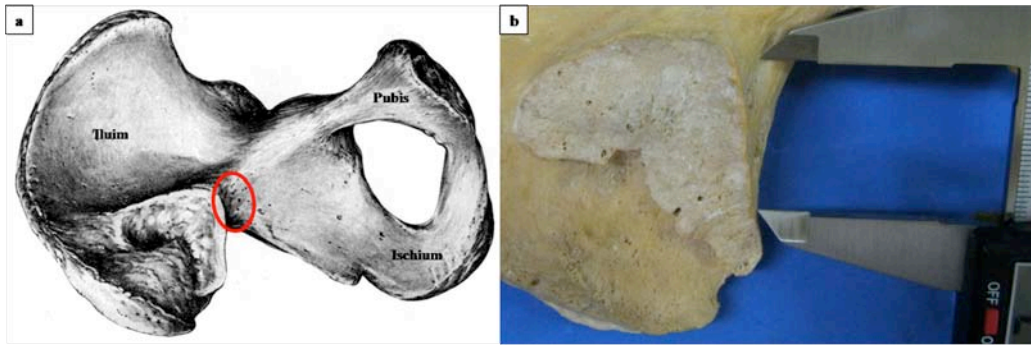


Figure 3.3: a. Medial view of the left innominate, showing the location of the preauricular sulcus; and b. an example of the measurement of the maximum length of the preauricular sulcus.

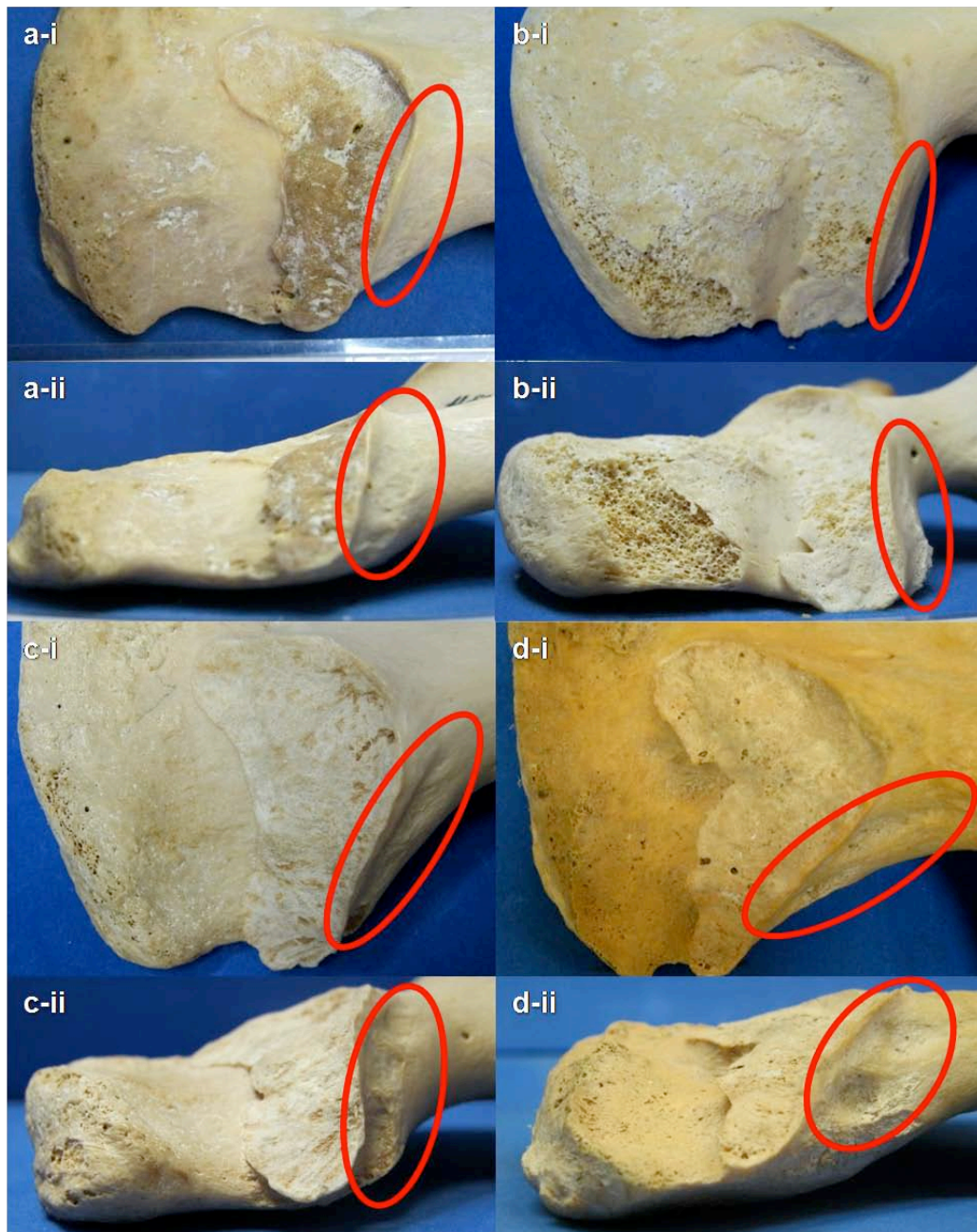


Figure 3.4: Medial (i) and inferior (ii) views of the left auricular region, showing examples of the classifications of the appearance of the preauricular sulcus (indicated by circles): a. "Broad-shallow", b. "Narrow-shallow", c. "Defined", and d. "Complex".

3.2.4. Interosseous groove

The maximum depth and maximum width of the interosseous groove were measured (Figure 3.5) and used to classify the appearance of the groove into one of the following categories (Figure 3.6):

- Shallow: < 3.0 mm deep and < 5.0 mm wide
- Moderate: > 3.0 mm deep and 5.0 mm – 10.0 mm wide
- Developed: > 3.0 mm deep and > 10.0 mm wide.

3.2.5. Iliac tuberosity

The thickness of the iliac tuberosity was measured from its highest point to the posterior of the ilium as described by Andersen (1986) (Figure 3.7). This measurement was then used to classify the appearance of the tuberosity into one of the following categories (Figure 3.8):

- No eminence: < 20.0 mm thick
- Depressed mound: 20.0 mm – 25.0 mm thick
- Pointed mound: > 25.0 mm thick

3.2.6. Body size estimates

The bicondylar length and maximum head diameter of the left femur (or right femur in the absence of the left) was measured according to the descriptions of Buikstra & Ubelaker (1994) (Figure 3.9) and used as proxies for stature and body mass, respectively. While regression formulae for reconstruction of stature and body mass from these measurements are available (Ruff *et al.*, 1991; McHenry, 1992; Grine *et al.*, 1995; Feldesman & Fortuin, 1996), such calculations would increase the error of further calculations in this study and were thus not employed. These regression formulae are also mainly derived from American or European samples and have been shown to be unreliable for reconstructing body size of smaller-bodied individuals, such as the archaeological individuals of this study (Kurki *et al.*, 2010). The degree of dimorphism of these two measurements was calculated using the formula of Hamilton (1982):

$$\text{Degree of sexual dimorphism} = [(\text{male mean} - \text{female mean}) \div \text{female mean}] \times 100$$

Positive values obtained by this formula indicate that males are larger than females for the measurement in question, while negative values indicate that females are larger than males for this measurement.

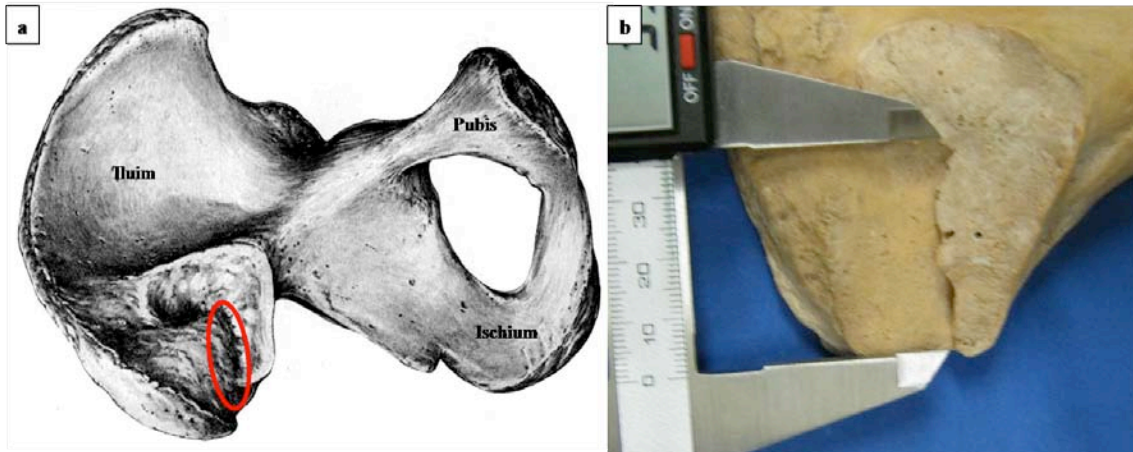


Figure 3.5: a. Medial view of the left innominate, showing the location of the interosseous groove, and b. an example of the measurement of the maximum length of the interosseous groove.

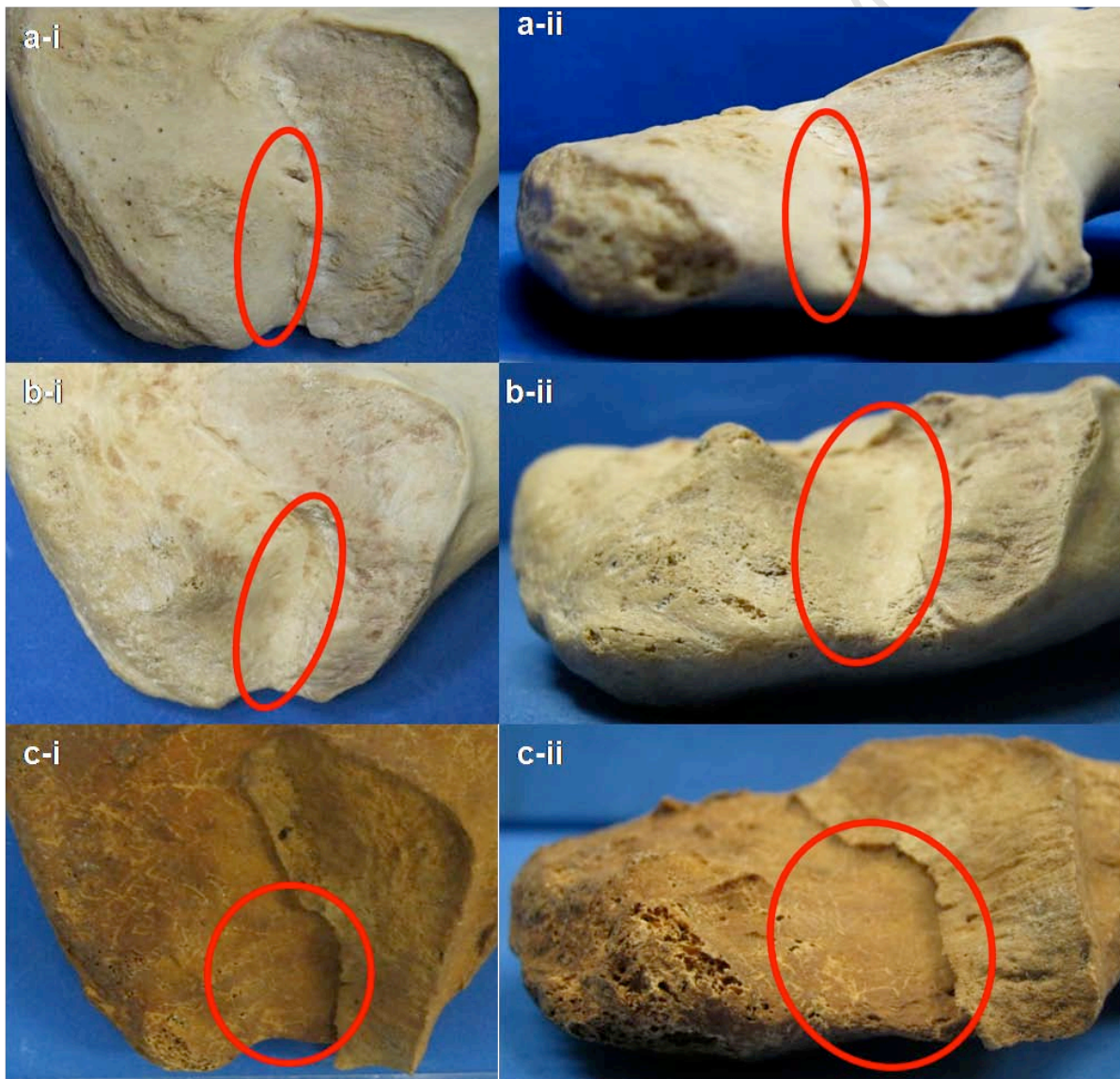


Figure 3.6: Medial (i) and inferior (ii) views of the left auricular region, showing examples of the classifications of the appearance of the interosseous groove: a. "Shallow", b. "Moderate", and c. "Developed".

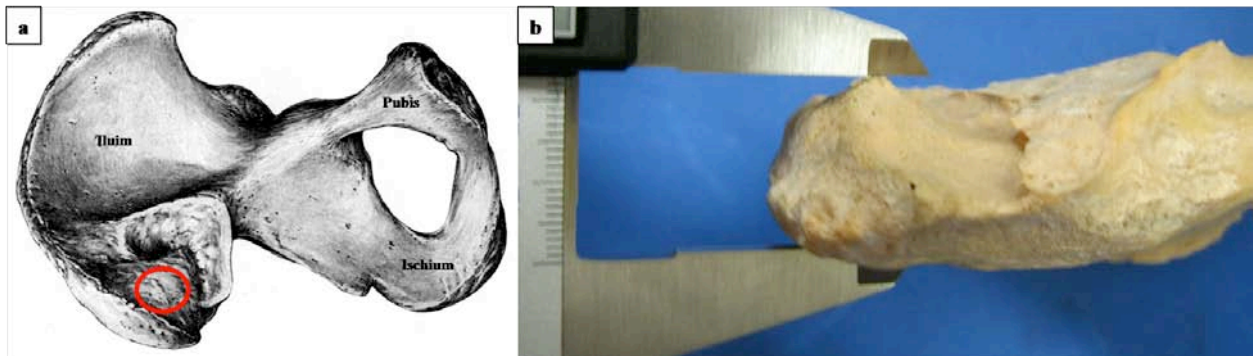


Figure 3.7: a. Medial view of the left innominate, showing the location of the iliac tuberosity; and b. an example of the measurement of the thickness of the iliac tuberosity.

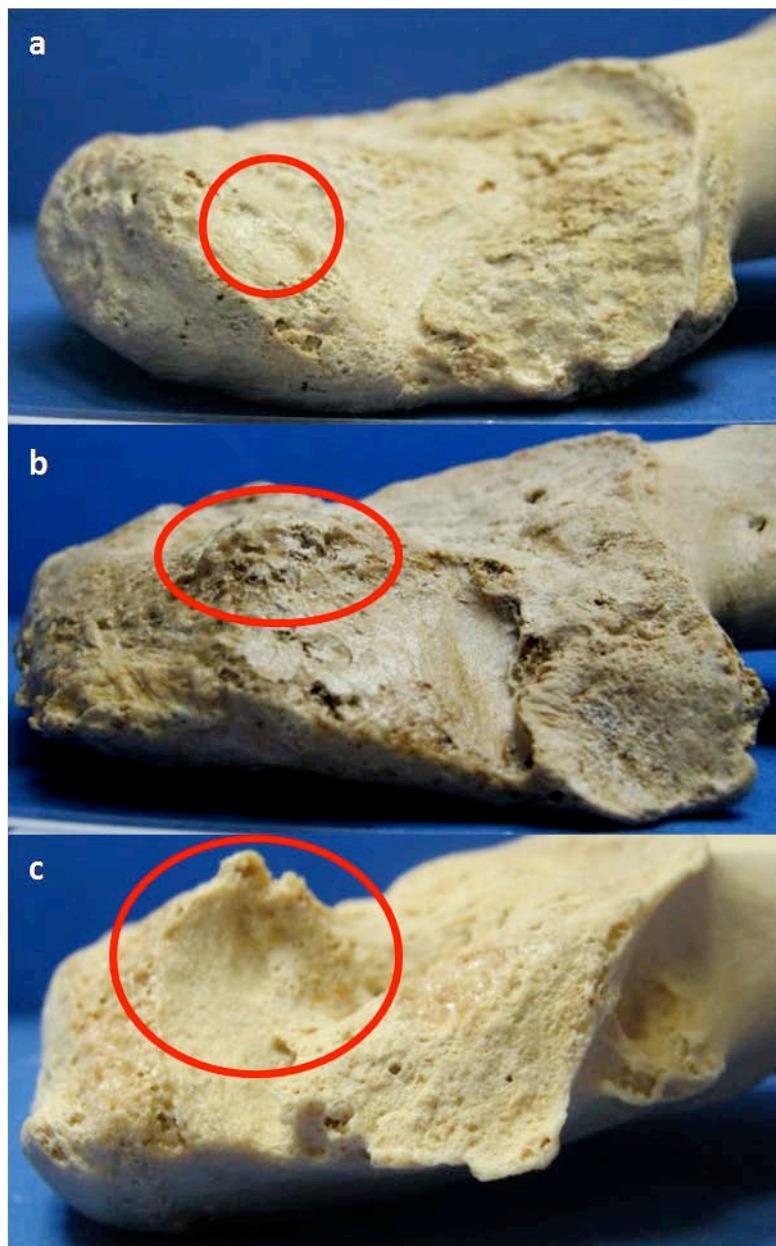


Figure 3.8: Inferior view of the left auricular region, showing examples of the classifications of the iliac tuberosity: a. "No eminence", b. "Depressed mound", and c. "Pointed mound".

3.2.7. Measurements of the articulated pelvic girdle

The pelvic girdle was re-articulated using elastic bands, using a rubber insert at the pubic symphysis to account for the absence of soft tissue in the joint spaces. The presence of the insert also made the articulation of the bones more stable, making it easier to perform the measurements (O'Connell, 2004). The thickness of the insert was set at 5.0 mm, as it is the average width of the pubic symphysis reported by several previous studies (Vix & Ryu, 1971; Garagiola *et al.*, 1989; Wurdinger *et al.*, 2002).

The measurements made on the articulated pelvic girdle are those commonly used in obstetric and gynaecological practice (Cunningham *et al.*, 2010; Kurki, 2011a). These measurements are illustrated in Figure 3.10, and are defined as follows:

- Anteroposterior diameter of pelvic inlet: sacral promontory to the pubic crest
- Anteroposterior diameter of pelvic outlet: end of fifth sacral segment to the lower border of the pubic symphysis
- Transverse diameter of pelvic inlet: maximum distance between arcuate lines
- Transverse diameter of pelvic outlet: posterior part of one ischial tuberosity to the corresponding point on the ischial tuberosity on the opposite side of the body
- Bi-iliac breadth: maximum distance between the outer margins of the iliac crests
- Interspinous diameter: distance between ischial spines (also called the transverse diameter of the midplane of the pelvis)

The degree of sexual dimorphism of these measurements was calculated using the same formula as for the femur measurements and were interpreted in a similar manner.

3.3. Data analysis

Statistical analysis of the gathered data was performed using the Statistica® software package for Windows® (Statsoft Inc., 2009).

3.3.1. Intra-observer error testing

Thirty randomly selected pelvises were re-measured approximately three months after completion of the collection of the original data set. This data was used to test for intra-observer repeatability using the statistical methods proposed by Bland & Altman (1986).

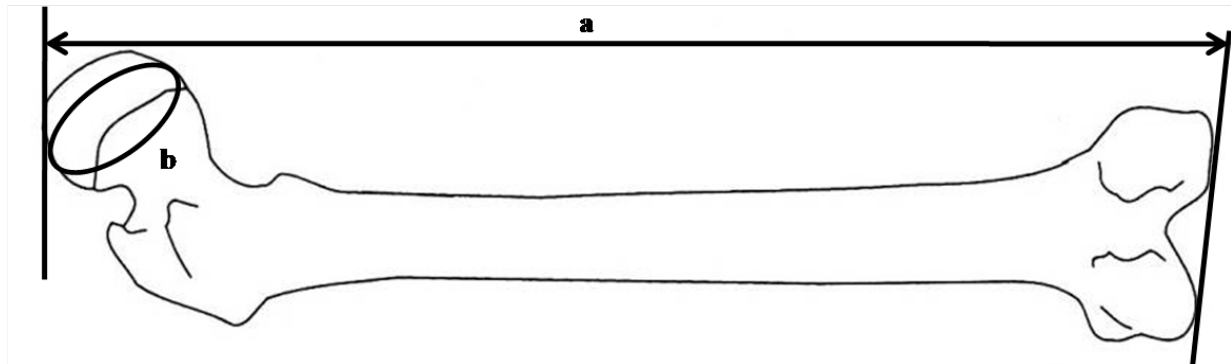


Figure 3.6: Measurements of the femur, posterior view: **a.** bicondylar length and **b.** maximum head diameter. [Adapted from Buikstra & Ubelaker, 1994]

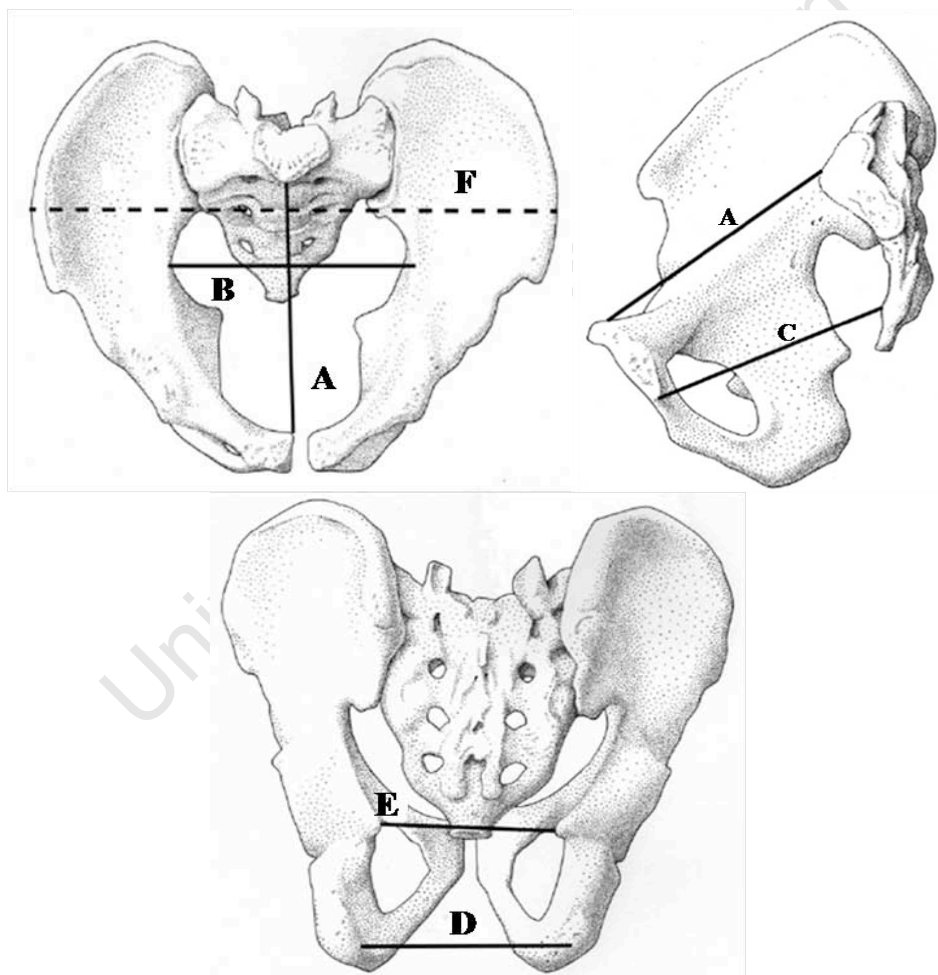


Figure 3.7: Measurements made on the articulated pelvic girdle: **A** anteroposterior diameter of pelvic inlet; **B** transverse diameter of pelvic inlet; **C** anteroposterior diameter of pelvic outlet; **D** transverse diameter of pelvic outlet; **E** interspinous diameter; **F** bi-iliac breadth. [Adapted from Kurki, 2011a]

3.3.2. Scar manifestation according to sex, age or time period sample

The data were submitted to Chi-squared and Fisher-exact testing to detect association of the scar features to either the sex, age or time period of origin of the individuals. In the case of both tests, p-values less than 0.05 were considered as significant. In the case of the Chi-squared test, high Chi-squared values (χ^2) indicated that the probability that the observed associations were due to random chance alone was low, while low χ^2 -values indicated that the probability that the observed associations were due to random chance was high.

3.3.3. Variation in body size estimates and pelvic measurements

The means of the pelvic measurements and body size estimates were compared between the sex, age and time period samples. In all cases the Shapiro-Wilkes test was performed to determine whether the data were normally distributed. In the case of comparison between the sexes, normally distributed data were assessed using the two-variable t-test and non-normally distributed data were assessed using the Mann-Whitney U-test. In the case of the age and time period samples, normally distributed data were analysed using analysis of variance (ANOVA) tests to detect differences between samples. If such differences were found, Post-hoc Scheffé testing was performed to determine between which of the samples the differences occurred. Non-normally distributed data were analysed using the Kruskal-Wallis test. Spearman Rank Correlation coefficients were also calculated to assess possible correlation between pelvic measurements and body size variables.

3.3.4. Relationship between body and pelvic size and scar manifestation

3.3.4.1. Univariate analysis

The sample was divided according to sex and time period of origin to give six study groups, namely archaeological females, archaeological males, historical females, historical males, modern females and modern males. These six study groups, as well as the pooled data of the females and the males were submitted to the Spearman Rank Correlation test in order to assess whether scars at the different areas examined were correlated to each other and whether body and pelvic size variables were correlated to each other. Significance testing was performed to identify true correlation values and exclude those that are due to chance or are affected by small sample sizes.

3.3.4.2. Multivariate analysis

The data were submitted to a Principal Components Analysis (PCA) in an attempt to identify size and shape patterns in the data. Before performing the analysis, data must be standardised to remove

possible bias that the differences in the classification systems used may have on the results (Ginter, 2008). Standardisation was done by subtraction of the mean followed by division by the standard deviation of the data set of each variable. Since PCA requires complete individual value sets, individuals with missing data also had to be excluded from the analysis. After the exclusion of such individuals, only the sex samples were sufficiently large for further analysis and thus comparison of the PCA results according to the age group or time period of origin was not possible. Since the effect of the time period of origin could not be determined, it was decided to perform the analysis using only the modern samples.

The first step in the analysis was to compute the eigenvalues and percentage of the total variance of each of the 12 possible principal components. To determine the number of principal components, the Kaiser or eigenvalue-one criterion (Kaiser, 1960) was applied. This stipulates that principal components which have eigenvalues greater than 1.0 should be retained for further analysis, since such components account for a greater amount of variance than had been contributed by a single variable (Hatcher, 1994). Typically, only the first two to four principal components are retained, since these account for the most variation (Pimentel, 1992). Principal component scores are interpreted by examination of the component loadings of each variable. The first principal component usually reflects size variation, while the remaining components usually reflect shape variation (Jolicoeur & Mosimann, 1960; Pimentel, 1992). The loadings of each variable represent the relationship between the principal component and that variable, with variables that have large scores for a particular component considered most important since they make the greatest contribution to the variance expressed by the component (Ginter, 2008). Conversely, variables with small component scores are usually excluded from the interpretation as they contribute very little to the overall variance. To assess the loadings of the variables of the present study, the eigenvalue coefficients (or component scores) were calculated for the principal components retained for analysis. Biplots of these coefficients were also created for each combination of the retained components. Together, the coefficients and the biplots allowed assessment of the nature of the relationships (positive or negative) of each of the scar, body and pelvic size variables to each principal component and to each other. Score plots representing the principal component scores of each of the individuals examined were then constructed to allow comparison of males and females by graphically representing the separation or lack thereof according to each principal component.

RESULTS

4.1. Intra-observer error testing

The differences between the repeated measurements of the two sets of measurements of the 30 randomly selected pelves were not significant for all measurements except the bi-iliac breadth, with the absolute mean difference between the sets of measurements being less than 1.0 mm in each case. In the case of the bi-iliac breadth, the absolute mean difference between the two data sets was 30.8 mm (Figure 4.1). The graph also shows that four measurements fell outside the 95% confidence intervals. It is possible that the discrepancy between the two data sets may have been the result of the lack of clear reference points on the iliac crests from which the measurements were taken, as well as fact that the re-articulation of the pelvic girdle may not have been as stable as anticipated. Measurement of the bi-iliac breadth of the sample of 30 pelves was performed for a third time. Despite the reduction in the number of outliers detected (Figures 4.2 and 4.3), the absolute mean differences between the first and second data sets and the third data set were 15.1 mm and 15.6 mm, respectively, and were thus not sufficiently similar to either the first or second data sets. It was thus decided to exclude the bi-iliac breadth from further analysis.

4.2. Scar manifestation according to sex, age and time period sample

4.2.1. Dorsal pubic surface

4.2.1.1. Sex

The occurrence of the dorsal pubic pitting was significantly associated with sex ($\chi^2 = 62.32$; $p < 0.01$) (Table 4.1). Pitting was absent in the majority of individuals of both sexes, but the proportion of females with medium to large pitting (31.3%) was significantly larger than that of males (2.3%). Neither of the sexes had trace to small pitting.

Table 4.1: Comparison of the occurrence of dorsal pubic pitting between sexes.

	Females		Males	
	n	%	n	%
Absent	101	68.7	46	97.7
Medium/large	216	31.3	5	2.3

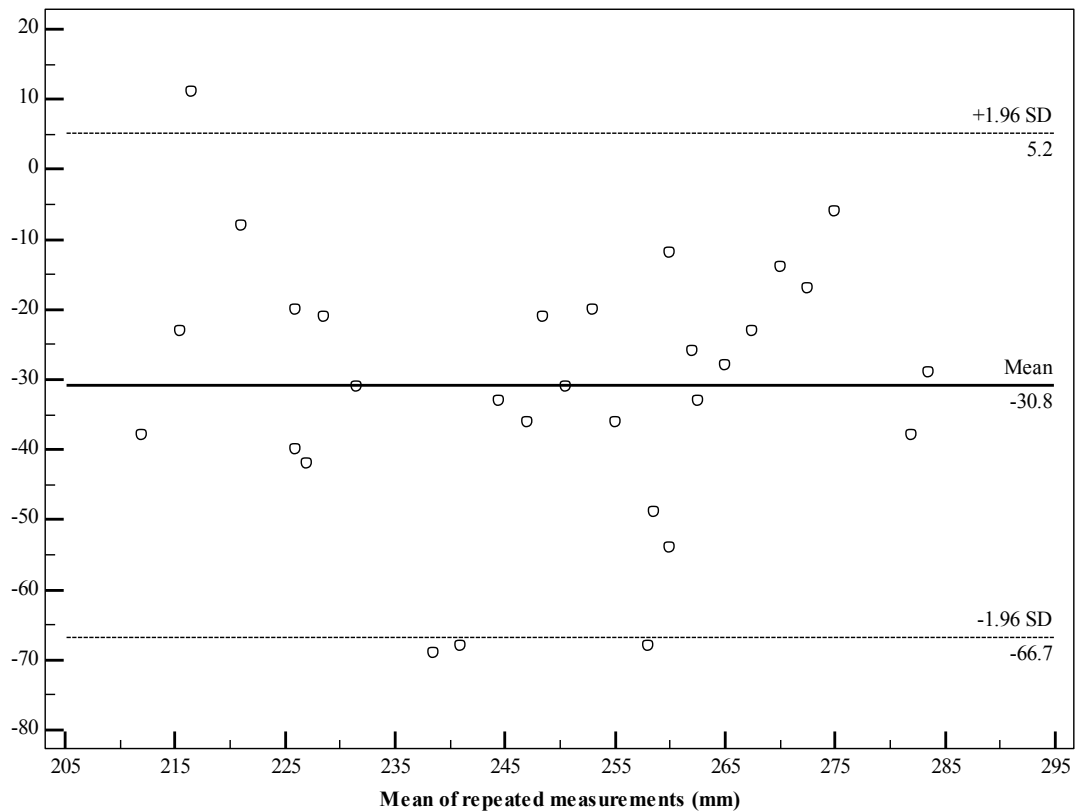


Figure 4.1: Results of the Bland-Altman repeatability analysis of the first and second test samples, showing four measurements outside of the 95% confidence interval.

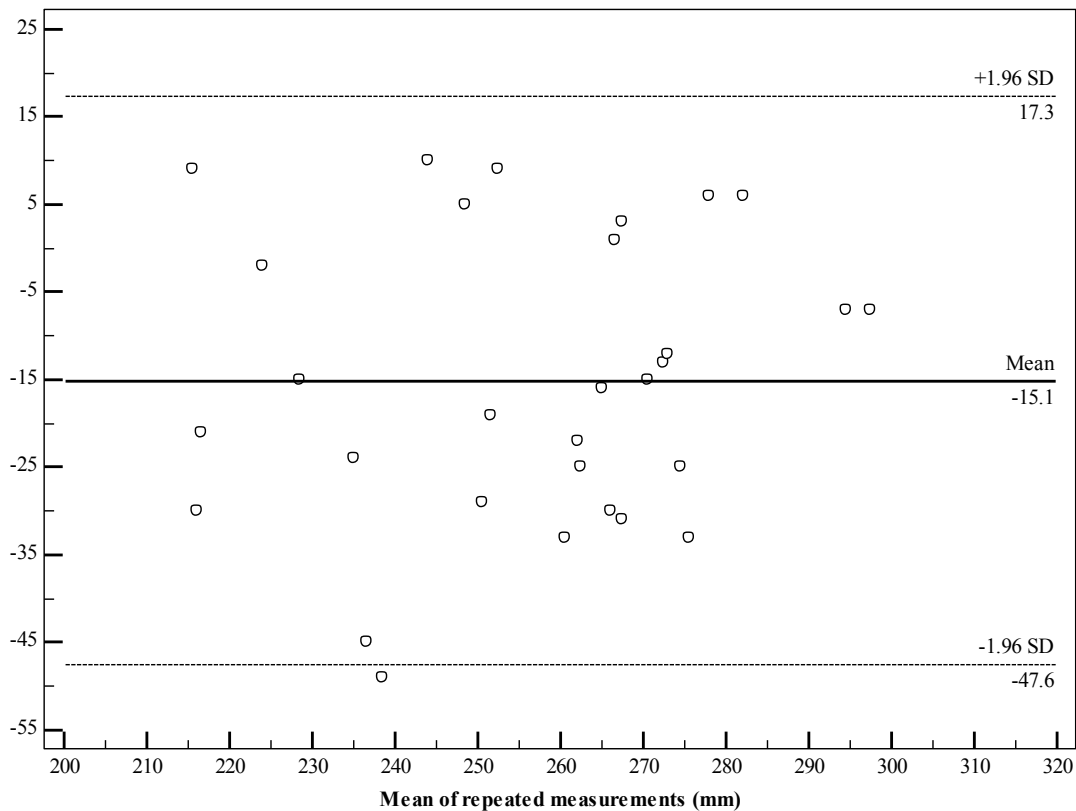


Figure 4.2: Results of the Bland-Altman repeatability analysis of the first and third test samples, showing one outlier outside of the 95% confidence interval.

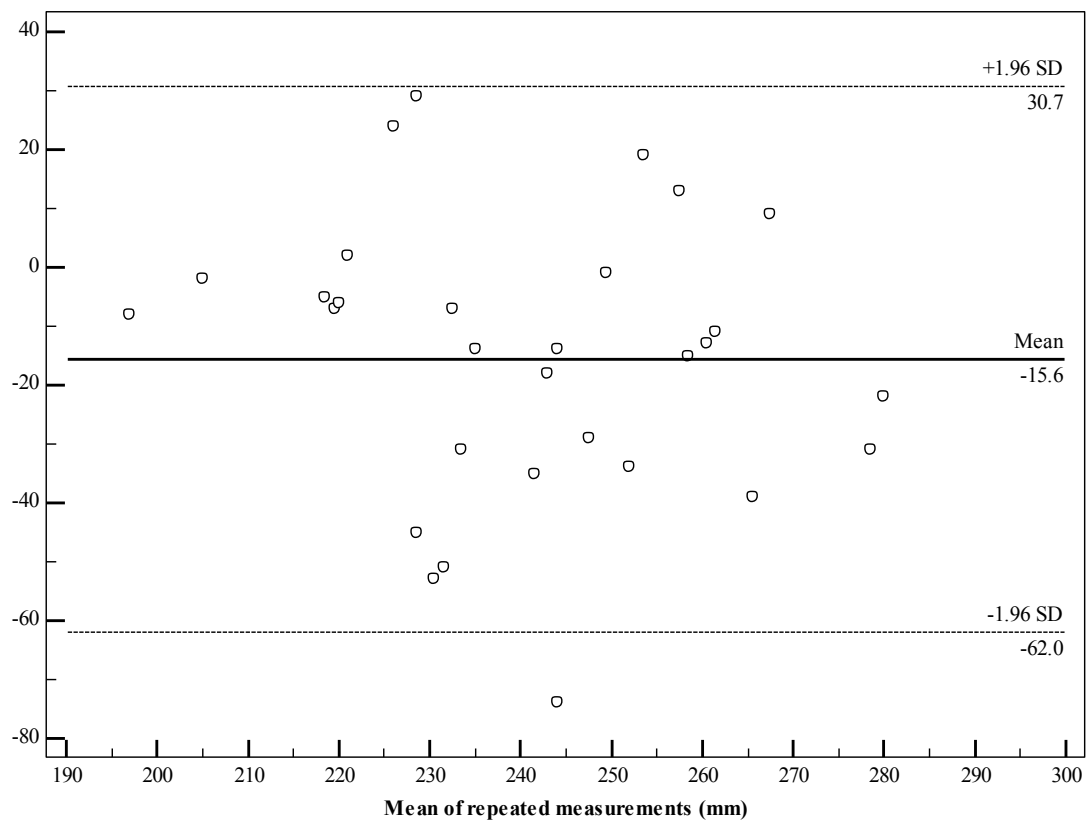


Figure 4.3: Results of the Bland-Altman repeatability analysis of the second and third test samples, showing one outlier outside of the 95% confidence interval.

4.2.1.2. Age

The occurrence of dorsal pubic pitting was not significantly associated with age ($\chi^2= 3.25$; $p= 0.35$) (Table 4.2). Less than 20% of the individuals of each of the age groups presented with medium to large pitting and none of the individuals had trace to small pitting.

Table 4.2: Comparison of the occurrence of dorsal pubic pitting between age groups.

	Absent		Medium/large	
	n	%	n	%
Young adult	65	91.5	6	8.5
Middle adult	88	85.4	15	14.6
Old adult	76	87.4	11	12.6
Very old adult	88	82.3	19	17.7

4.2.1.3. Time period

The occurrence of dorsal pubic pitting was not significantly associated with the time period sample from which the individual came (Fisher exact $p= 0.24$) (Table 4.3). Less than 20% of the individuals of each time period sample presented with medium to large pitting and none had trace to small pitting.

Table 4.3: Comparison of the occurrence of dorsal pubic pitting between time period samples.

	Absent		Medium/large	
	n	%	n	%
Archaeological sample	36	94.7	2	5.3
Historical sample	23	88.5	3	11.5
Modern sample	258	84.9	46	15.1

4.2.2. Pubic tubercle

4.2.2.1. Sex

The degree of extension of the pubic tubercle was significantly associated with sex ($\chi^2= 8.44$; $p= 0.01$) (Table 4.4 and Figure 4.4). While the majority of both males and females had medium tubercles, more females than males had small tubercles, while more males than females had large tubercles.

Table 4.4: Comparison of the extension of the pubic tubercle between sexes.

	Females		Males	
	n	%	n	%
Small	21	22.5	11	9.7
Medium	66	71.0	86	76.1
Large	6	6.5	16	14.5

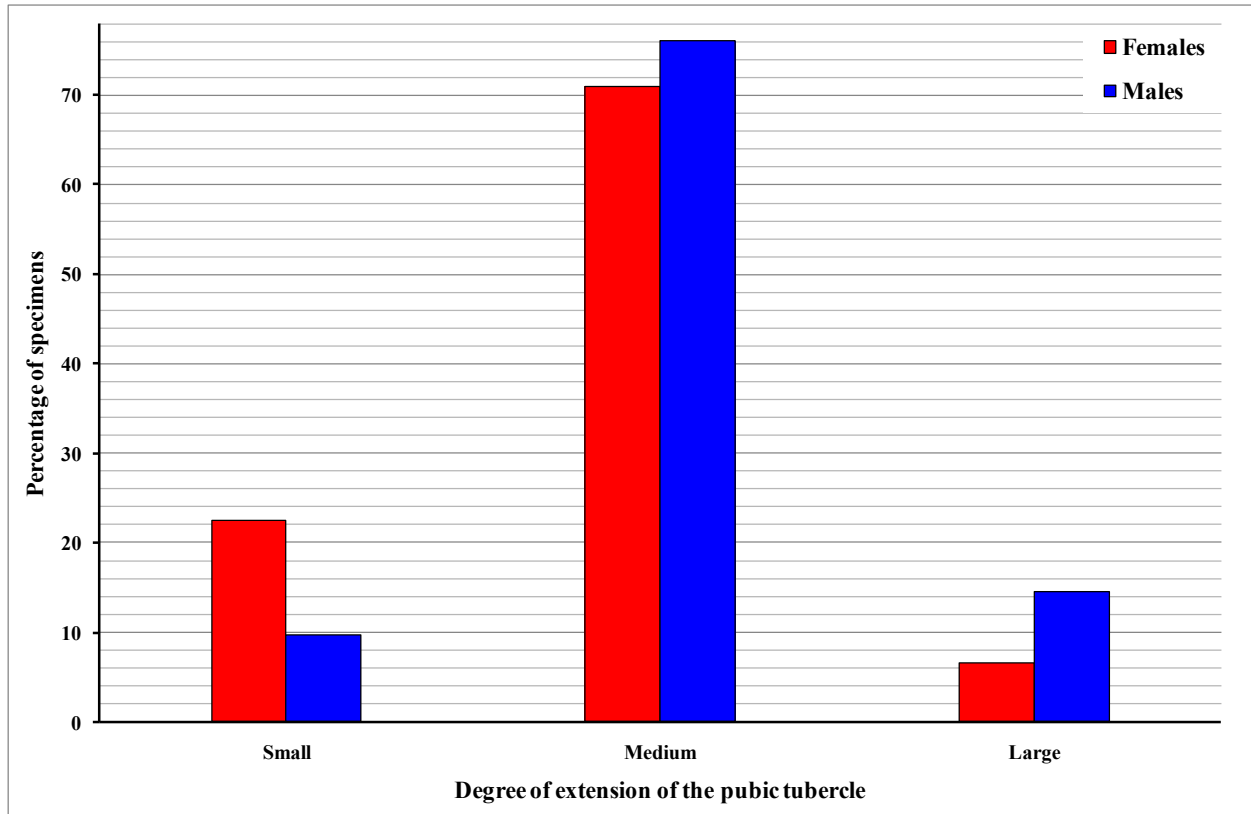


Figure 4.4: Comparison of the degree of extension of the pubic tubercle between sexes.

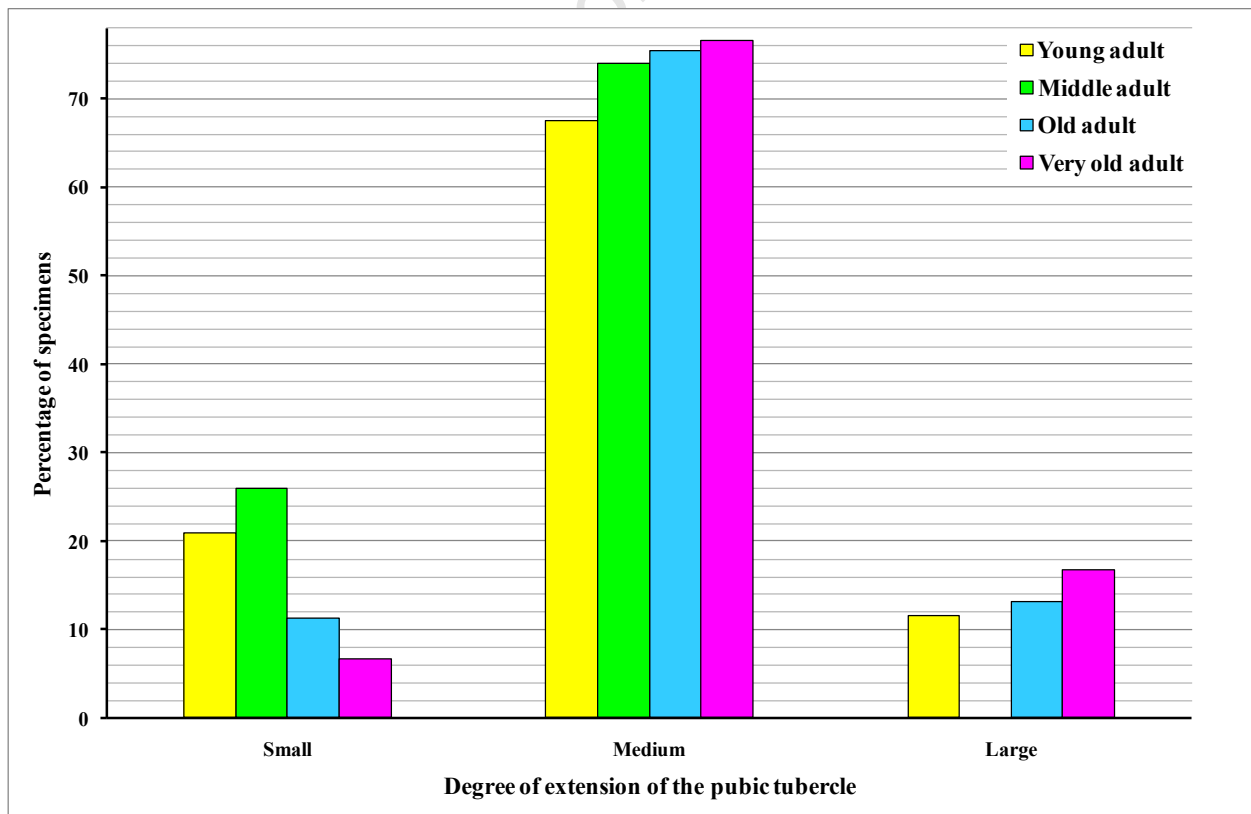


Figure 4.5: Comparison of the degree of extension of the pubic tubercle between age groups.

4.2.2.2. Age

The degree of extension of the pubic tubercle was significantly associated with age (Fisher exact $p=0.01$) (Table 4.5 and Figure 4.5). The young and middle adult individuals tended to have mostly small or medium tubercles, while the old and very old individuals tended to have mostly medium or large tubercles.

Table 4.5: Comparison of the extension of the pubic tubercle between age groups.

	Small		Medium		Large	
	n	%	n	%	n	%
Young adult	9	20.9	29	67.5	5	11.6
Middle adult	13	26.0	37	74.0	0	0
Old adult	6	11.3	40	75.5	7	13.2
Very old adult	4	6.7	46	76.6	10	16.7

4.2.2.3. Time period

The degree of extension of the pubic tubercle was not significantly associated with the time period sample from which it came (Fisher exact $p=0.60$) (Table 4.6). The majority of the individuals of all three samples had medium tubercles.

Table 4.6: Comparison of the extension of the pubic tubercle between time period samples.

	Small		Medium		Large	
	n	%	n	%	n	%
Archaeological sample	4	20.0	14	70.0	2	10.0
Historical sample	0	0	10	83.3	2	16.7
Modern sample	28	16.1	128	73.6	18	10.3

4.2.3. Preauricular sulcus

4.2.3.1. Sex

The appearance of the preauricular sulcus was significantly associated with sex ($\chi^2=77.19$; $p<0.01$) (Table 4.7 and Figure 4.6). The female sample had approximately equal proportions of narrow-shallow, defined and complex sulci, with only 19.1% of females having absent/broad-shallow sulci. The majority of the male sample had either absent/broad-shallow or narrow-shallow sulci, with 11.8% having defined sulci and only 2.7% having complex sulci.

Table 4.7: Comparison of preauricular sulcus appearance between sexes.

	Females		Males	
	n	%	n	%
Absent/ broad-shallow	30	19.1	106	46.5
Narrow-shallow	45	28.7	89	39.0
Defined	38	24.2	27	11.8
Complex	44	28.0	6	2.7

4.2.3.2. Age

The appearance of the preauricular sulcus was not significantly associated with age ($\chi^2 = 15.46$; $p = 0.08$) (Table 4.8). The majority of individuals of each of the four age groups had either absent/broad-shallow or narrow-shallow sulci, while small proportions of the samples had either defined or complex sulci.

Table 4.8: Comparison of preauricular sulcus appearance between age groups.

	Absent/broad-shallow		Narrow-shallow		Defined		Complex	
	n	%	n	%	n	%	n	%
Young adult	37	45.1	28	34.2	11	13.4	6	7.3
Middle adult	38	35.2	38	35.2	17	15.7	15	13.9
Old adult	30	34.9	36	41.8	11	12.8	9	10.5
Very old adult	31	28.4	32	29.4	26	23.8	20	18.4

4.2.3.3. Time period

The appearance of the preauricular sulcus was not significantly associated with the time period from which the individual came (Fisher exact $p = 0.28$) (Table 4.9). The majority of individuals of each time period sample had either absent/broad-shallow or narrow-shallow sulci, with smaller proportions having defined sulci and less than 15% of each sample having complex sulci.

Table 4.9: Comparison of preauricular sulcus appearance between time period samples.

	Archaeological sample		Historical sample		Modern sample	
	n	%	n	%	n	%
Absent/broad-shallow	11	24.5	13	41.8	112	36.3
Narrow-shallow	20	44.4	9	29.0	105	34.0
Defined	11	24.5	6	19.4	48	15.5
Complex	3	6.6	3	9.8	44	14.2

4.2.4. Interosseous groove

4.2.4.1. Sex

The appearance of the interosseous groove was significantly associated with sex ($\chi^2 = 142.54$; $p < 0.01$) (Table 4.10 and Figure 4.7). The majority of the male sample had shallow grooves (88.0%), with only small proportions having either moderate or developed grooves. Though a large proportion of female sample also had shallow grooves (30.4%), the majority of females had developed grooves (51.7%) and only 17.9% had moderate grooves.

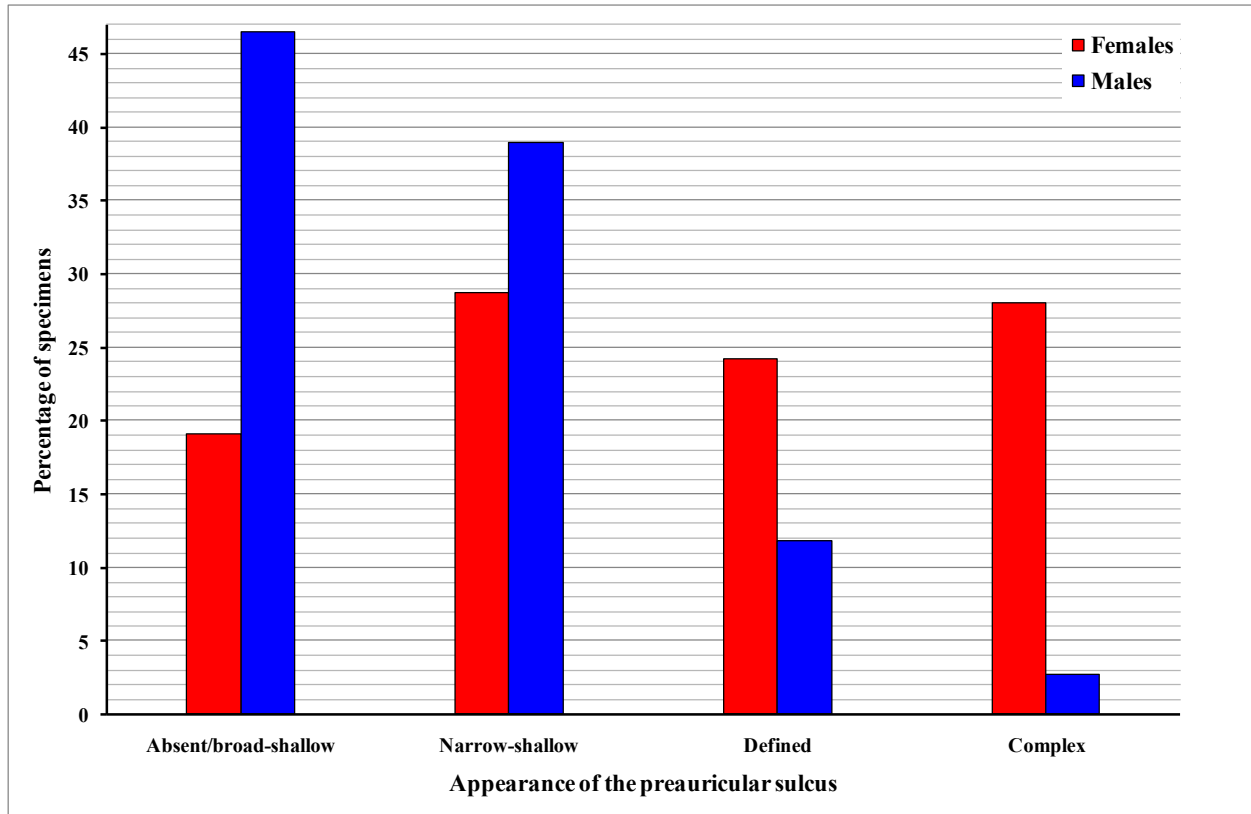


Figure 4.6: Comparison of the appearance of the preauricular sulcus between sexes.

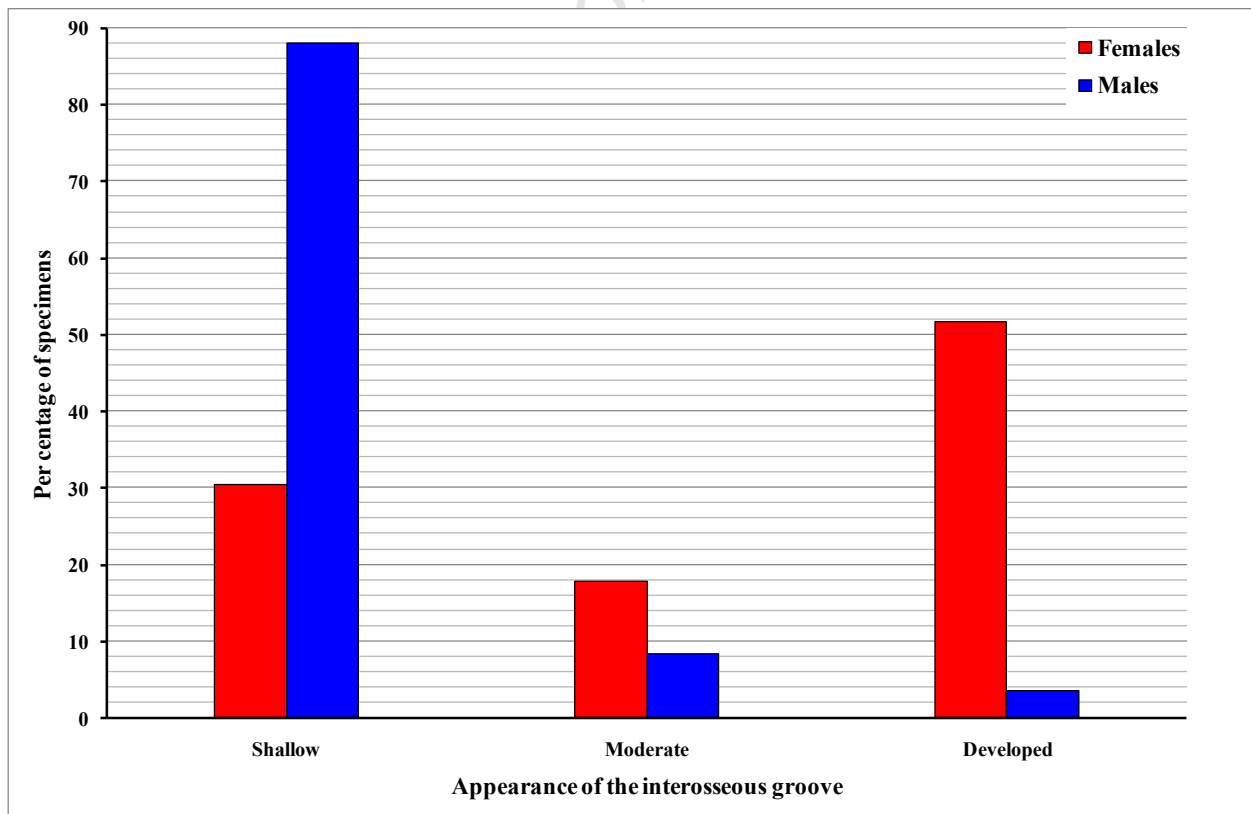


Figure 4.7: Comparison of the appearance of the interosseous groove between sexes.

Table 4.10: Comparison of interosseous groove appearance between sexes.

	Females		Males	
	n	%	n	%
Shallow	44	30.4	198	88.0
Moderate	26	17.9	19	8.4
Developed	75	51.7	8	3.6

4.2.4.2. Age

The appearance of the interosseous groove was not significantly associated with age ($\chi^2= 8.82$; $p= 0.18$) (Table 4.11). The majority of individuals of all four age groups had shallow grooves, a large proportion had developed grooves and less than 20% of each group had moderate grooves.

Table 4.11: Comparison of interosseous groove appearance between age groups.

	Shallow		Moderate		Developed	
	n	%	n	%	n	%
Young adult	49	64.5	14	18.4	13	17.1
Middle adult	68	66.7	10	9.8	24	23.5
Old adult	61	71.8	5	5.9	19	22.3
Very old adult	64	59.8	16	15.0	27	25.2

4.2.4.3. Time period

The appearance of the interosseous groove was not significantly associated with the time period from which the individual came (Fisher exact $p= 0.21$) (Table 4.12). More than 60% of the individuals of each of the three time period samples had shallow grooves, while lesser proportions of the samples had moderate or developed grooves.

Table 4.12: Comparison of interosseous groove appearance between time period samples.

	Shallow		Moderate		Developed	
	n	%	n	%	n	%
Archaeological sample	27	61.4	9	20.4	8	18.2
Historical sample	22	66.6	6	18.2	5	15.2
Modern sample	193	65.9	30	10.2	70	23.9

4.2.5. Iliac tuberosity

4.2.5.1. Sex

The appearance of the iliac tuberosity was not significantly associated with sex ($\chi^2= 4.36$; $p= 0.11$) (Table 4.13). The iliac tuberosity appeared as a depressed mound in the majority of both sexes, with a lesser proportion of the individuals of both sexes having no eminence and only a small proportion having pointed mound tuberosities.

Table 4.13: Comparison of iliac tuberosity appearance between sexes.

	Females		Males	
	n	%	n	%
No eminence	44	28.8	60	27.0
Depressed mound	74	48.4	128	57.7
Pointed mound	35	22.8	34	15.3

4.2.5.2. Age

The appearance of the iliac tuberosity was significantly associated with age ($\chi^2= 28.61$; $p< 0.01$) (Table 4.14 and Figure 4.8). The majority of the individuals of the old and very old adult groups had tuberosities with a depressed mound appearance (58.8% and 60.0%, respectively), with smaller proportions of the individuals of these groups having either no eminence or tuberosities with a pointed mound appearance. The majority of the individuals of the young and middle adult groups also had tuberosities with a depressed mound appearance (46.8% and 48.6%, respectively), but a large proportion of the individuals of these two groups also had no eminence (42.9% and 35.9%). The proportion of young and middle adult individuals with pointed mound tuberosities were less than those of the old and very old adult groups.

Table 4.14: Comparison of iliac tuberosity appearance between age groups.

	No eminence		Depressed mound		Pointed mound	
	n	%	n	%	n	%
Young adult	33	42.9	36	46.8	8	10.4
Middle adult	37	35.9	50	48.6	16	15.5
Old adult	20	23.5	50	58.8	15	17.7
Very old adult	14	12.7	66	60.0	30	27.3

4.2.5.3. Time period

The appearance of the iliac tuberosity was not significantly associated with the time period from which the individual came ($\chi^2= 3.41$; $p= 0.49$) (Table 4.15). The majority of individuals of each of the three time period samples had depressed mound tuberosities, while a large proportion of all three samples also had no eminence and only a small proportion had pointed mound tuberosities.

Table 4.15: Comparison of iliac tuberosity appearance between time period samples.

	No eminence		Depressed mound		Pointed mound	
	n	%	n	%	n	%
Archaeological sample	15	34.9	19	44.2	9	20.9
Historical sample	11	35.5	16	51.6	4	12.9
Modern sample	78	25.9	167	55.5	56	18.6

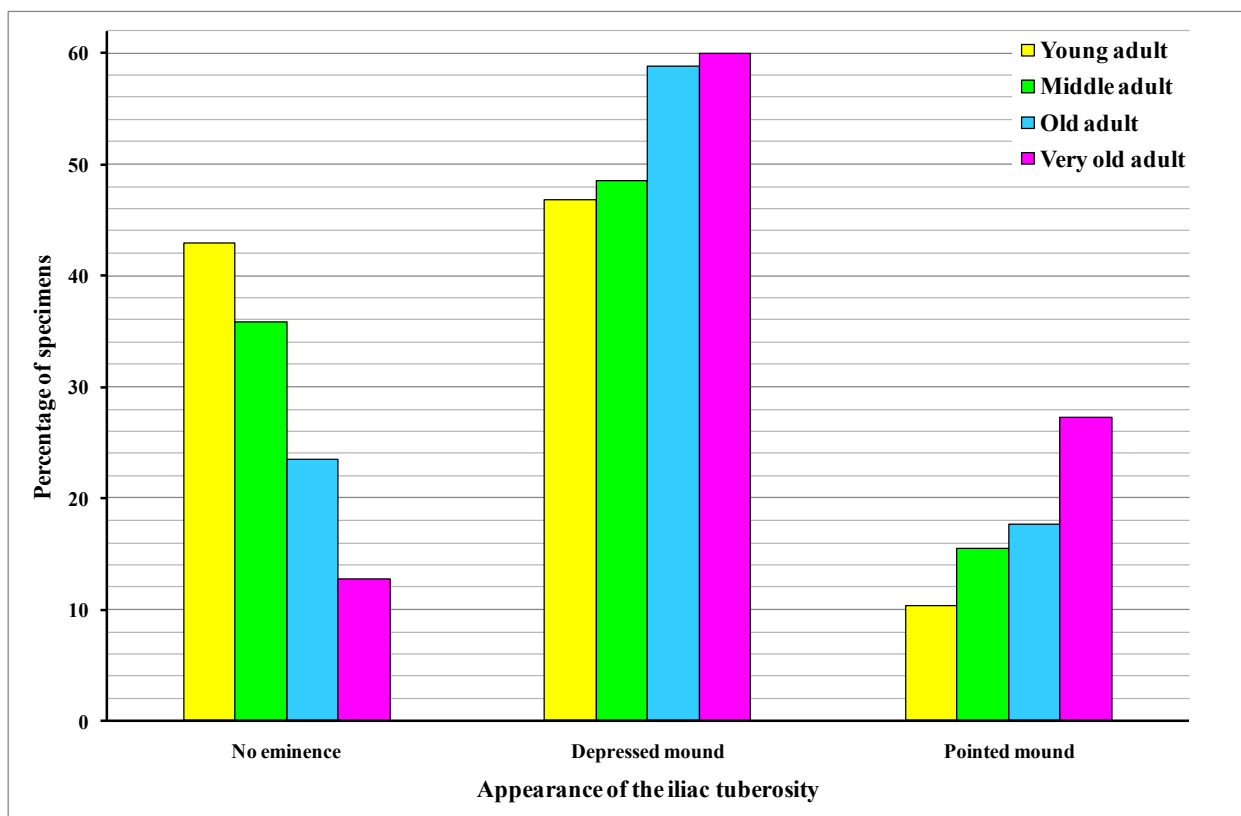


Figure 4.8: Comparison of the appearance of the iliac tuberosity between age groups.

4.3. Relationship between scar features

Spearman Rank Correlation tests showed that the archaeological female, archaeological male and historical female samples did not have any significant correlation between scarring at the five areas examined. The only significant correlation in the historical male sample was between the appearance of the interosseous groove and that of the iliac tuberosity, with $r = -0.46$. In the modern female sample and the pooled female data, the only significant correlations were between the appearance of the preauricular sulcus and both that of the interosseous groove ($r = 0.28$ and 0.27 , respectively) and the iliac tuberosity ($r = 0.25$ and 0.17 , respectively). The only significant correlation in the modern male sample and the pooled male data was between the occurrence of dorsal pubic pitting and the appearance of the preauricular sulcus ($r = 0.22$ and 0.20 , respectively).

4.4. Variation in body size estimates

4.4.1. Femur length

The mean femur length was larger in males than in females within each study group, though the difference was only significant in the modern sample (Mann-Whitney U-test $p < 0.01$) (Table 4.16). The degree of sexual dimorphism of the mean femur length was similar in the three time period samples, with males being larger than females by 4% to 7%. The modern samples had the largest mean femur length for both males and females (45.0 cm and 41.9 cm, respectively), while the historical sample had the smallest mean for both sexes (42.5 cm and 40.7 cm, respectively) (Figure 4.9). The means of the historical samples were significantly smaller than those of individuals of the same sex in the modern samples (Scheffé Test $p < 0.01$), while the means of the archaeological samples were intermediate to individuals of the same sex in the other two sample groups. The mean femur length appeared to be associated with age in the pooled female data ($r = 0.23$), the archaeological female sample ($r = 0.57$) and in the historical male and female samples ($r = -0.90$ and -0.60 , respectively).

Table 4.16: Mean femur length according to study group.

	Females		Males		Degree of sexual dimorphism (%) *
	n	cm	n	cm	
Archaeological sample	17	41.4 ± 2.3	26	43.6 ± 2.3	5
Historical sample	7	40.7 ± 2.6	15	42.5 ± 2.0	4
Modern sample	117	41.9 ± 2.2	174	45.0 ± 2.5	7
Pooled data	141	41.8 ± 2.2	215	44.6 ± 2.5	7

* Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

4.4.2. Femur head diameter

The mean femur head diameter was larger in males than in females within each study group, though the difference was only significant in the modern sample (Mann-Whitney U-test $p < 0.01$) (Table 4.17). The degree of sexual dimorphism of the mean femur head diameter was similar for the three time period samples, with males being larger than females by 11% to 14%. The modern samples had the largest mean diameter for both males and females (46 mm and 41 mm, respectively), while the archaeological female sample had the smallest mean of the female samples (37 mm) and the means of the archaeological and historical male samples were equal (42 mm) (Figure 4.10). The means of both the archaeological and historical samples were significantly smaller than those of the modern samples (Scheffé Test $p < 0.01$). The mean femur head diameter appeared to be associated with age in the pooled female and male data ($r = 0.50$ and 0.41 , respectively), in the archaeological male sample ($r = 0.43$) and in the modern female and male samples ($r = 0.40$ and 0.33 , respectively).

Table 4.17: Mean femur head diameter according to study group.

	Females		Males		Degree of sexual dimorphism (%) *
	n	mm	n	mm	
Archaeological sample	18	37 ± 3.3	26	42 ± 4.0	14
Historical sample	13	38 ± 2.4	17	42 ± 2.9	11
Modern sample	117	41 ± 2.7	169	46 ± 3.3	12
Pooled data	148	40 ± 3.1	212	45 ± 3.7	13

* Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

4.5. Relationship between body size estimates and pelvic measurements

In the archaeological female sample, the only significant correlations between the pelvic measurements and the body size variables were between the transverse inlet diameter and the interspinous diameter ($r = 0.69$), and between the femur length and the anteroposterior inlet diameter ($r = 0.81$), the transverse inlet diameter ($r = 0.57$) and femur head diameter ($r = 0.69$).

In the archaeological male sample, the only significant correlations found were between the anteroposterior diameters of the pelvic inlet and outlet ($r = 0.60$), between the transverse diameter of the pelvic outlet and both the interspinous diameter ($r = 0.77$) and the anteroposterior diameter of the pelvic outlet ($r = 0.51$). The femur length and the femur head diameter were also significantly correlated ($r = 0.45$).

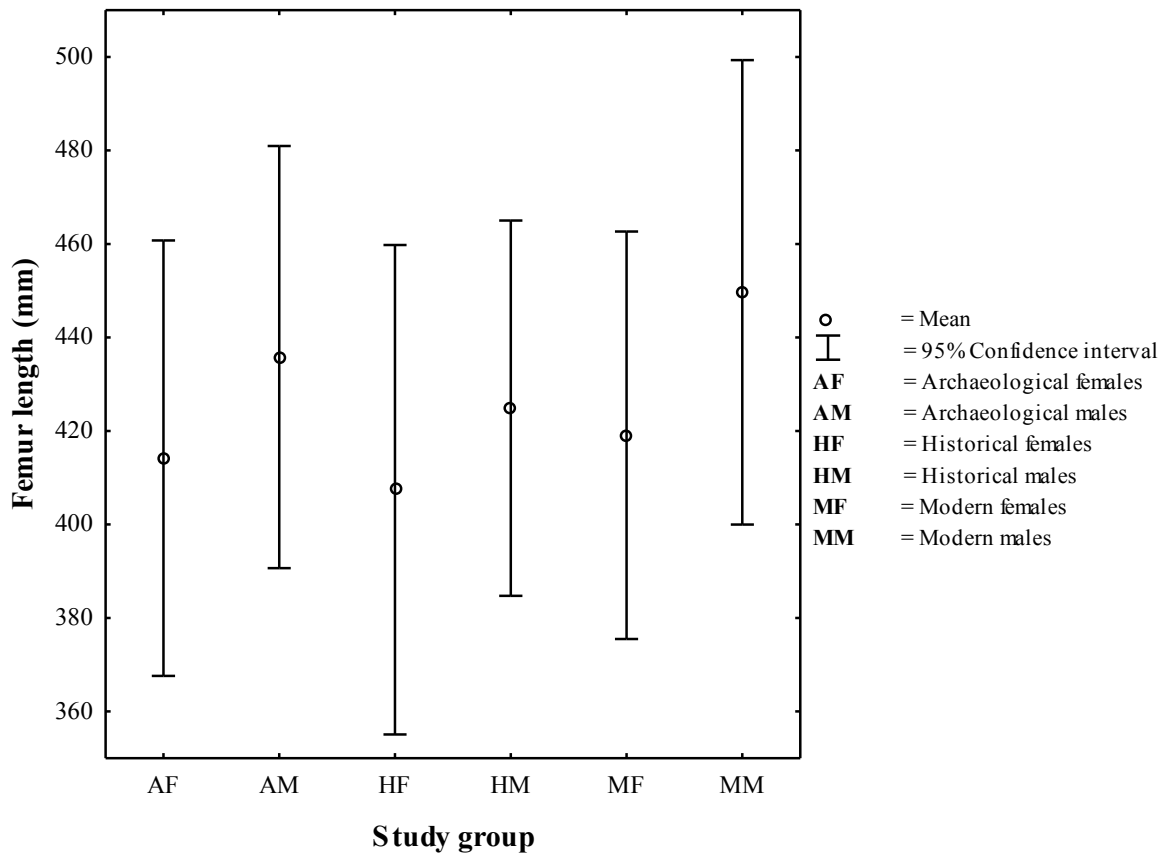


Figure 4.9: Mean plot of femur length according to study group.

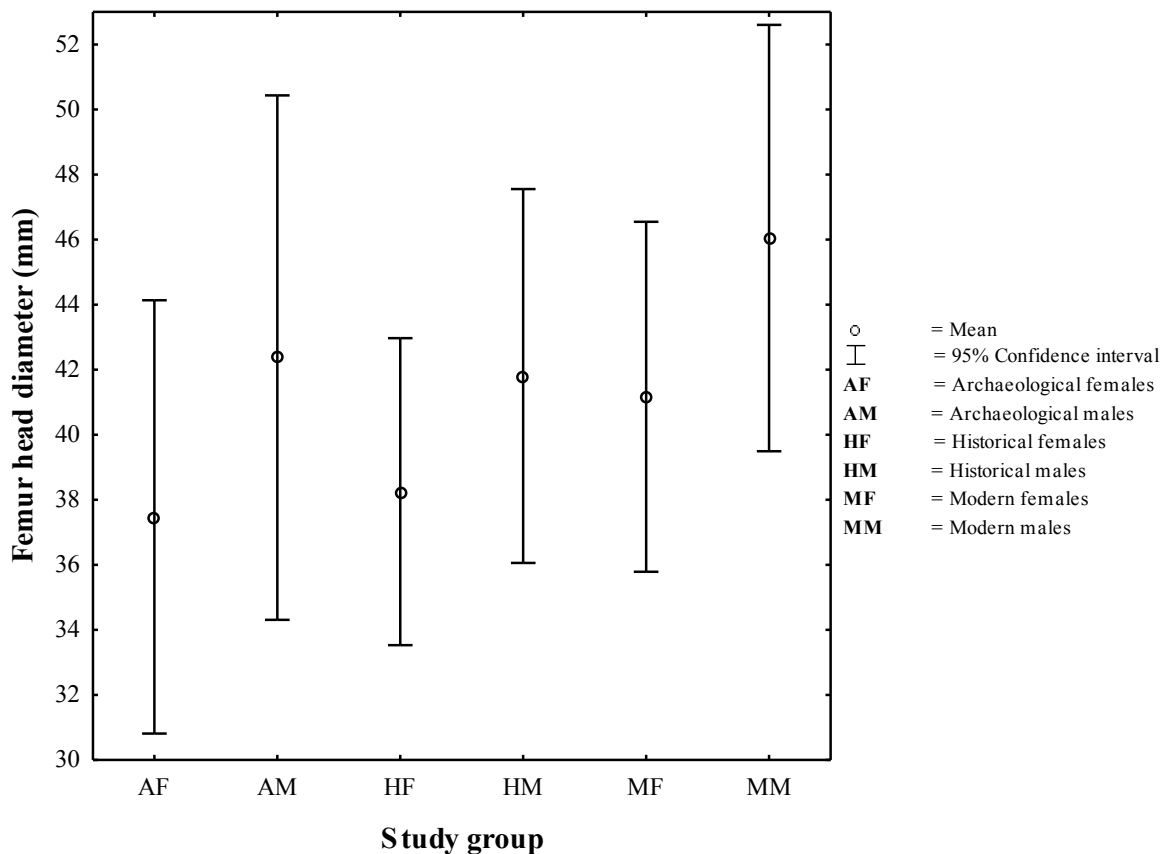


Figure 4.10: Mean plot of femur head diameter according to study group.

No significant correlation between the pelvic measurements and the body size variables were found in either the historical male or female samples.

The correlation coefficients of the pelvic measurements and body size variables of the modern female sample are given in Table 4.18. The anteroposterior inlet diameter was significantly correlated to all of the other measurements, except the interspinous diameter. The transverse inlet diameter was significantly correlated to all of the other measurements. The interspinous diameter was significantly correlated to the transverse inlet and outlet diameters ($r= 0.46$ and 0.60 , respectively) and to the femur length ($r= 0.27$). The anteroposterior outlet diameter was significantly correlated to the anteroposterior and transverse inlet diameters ($r= 0.49$ and 0.24 , respectively) and to the femur length (0.25). The femur length and the femur head diameter were also significantly correlated ($r= 0.65$).

Table 4.18: Significant correlations (*r*-values) between pelvic measurements and body size variables in the modern female data.

	Anteroposterior inlet diameter	Transverse inlet diameter	Interspinous diameter	Anteroposterior outlet diameter	Femur length
Transverse inlet diameter	0.51				
Interspinous diameter	—	0.46			
Anteroposterior outlet diameter	0.49	0.24	—		
Transverse outlet diameter	0.25	0.25	0.60	—	
Femur length	0.40	0.53	0.27	0.25	
Femur head diameter	0.39	0.58	—	—	0.65

— = not significant

The correlation coefficients of the pelvic measurements and body size variables of the modern male sample are given in Table 4.19. All of the measurements were significantly correlated to each other, with the exception of the interspinous diameter which was not significantly correlated to the anteroposterior inlet and outlet diameters.

Table 4.19: Significant correlations (*r*-values) between pelvic measurements and body size variables in the modern male data.

	Anteroposterior inlet diameter	Transverse inlet diameter	Interspinous diameter	Anteroposterior outlet diameter	Transverse outlet diameter	Femur length
Transverse inlet diameter	0.39					
Interspinous diameter	—	0.45				
Anteroposterior outlet diameter	0.43	0.29	—			
Transverse outlet diameter	0.28	0.50	0.68	0.18		
Femur length	0.44	0.46	0.20	0.42	0.28	
Femur head diameter	0.28	0.53	0.26	0.20	0.27	0.59

— = not significant

The correlation coefficients of the pelvic measurements and body size variables of the pooled female data are given in Table 4.20. All of the measurements were significantly correlated to each other, with the exception of the interspinous diameter which was not significantly correlated to the anteroposterior inlet and outlet diameters and the femur head diameter, and the interspinous diameter which was not significantly correlated to the transverse outlet diameter and the femur head diameter.

Table 4.20: Significant correlations (*r*-values) between pelvic measurements and body size variables in the pooled female data.

	Anteroposterior inlet diameter	Transverse inlet	Interspinous diameter	Anteroposterior outlet diameter	Femur length
Transverse inlet diameter	0.51				
Interspinous diameter	—	0.48			
Anteroposterior outlet diameter	0.46	0.26	—		
Transverse outlet diameter	0.28	0.26	0.55	—	
Femur length	0.44	0.52	0.29	0.28	
Femur head diameter	0.44	0.59	—	—	0.63

— = not significant

The correlation coefficients of the pelvic measurements and body size variables of the pooled male data are given in Table 4.21. All of the measurements were significantly correlated to each other,

with the exception of the interspinous diameter which was not significantly correlated to the anteroposterior inlet and outlet diameters, and the transverse outlet diameter which was not significantly correlated to the anteroposterior outlet diameter.

Table 4.21: *Significant correlations (r-values) between pelvic measurements and body size variables in the pooled male data.*

	Anteroposterior inlet diameter	Transverse inlet diameter	Interspinous diameter	Anteroposterior outlet diameter	Transverse outlet diameter	Femur length
Transverse inlet diameter	0.40					
Interspinous diameter	—	0.45				
Anteroposterior outlet diameter	0.44	0.26	—			
Transverse outlet diameter	0.29	0.48	0.71	—		
Femur length	0.49	0.49	0.30	0.39	0.30	
Femur head diameter	0.32	0.54	0.21	0.19	0.34	0.62

— = not significant

4.6. Variation in pelvic measurements

The mean measurements of the articulated pelvic girdle for each of the samples are given in Table 4.22. The sizes of the samples used for each of these measurements are given in Appendix B.

4.6.1. Anteroposterior diameter of the pelvic inlet

The anteroposterior diameter of the pelvic inlet was larger in females than in males within each sample group, though the difference was only significant in the modern sample (Mann-Whitney U-test $p < 0.01$). The degree of sexual dimorphism of the anteroposterior inlet diameter was similar for the three time period samples, with females having mean diameters that were 8% to 11% larger than those of males (Table 4.23). The modern sample had the largest mean for both males and females (111 mm and 102 mm, respectively), while the historical sample had the smallest means for both sexes (100 mm and 89 mm, respectively) (Figure 4.11). The archaeological and historical samples had significantly smaller means than the modern sample (Scheffé Test $p < 0.01$). The anteroposterior diameter of the pelvic inlet was not significantly associated to age in any of the sample groups.

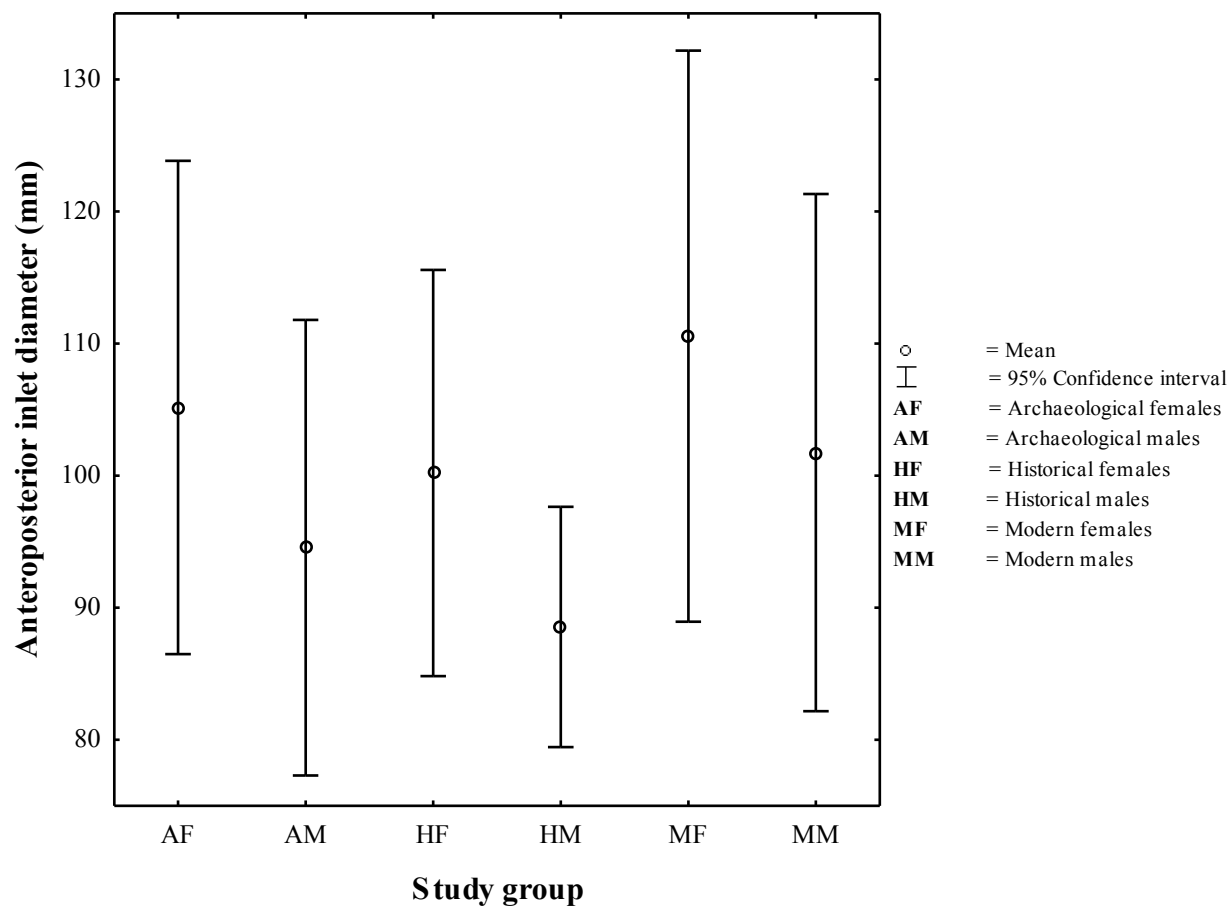


Figure 4.11: Mean plot of the anteroposterior inlet diameter according to study group.

Table 4.22: Mean measurements of the articulated pelvic girdle according to study group.

	Archaeological sample		Historical sample		Modern sample		Pooled data	
	Females	Males	Females	Males	Females	Males	Females	Males
Anteroposterior inlet diameter (mm)	105 ± 9.3	95 ± 8.6	100 ± 7.7	89 ± 4.5	111 ± 10.8	102 ± 9.8	110 ± 10.8	101 ± 10.0
Transverse inlet diameter (mm)	117 ± 11.3	106 ± 8.1	121 ± 2.1	112 ± 1.0	124 ± 9.5	115 ± 9.4	123 ± 9.9	114 ± 9.6
Interspinous diameter (mm)	104 ± 9.3	82 ± 8.3	106 ± 5.5	78 ± 5.9	105 ± 7.6	86 ± 8.3	105 ± 7.7	85 ± 8.4
Anteroposterior outlet diameter (mm)	118 ± 10.8	106 ± 7.2	121 ± 4.8	100 ± 5.2	118 ± 9.3	107 ± 8.6	118 ± 9.4	107 ± 8.4
Transverse outlet diameter (mm)	119 ± 7.7	94 ± 11.6	119 ± 3.6	93 ± 4.9	124 ± 10.0	103 ± 12.2	123 ± 9.8	102 ± 12.5

Table 4.23: Degree of sexual dimorphism of pelvic measurements according to study group.

	Degree of sexual dimorphism (%) *			
	Archaeological sample	Historical sample	Modern sample	Pooled data
Anteroposterior inlet diameter	-10	-11	-8	-8
Transverse inlet diameter	-9	-7	-7	-7
Interspinous diameter	-21	-26	-18	-19
Anteroposterior outlet diameter	-10	-17	-9	-9
Transverse diameter	-21	-22	-17	-17

* Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

4.6.2. Transverse diameter of the pelvic inlet

The transverse diameter of the pelvic inlet was larger in females than in males within each sample group, though the difference was only significant in the modern sample (Mann-Whitney U-test $p < 0.01$). The degree of sexual dimorphism of the transverse inlet diameter was similar for the three time period samples, with females being larger than males by 7% to 9% (Table 4.23). The transverse inlet diameter was also found to be the least dimorphic of the pelvic measurements. The modern sample had the largest mean for both males and females (115 mm and 124 mm, respectively), while the archaeological sample had the smallest means for both sexes (106 mm and 119 mm, respectively) (Figure 4.12). The means of the archaeological samples were significantly smaller than those of the modern samples (Scheffé Test $p < 0.01$). The means of the historical samples were intermediate to the archaeological and modern samples and did not differ significantly from either. The transverse diameter of the pelvic inlet appeared to be associated with age in the pooled female and male data ($r = 0.38$ in both cases), and in the modern female and male samples ($r = 0.35$ and 0.33 , respectively).

4.6.3. Interspinous diameter

The interspinous diameter of the pelvic canal was significantly larger in females than in males in all of the samples (Mann-Whitney U-test $p < 0.01$). The interspinous diameter was the most dimorphic of the pelvic measurements (Table 4.23), with the historical sample having a larger degree of sexual dimorphism of this diameter (females larger than males by 26%) than the archaeological and modern samples (females larger than males by 21% and 18%, respectively). The largest mean of the female samples was that of the historical female sample (106 mm), while the archaeological female sample had the smallest mean of the female samples (104 mm) (Figure 4.13). The largest mean of the male samples was that of the modern male sample (86 mm), while the historical male sample had the smallest mean of the male samples (78 mm). The interspinous diameter was, however, not significantly associated with the time period sample from which the individual came (Scheffé Test $p = 0.15$). The interspinous diameter appeared to be associated with age in the pooled female and male data ($r = 0.22$ and 0.21 , respectively), and in the modern female and male samples ($r = 0.24$ and 0.17 , respectively).

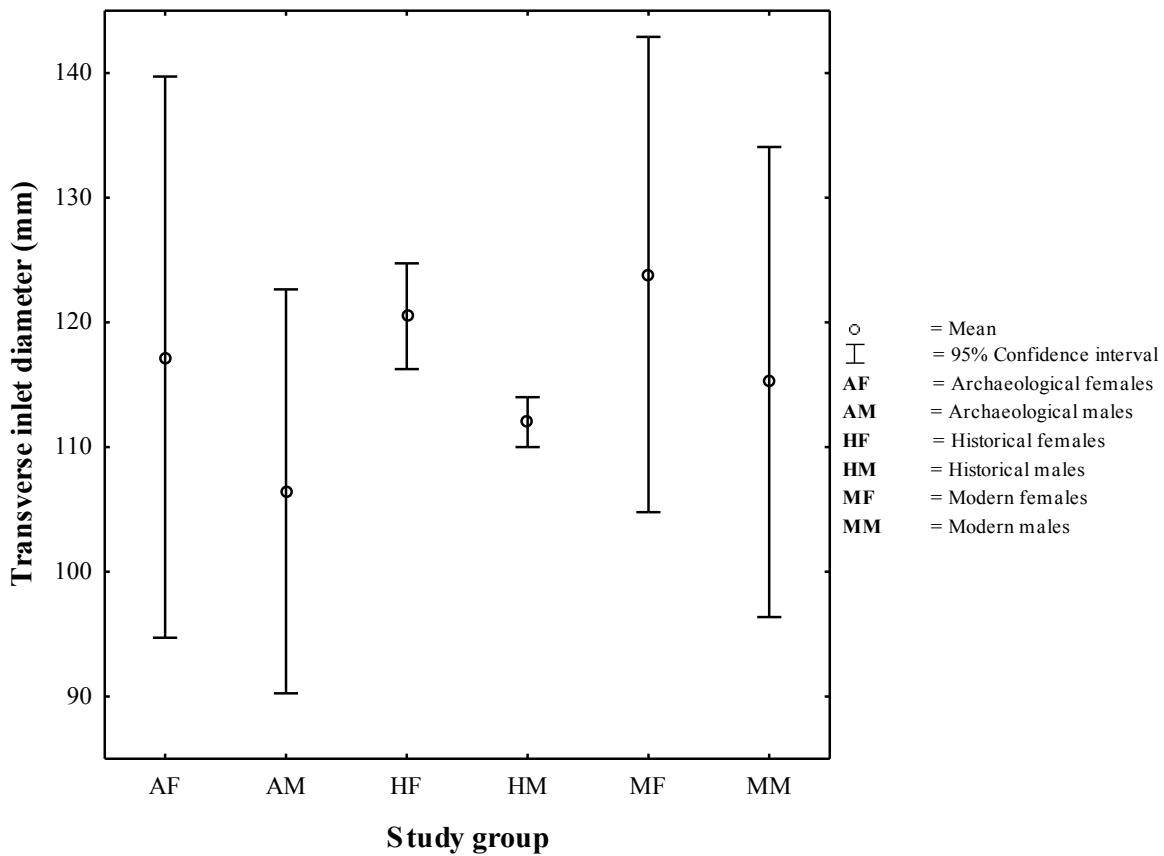


Figure 4.12: Mean plot of the transverse inlet diameter according to study group.

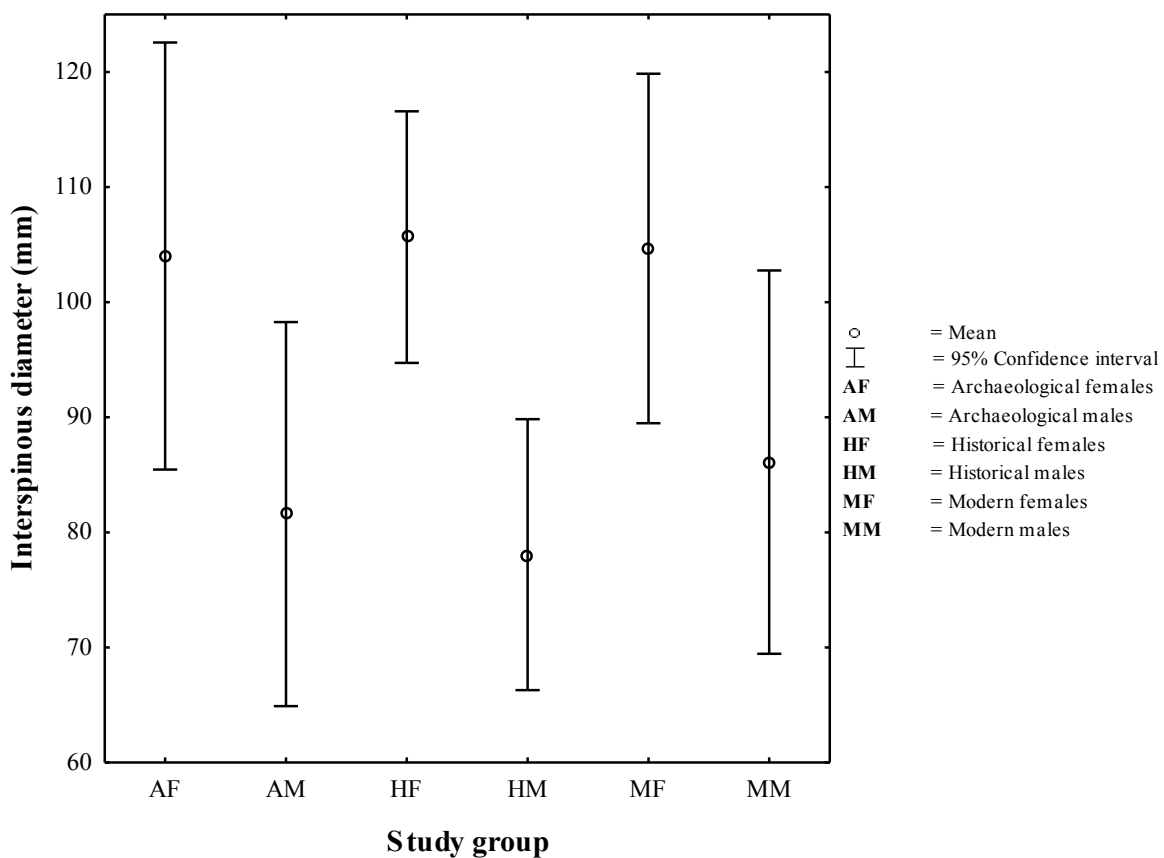


Figure 4.13: Mean plot of the interspinous diameter according to study group.

4.6.4. Anteroposterior diameter of the pelvic outlet

The anteroposterior diameter of the pelvic outlet was significantly larger in females than in males in all except the historical sample (Mann-Whitney U-test $p \leq 0.01$). The degree of sexual dimorphism of the anteroposterior outlet diameter was similar for the archaeological and modern samples, with females being larger than males by 10% and 9%, respectively (Table 4.23). The degree of dimorphism in the historical sample, however, was greater than those of the other two samples, with females being larger than males by 17%. The historical female sample had the largest mean diameter (121 mm), while the means of the archaeological and modern samples were equal (118 mm) (Figure 4.14). The largest mean diameter of the male samples was that of the modern male sample (107 mm), while the mean of the historical male sample was the smallest (100 mm). The mean anteroposterior diameter of the pelvic outlet was not significantly associated with either age (Kruskall-Wallis test $p = 0.84$) or the time period from which the individual came (Kruskall-Wallis $p = 0.65$).

4.6.5. Transverse diameter of pelvic outlet

The transverse diameter of the pelvic outlet was significantly larger in females than in males in all except the historical sample (Mann-Whitney U-test $p < 0.01$). The degree of sexual dimorphism of the transverse outlet diameter was similar for the three time period samples, with females being larger than males by 17% to 22% (Table 4.23). The transverse outlet diameter was also found to be one of the least dimorphic of pelvic measurements. The modern sample had the largest mean diameter for both males and females (103 mm and 123 mm), while the historical sample had the smallest mean for both sexes (92 mm and 118 mm, respectively) (Figure 4.15). The means of the archaeological samples were significantly smaller than those of the modern samples (Scheffé Test $p < 0.01$). The means of the historical samples were intermediate to the archaeological and modern samples and did not differ significantly from either. The transverse diameter of the pelvic outlet appeared to be associated with age in the pooled female and male data ($r = 0.21$ and 0.26 , respectively) and in the modern male sample ($r = 0.20$).

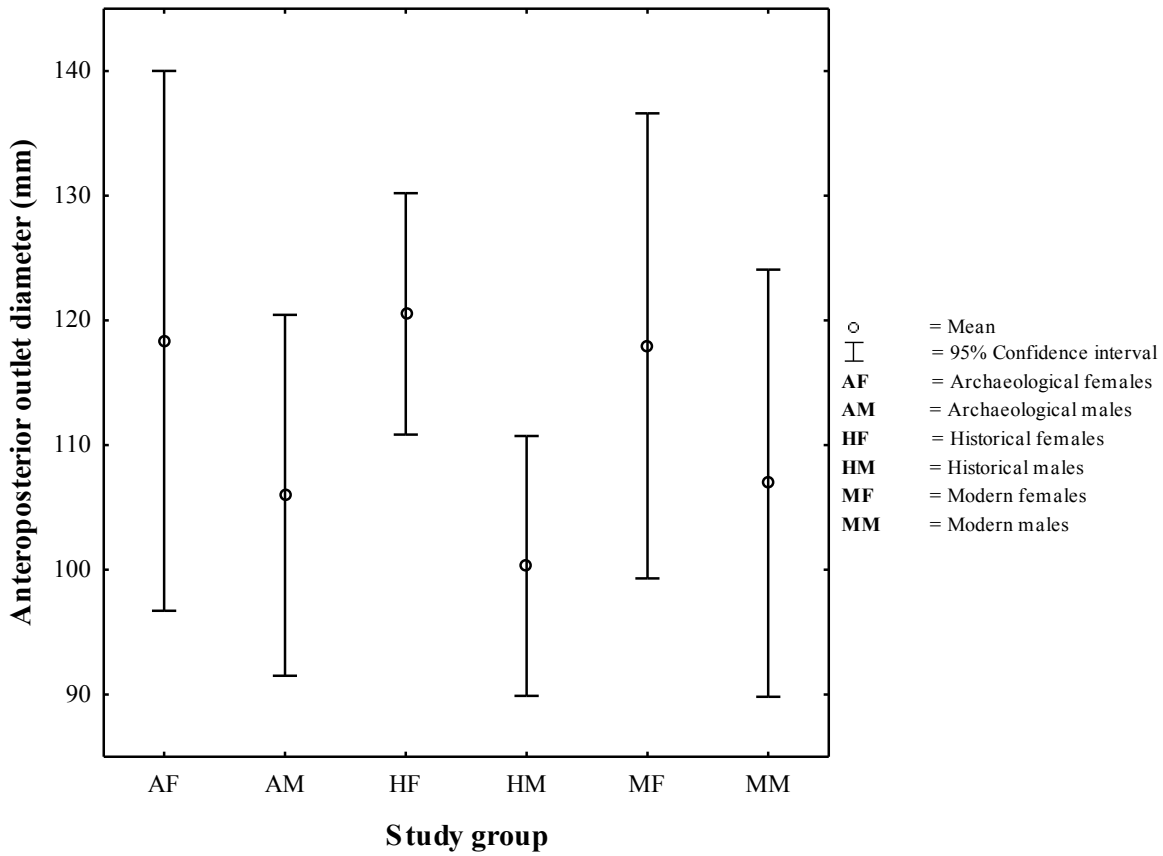


Figure 4.14: Mean plot of the anteroposterior outlet diameter according to study group.

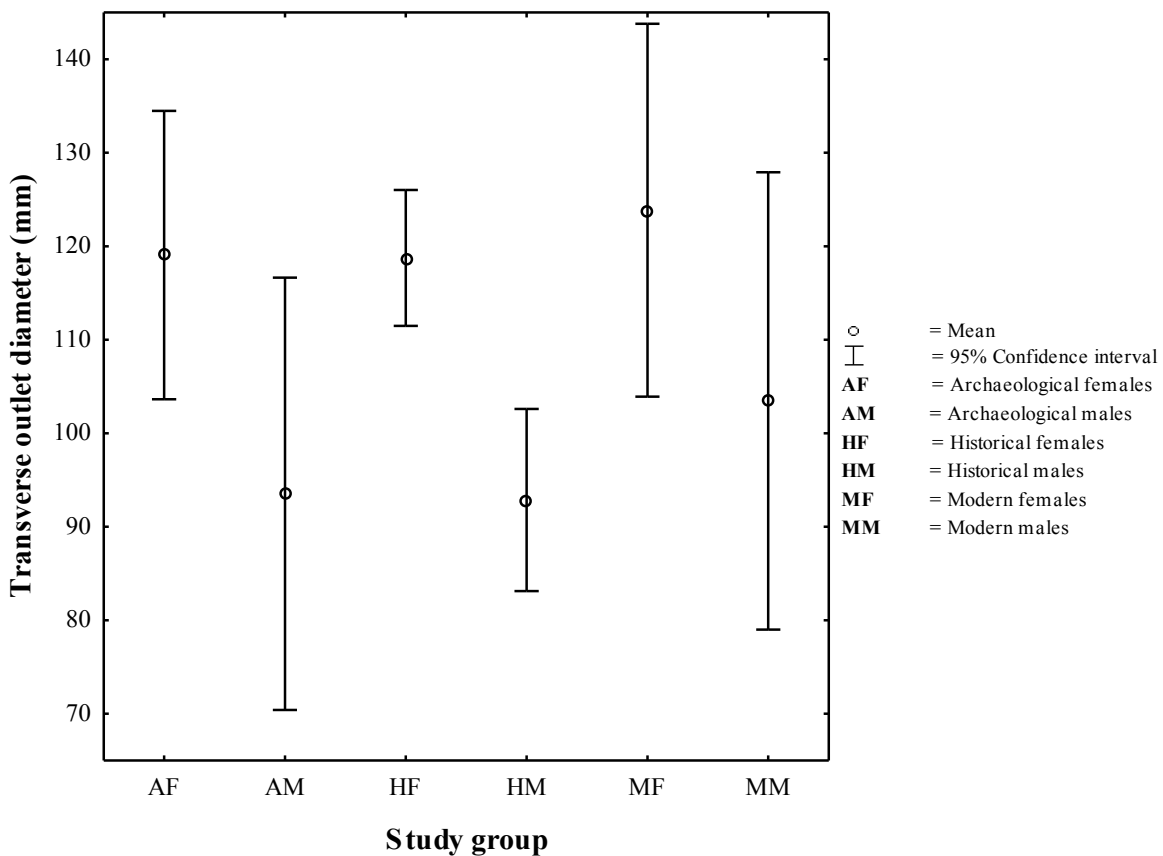


Figure 4.15: Mean plot of the transverse outlet diameter according to study group.

4.7. Relationship between body and pelvic size and scar manifestation

Table 4.24 shows the eigenvalues and percentages of the total variance of each of the 12 possible principal components that could be used. Only the first three components presented with eigenvalues greater than 1.0 and were thus retained for further analysis. The combined amount of variance accounted for by these three components was approximately 60%.

Table 4.24: *Eigenvalues and percentage of total variance of the twelve possible principal components.*

Principal component	Eigenvalue	Percentage of total variance	Cumulative percentage of total variance
1	4.1	34.4	34.4
2	2.0	16.9	51.2
3	1.0	8.5	59.7
4	0.9	7.6	67.4
5	0.8	6.9	74.2
6	0.8	6.5	80.8
7	0.7	5.8	86.5
8	0.5	4.0	90.6
9	0.4	3.7	94.2
10	0.3	2.7	96.9
11	0.2	2.0	98.9
12	0.1	1.1	100

The first principal component accounted for 34.4% of the total variance, and as can be seen in Table 4.25a and Figures 4.16 and 4.17, primarily contrasted the body size variables (strongest negative coefficients) with the pelvic size variables (strong positive coefficients). All of the scar features were positively correlated to this component, except the extension of the pubic tubercle which showed weak negative correlation of -0.10.

Table 4.25a: *Eigenvalue coefficients of the first principal component.*

Variable	Eigenvalue coefficient
Interspinous diameter	0.87
Transverse outlet diameter	0.84
Interosseous groove	0.65
Transverse inlet diameter	0.62
Anteroposterior outlet diameter	0.62
Preauricular sulcus	0.54
Anteroposterior inlet diameter	0.52
Dorsal pubic pitting	0.52
Iliac tuberosity	0.27
Pubic tubercle	-0.10
Femur length	-0.48
Femur head diameter	-0.57

The second principal component accounted for 16.9% of the total variance. Table 4.25b and Figures 4.16 and 4.18 show that all of the variables were positively loaded on this component, except dorsal pubic pitting which was negatively loaded with a coefficient of -0.28, and the interspinous diameter which had a coefficient of 0.

Table 4.25b: *Eigenvalue coefficients of the second principal component.*

Variable	Eigenvalue coefficient
Femur length	0.70
Femur head diameter	0.65
Pubic tubercle	0.58
Transverse inlet diameter	0.50
Iliac tuberosity	0.47
Anteroposterior inlet diameter	0.40
Anteroposterior outlet diameter	0.21
Preauricular sulcus	0.19
Transverse outlet diameter	0.02
Interosseous groove	0.01
Interspinous diameter	0
Dorsal pubic pitting	-0.28

The third principal component accounted for 8.5% of the total variance and primarily contrasted the pelvic diameters and scars on the anterior pelvic girdle (strongest negative coefficients) with the scars on the posterior pelvic girdle (strongest positive coefficients), as can be seen in Table 4.25c and Figures 4.17 and 4.18.

Table 4.25c: *Eigenvalue coefficients of the third principal component.*

Variable	Eigenvalue coefficient
Preauricular sulcus	0.51
Iliac tuberosity	0.45
Interosseous groove	0.39
Anteroposterior outlet diameter	0.01
Pubic tubercle	-0.04
Femur head diameter	-0.04
Interspinous diameter	-0.08
Femur length	-0.11
Transverse outlet diameter	-0.15
Transverse inlet diameter	-0.23
Dorsal pubic pitting	-0.35
Anteroposterior inlet diameter	-0.43

Figures 4.19 – 4.21 are scatterplots of the individual component scores for the first three principal components, showing the distribution of the scores for each component for males and females. The sexes were clearly separated according to the first principal component, showing very little overlap between males and females, but not according to the second or third components, which both showed large areas of overlap between the sexes.

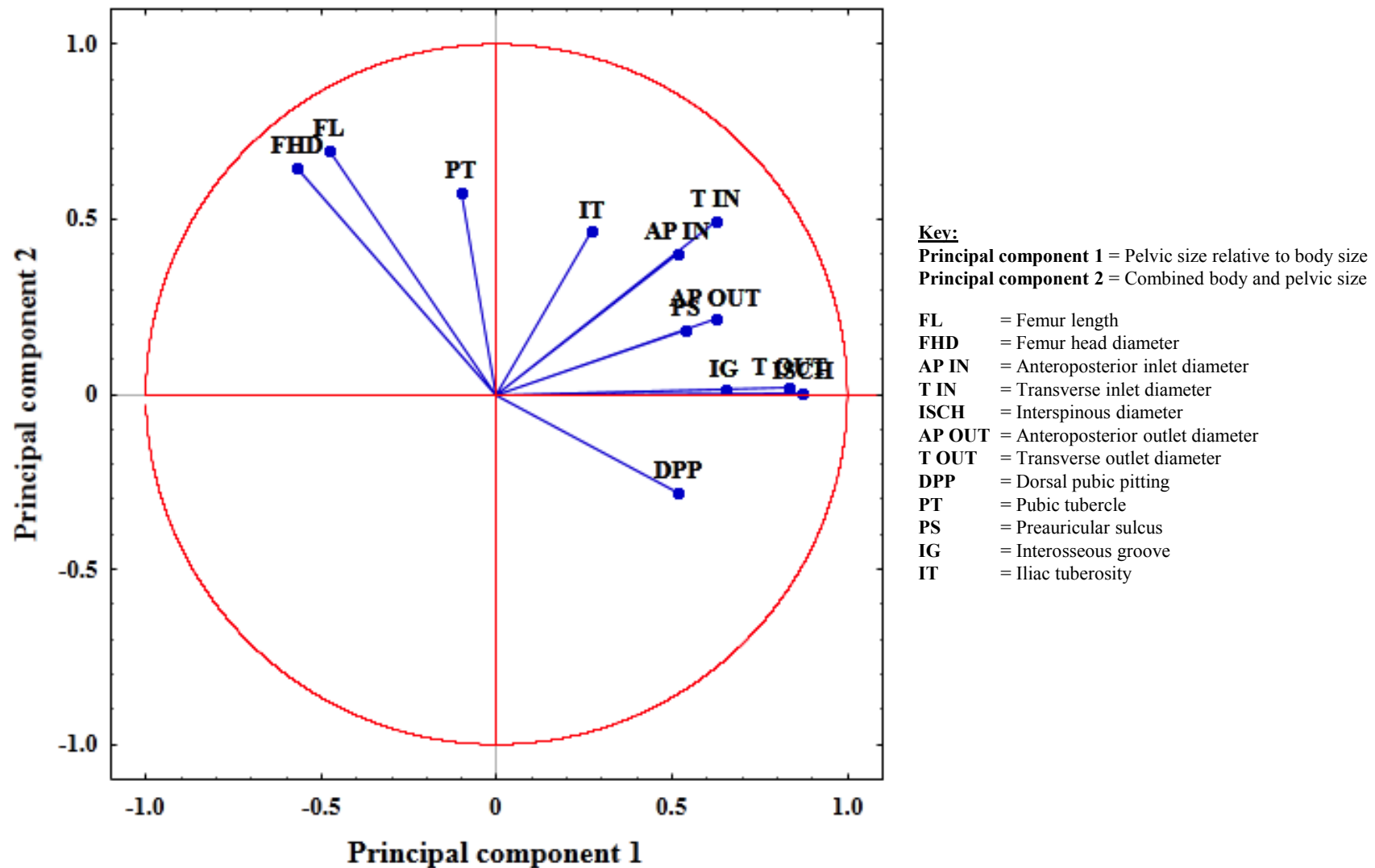


Figure 4.16: Biplot of the first and second principal components showing the relationships of the scar, body size and pelvic size variables to each of these components.

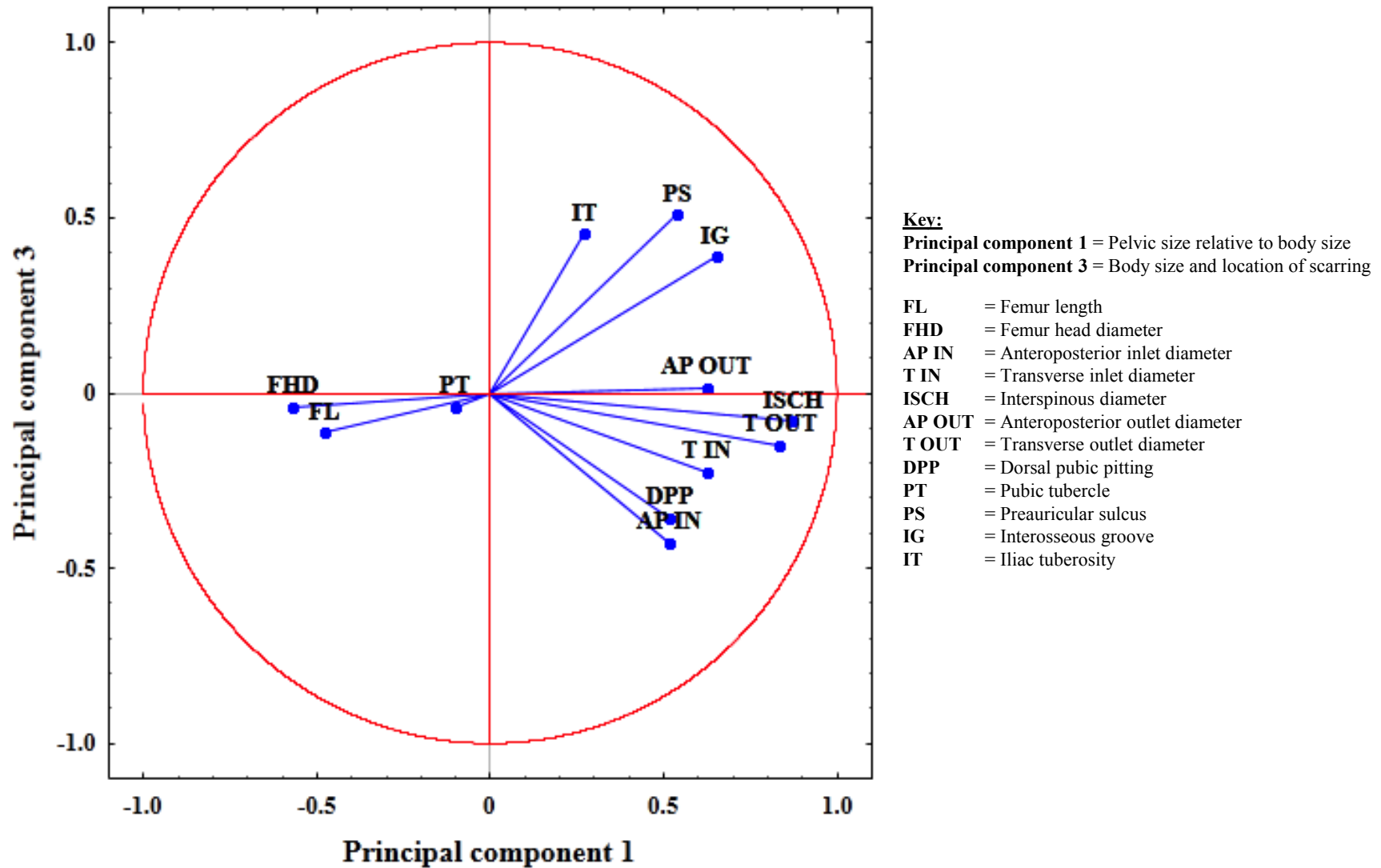


Figure 4.17: Biplot of the first and third principal components showing the relationships of the scar, body size and pelvic size variables to each of these components.

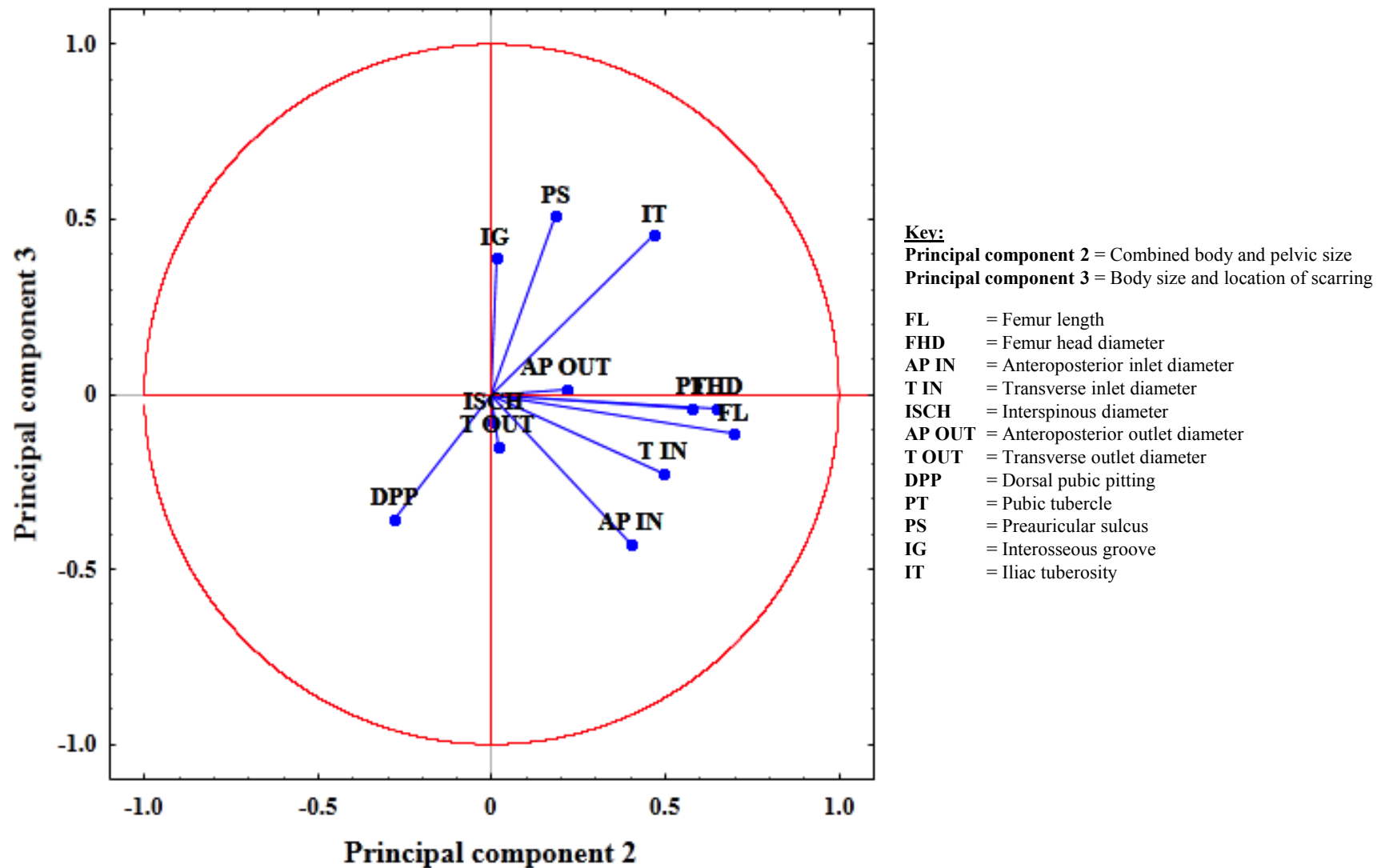


Figure 4.18: Biplot of the second and third principal components showing the relationships of the scar, body size and pelvic size variables to each of these components.

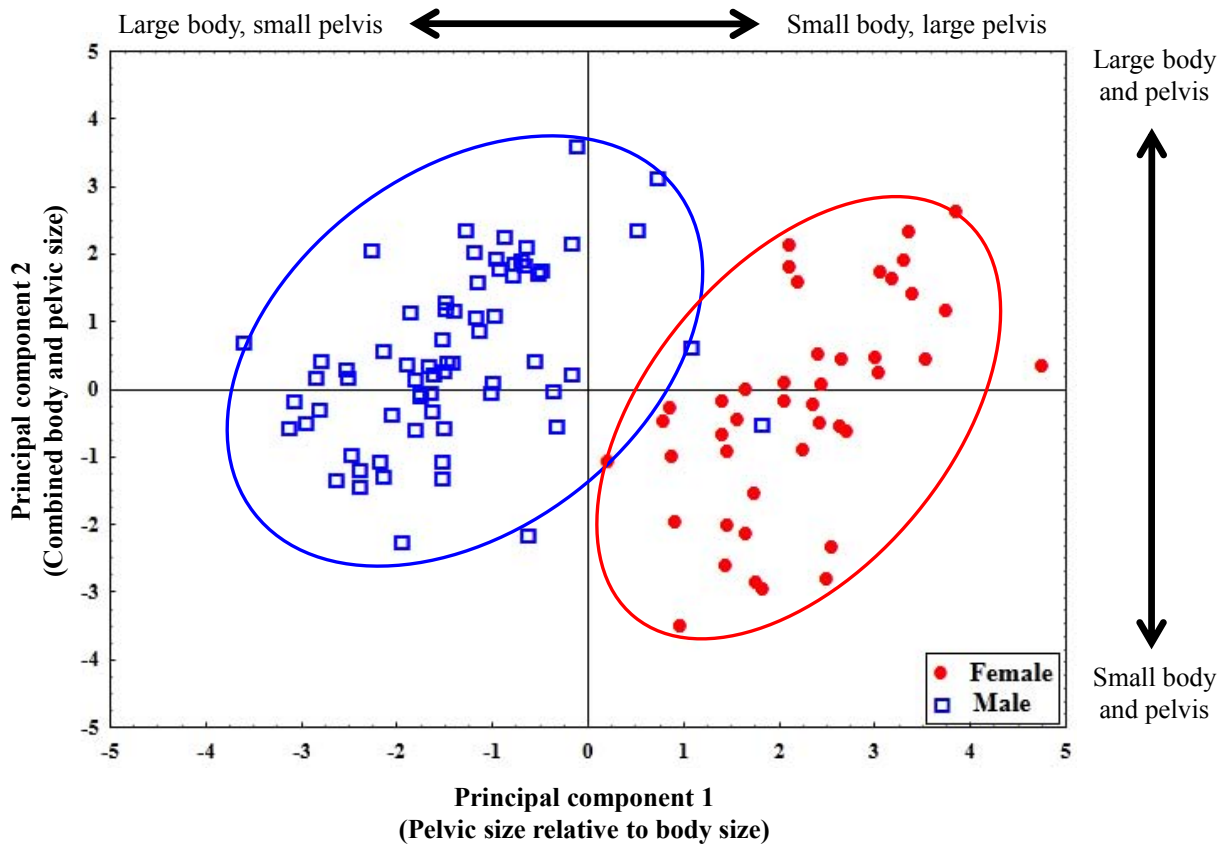


Figure 4.19: Score plot of individual component scores of males and females for the first and second principal components.

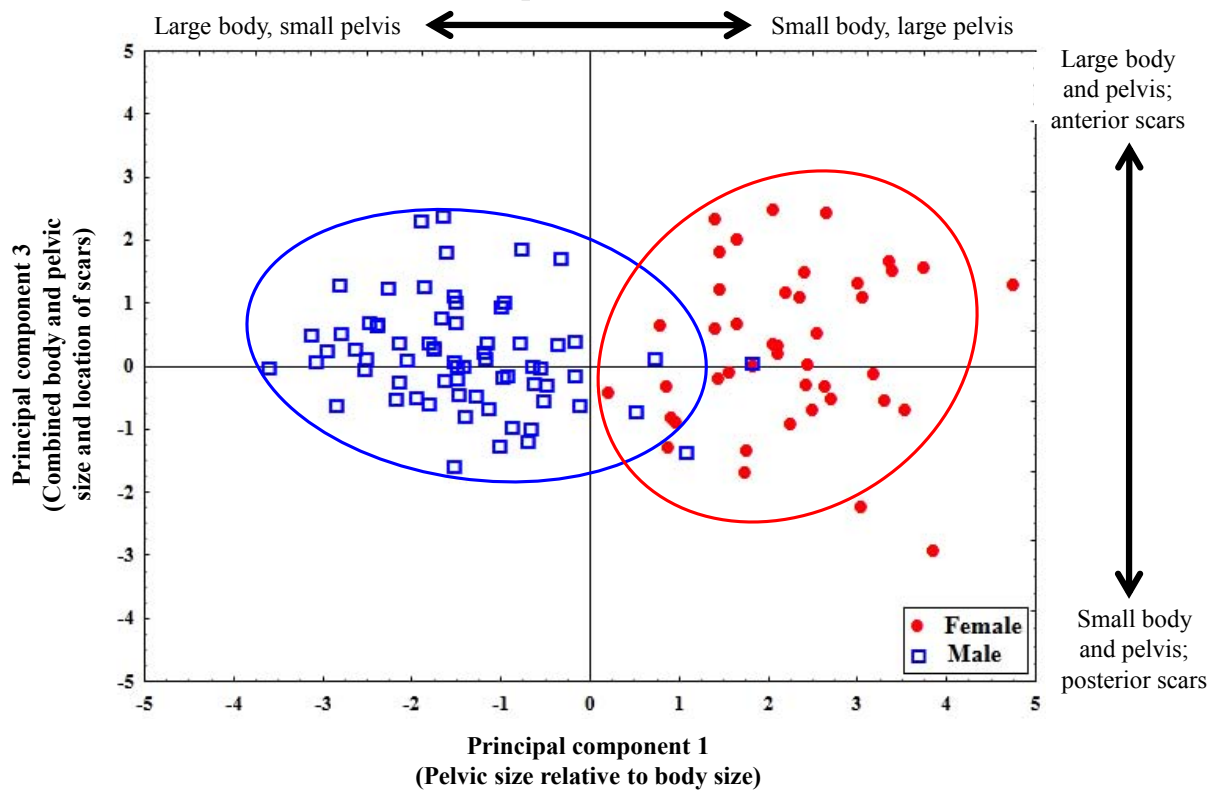


Figure 4.20: Score plot of individual component scores of males and females for the first and third principal components.

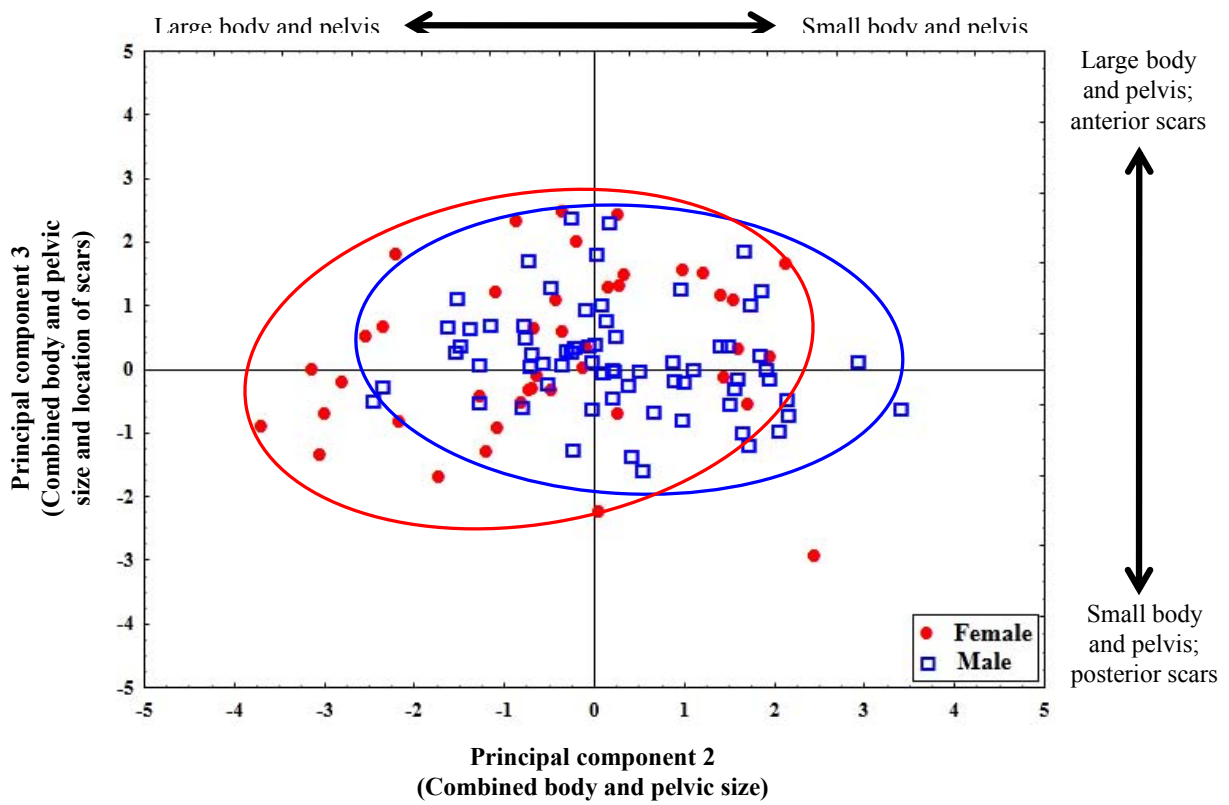


Figure 4.21: Score plot of individual component scores of males and females for the second and third principal components.

DISCUSSION

5.1. Problems with methodology

This study utilized the most commonly used system of classification of pitting on the dorsal pubic surface, defined by Stewart (1970), which classifies the pitting as either “absent”, “trace to small” or “medium to large”, based mainly on the diameter of the pits. It was noted early in the study that, because of the 2mm cut-off between “trace to small” and “medium to large”, no pits were classified as “trace to small”, while pits that are just visible were classified in the same group as very large and prominent pits. Other studies have also reported difficulty in using this system of classification (Suchey *et al*, 1979). The only alternative classification found in the literature was that of Ullrich (1975), but this system did not provide a solution, as it is very similar to that of Stewart (1970) except for the cut-off now being 3mm, which would result in the same distribution of results. It was thus decided to continue analysis with the original Stewart classification.

5.2. Scar manifestation according to sex, age and time period sample

5.2.1. Differences between sexes

The occurrence and severity of scarring at all of the sites examined, with the exception of the iliac tuberosity, were significantly associated with sex. In the case of the occurrence of dorsal pubic pitting and the appearance of the preauricular sulcus and interosseous groove, females presented with more severe scarring than males (c.f. Tables 4.1, 4.7, 4.10). The fact that significant proportions of the male sample also presented with scarring, albeit to a lesser degree than females, indicated that parturition was not the only cause of scar formation. Angel (1969) suggested that if scarring is present in males, the cause of this scarring is likely related to disease or trauma. While this may have been true for the small proportion of males that presented with dorsal pubic pitting (n= 5), the proportions of males that presented with more severe scarring at the preauricular sulcus and interosseous groove do not support this claim. While the occurrence of scarring in both sexes suggested that the cause of the strain acting on the ligaments was the same, the fact that females presented with more severe scarring suggested that the magnitude of the strain was larger in females than in males. Despite the majority of the female individuals presenting with more severe scars than

the male individuals, large proportions of the female sample also presented with less severe scarring, similar to those of the male sample. Angel (1969), Houghton (1974 and 1975) and Kelley (1979) reported similar results, suggesting that those females that had more severe scarring were parous and those that presented with less severe scarring similar to that of the males were nulliparous. Since the parity histories of the individuals examined in the present study were not available, this claim could not be tested.

The pubic tubercle was the only scar feature that was larger in males than in females (c.f. Table 4.13). While the majority of individuals of both sexes presented with moderately extended tubercles, the majority of the remaining individuals in the male sample had large tubercles, while the majority of the remaining individuals of the female sample had small tubercles. This indicated that the strain of the rectus abdominis muscle on its attachment site at the tubercle was larger in males than in females, possibly due to males generally being more muscular than females and also performing more activities that involve flexion of the trunk and carrying of heavy loads (Ruff, 1987; Abitbol, 1996). The large overlap in the appearance of the tubercle between sexes could thus simply have been a reflection of the differences in body size and activity patterns between sexes. Alternatively, the similarity may also have been due to the extension of the tubercle in females after pregnancy which could have caused it to become extended to a similar degree to those of males, as suggested by Cox & Scott (1992). Again, since parity histories of the individuals examined were not available, the effect of pregnancy-related strain on the extension of the tubercle could not be tested for directly. The influence of body size on the tubercle was, however, examined and will be discussed in a later section.

Scarring was present in both sexes, and thus pregnancy and parturition-related strains were not the only causes of scar formation. Andersen (1986) suggested that scar formation was the result of excess movement allowed by the more flexible architecture of the female pelvic girdle and that this increased flexibility caused an increase in the strain on the pelvic ligaments, resulting in the remodelling of the ligamentous attachment sites and the formation of more severe scars in females. It thus appears that weight-bearing strain on the pelvic ligaments may be the primary cause of scar formation, with the capacity of the pelvic ligaments to absorb this strain determining the severity of the resulting scar formation. The fact that pregnancy-related strain is essentially an extreme form of weight-bearing, could explain the association of scar formation and parity history reported in the literature.

5.2.2. Differences in scar manifestation between age groups

5.2.2.1. Difficulties in investigating the effect of age on scar manifestation

Investigating the effect of age on skeletal material of archaeological and historical origin tends to be problematic, since the age at death of such individuals can only be estimated. The range of error associated with these estimations may cause some correlations that are not truly significant to appear significant or correlations that are truly significant to not be detected as such (O'Connell, 2004). The small sizes of archaeological and historical samples further confound the problem. On the other hand, accurate ages of skeletal material of cadaveric origin are generally readily available and allow for more accurate assessment of the effects of age. In this study, both archaeological and historical individuals whose ages had to be estimated and modern individuals whose ages were known were examined. To reduce the possible effect of error associated with age estimates on the analyses being performed, all individuals were divided into broad age ranges. The disadvantage of this was, however, that the sensitivity at which potential relationships between age and the scar features could be detected was reduced. Differences in life expectancy in different time period samples also complicate the investigation of the effect of age on skeletal material. It has been reported that the average life expectancy of individuals such as those in the archaeological sample of this study, would have been about 33 years (Patrick, 1989), while the life expectancy of modern South African individuals such as those in the modern sample was between 50 and 60 years (World Bank, 2012). This would mean that the majority of available archaeological material would be of young individuals and may not yet show the effects of old age, while the modern samples would lack sufficient young individuals to allow detection of age-related changes.

5.2.2.2. The effect of age on scar manifestation

It has been reported that young females are more likely to experience parturition-related trauma (and hence present with more scarring), since they are at a higher risk of developing complications during labour due to the immaturity of their pelvis (Stewart, 1970; Treffers *et al.*, 2001). Age is also a reflection of the interval between the birth event and the death of the mother, with older individuals generally having longer intervals between these events than young individuals. Houghton (1974), Kelley (1979) and Bergfelder & Herrmann (1980) suggested that since the strain associated with pregnancy and parturition will no longer be present after the last birth event, it can be expected that remodelling of the bone would gradually cause parturition scars to recede over time.

In this study, the appearance of scars at the dorsal pubic surface, preauricular sulcus and interosseous groove were not significantly associated with age (c.f. Tables 4.2, 4.8, 4.11). This lack

of change in scarring with age indicated that the strains acting on the pelvic ligaments and that caused scar formation remained fairly constant with age. The development of the other ligamentous attachment site examined, the iliac tuberosity, was significantly associated with age (c.f. Tables 4.14 and Figure 4.8) and showed an increase, rather than decrease, in size with age, suggesting that the strains on the ligaments attached to the tuberosity increased with age. The extension of the pubic tubercle was also significantly associated with age (c.f. Table 4.5 and Figure 4.5), and like the iliac tuberosity, increased with age, suggesting that the strain on the rectus abdominis muscle which attaches at the pubic tubercle increased with age. In all of these cases, the observed lack of change or the increase in strain on the attachment sites was the opposite of what was expected if pregnancy and parturition-related strains were the cause of scar formation. These results were similar to those reported by Suchey *et al.* (1979), who found that females that died more than 15 years after the last birth event tended to have larger scars than those who died within a shorter interval. Suchey *et al.* (1979) also reported that nulliparous females older than 30 years presented with more pitting on the dorsal pubic surface than those younger than 30 years old.

Comparison of scar manifestation between age groups showed that scarring was either not associated with age or increased in severity with age. This indicated that the strains causing scar formation remained fairly constant or may even have increased with age. Since the strains of pregnancy and parturition are transient in nature, it is unlikely that such strains are the cause of scar formation. This is in agreement with the results of the comparison of scar manifestation between sexes, which suggested that the strains acting on the pelvic ligaments in order to maintain pelvic stability may have been the cause of scar formation. Such strains would have been present until death and may even have increased with age due to age-related changes in stature, body mass or body composition (Deurenberg *et al.*, 1991; Ruff *et al.*, 1991; Galloway *et al.*, 1998), resulting in changes like those observed in this study.

5.2.3. Differences in scar manifestation between time period samples

The three time period samples of this study were expected to have experienced very different living conditions. The archaeological sample consisted of Later Stone Age (LSA) individuals, who were mostly hunter-gatherers that lived active lifestyles involving lots of walking or running, but not the strenuous labour associated with agricultural practices, and who often had to survive on restricted food resources (Deacon & Deacon, 1999; Sealy & Pfeiffer, 2000; Parkington, 2001). The historical sample consisted of individuals from the Cobern Street and Marina Residence sites, which are reported to have lived hard lives involving prolonged strenuous physical labour (Friedling, 2007). The modern sample consisted of 20th century cadaveric and forensic individuals that lived less

active Western lifestyles involving little strenuous activity and had access to food resources of greater quality and quantity than those of the other samples (Puoane *et al.*, 2002; Cole, 2003; Driscoll, 2010).

None of the five areas of scarring examined in this study differed significantly between the three time period samples (c.f. Tables 4.3, 4.6, 4.9, 4.12 and 4.15). This indicated that the temporal and cultural differences between these samples did not significantly influence the manifestation of scarring. Cox (1989) reported that scarring was more common in larger-bodied individuals and thus it was expected that the larger-bodied modern individuals of the present study would have presented with more developed scars than those of the smaller-bodied archaeological and historical samples. This was, however, not the case, which suggested that the magnitude of the strains acting on the ligaments and muscles that attach to the sites where scarring occurs was similar in the three time period samples.

5.2.4. Summary

Scarring was present in both sexes, suggesting that the cause of scar formation was common to both sexes. The degree of scarring was, however, greater in females. This may have been due to the need for female pelvises to have more flexible articulation to allow widening of the pelvic canal during labour. This increased flexibility would have reduced the stability of the girdle and would thus have created the need for increased ligamentous stabilization, which in turn would have caused increased remodelling of the sites where the ligaments attach to the bones of the pelvis. If pregnancy and parturition-related strains were the primary causes of scar formation, one would expect the scars to become reduced over time due to the transient nature of such strains. The results of this study showed that the degree of development of all of the scar features either increased with age or remained unchanged and that the strain causing scar formation thus either increased or remained constant with age. None of the scar features examined differed between the modern, historical and archaeological time period samples. This suggested that the magnitude of the strains that lead to scar formation were not significantly affected by the temporal and cultural differences between the three time period samples.

5.3. Relationship between scar features

The scar features of the archaeological male and female samples and the historical female sample were not significantly correlated to each other. This indicated that the scars at the five areas

examined were not related to each other. It is, however, also possible that correlations did exist between features, but that the small sample sizes of these three samples prevented statistical detection of such correlations.

In the historical male sample, the appearance of the interosseous groove was negatively correlated to that of the iliac tuberosity. This indicated that as the strain on the interosseous groove became larger, the strain on the iliac tuberosity was reduced. This inverse relationship was unexpected, since the strong interosseous ligament is attached to both areas and one would thus have expected that the relationship between the scarring at these areas would have been positive. It is possible that as the attachment of the interosseous ligament became larger and stronger at the interosseous groove, the need for accessory attachments, such as the attachment to the iliac tuberosity, was reduced and thus the main source of strain on the tuberosity would have been the other smaller ligaments attached to it. It is, however, also possible that this relationship was merely statistical in nature, since it was based on a small sample of only 19 historical males. This theory was supported by the lack of similar correlation in the other samples examined.

In the modern male sample, the occurrence of dorsal pubic pitting was weakly correlated to the appearance of the preauricular sulcus ($r = 0.22$). This relationship indicated that an increase in the strain on the pubic ligaments tended to coincide with an increase in the strain on the sacroiliac ligaments, and *vice versa*. This suggested that the actions of the ligaments at these two sites balanced each other in order to maintain the stability of the pelvic girdle and prevent separation of either of the joints. While the relationship between these features was a logical one, it is important that this result is considered with caution, since it was based on a sample of only five males that presented with dorsal pubic pitting.

In the modern female sample, the appearance of the preauricular sulcus was significantly correlated to both the appearance of the interosseous groove and the iliac tuberosity. These correlations suggested that as the strain on the anterior sacroiliac ligament which is attached to the preauricular sulcus was altered, the strain on the posterior sacroiliac ligaments that attach to the interosseous groove and iliac tuberosity tended to be altered in a similar manner. Similar to the balance between the pubic and sacroiliac ligaments, as shown in the modern male sample, the relationship between the anterior and posterior sacroiliac ligaments indicated that the actions of these sets of ligaments balanced each other in order to maintain stability of the sacroiliac joint. It is possible that a similar anterior-posterior balance existed between the pubic symphyseal ligaments, but could not be observed in this study since only the dorsal pubic ligament attachment sites were examined.

5.3.1. Summary

The relationships between the scar features indicated that there is a balance between the actions of the pubic ligaments and those of the sacroiliac joint and similarly between the anterior and posterior sacroiliac ligaments. This balance is important in preventing separation of either the pubic symphyseal or sacroiliac joints and maintaining the stability of the pelvic girdle under the strains of weight transfer through the girdle to the lower limbs.

5.4. Variation in body size estimates

5.4.1. Femur length

5.4.1.1. Sex

The mean femur length was larger in the males than in the females of the same time period samples, though the difference was only significant in the modern sample (c.f. Table 4.16 and Figure 4.9). The lack of significance in the archaeological and historical samples was likely due to their small sample sizes, with the archaeological sample consisting of only 17 females and 26 males and the historical sample consisting of seven females and 15 males. The degree of sexual dimorphism of the femur length was, however, similar for the three time period samples and also similar to the degree of dimorphism reported in the literature (Table 5.1). The small degree of sexual dimorphism of the femur length (4%-10%) further indicated that while males did have longer femora than females, the difference between the sexes was relatively small. The larger mean femur length in males was not unexpected, since males are reported to have a longer period of bone growth in adolescence, with long bone fusion occurring about two years later in males than in females (Lieberman, 1982; Buikstra & Ubelaker, 1994; Scheuer & Black, 2000).

5.4.1.2. Age

Changes in the mean femur length with age were detected in the archaeological female, historical male and female samples and in the pooled female data. Despite the expected decrease in stature with age (Trotter & Gleser, 1958; Galloway *et al.*, 1998; Snodgrass & Galloway, 2003), the length of the femur is not expected to change since the reduction in stature is mostly due to changes in the heights of the vertebrae and vertebral discs (Trotter and Gleser, 1951). There are several possible reasons for the association between age and femur length detected in this study. Firstly, the small sizes of the archaeological female sample (n= 17) and of the historical male and female samples (n= 15 and 7, respectively) may have caused non-significant associations to be detected as significant.

The observed association to age may thus have been due to sampling bias rather than a true relationship between age and femur length. The lack of accuracy in age estimation of the archaeological and historical samples may also have caused the detection of false associations, as discussed earlier. This would explain the fact that the modern samples for which accurate age-at-death information was available did not show similar associations between age and femur length. Lastly, the observed association of age and femur length in the pooled female data may have been the result of the composition of this sample. The pooled female data consisted of a small proportion of young archaeological females, which are expected to be of smaller stature (and thus femur length), and a large proportion of older modern females, which are expected to be of greater stature and femur length. This suggested that the observed association may have been the result of secular trends in stature and femur length, rather than of true association between age and femur length.

Table 5.1: Comparison of mean femur length. *

Sample	Females (cm)	Males (cm)	Degree of sexual dimorphism (%) **	Source
South African individuals				
Archaeological sample	41.4	43.6	5	This study
Historical sample	40.7	42.5	4	“
Modern sample	41.9	45.0	7	“
Pooled data	41.8	44.6	7	“
Black South African individuals				
Cape Nguni	42.5	45.3	7	Lundy (1986)
Sotho	42.1	44.5	6	“
Venda	39.5	42.0	6	“
South African individuals	43.7	46.9	7	Steyn & İşcan (1997)
Hamann-Todd Collection (mixed) ***	43.0	46.8	8	Tague (2005)
Later Stone Age foragers	40.1	40.9	2	Kurki (2011a)
Coimbra Identified Skeletal Collection ***	40.1	44.2	10	“
Hamann-Todd Collection (mixed) ***	41.8	44.6	7	“
South African individuals	43.1	46.5	8	Dayal <i>et al.</i> (2008)

* Sample sizes are given in Appendix C

** Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

*** For a brief description of these collections, see Appendix D.

5.4.1.3. Time period

Stature, and thus femur length as its proxy, is a complex trait which is affected by both genetic and environmental influences, even over short periods of time (Trotter & Gleser, 1958; Allbrook, 1962; Tobias, 1975 and 1985; Feldesman & Fountain, 1996; Kemkes-Grottenthaler, 2005; Kurki, 2011b). It was thus expected that temporal and cultural differences between time period samples would result in differences in femur length between such samples.

The mean femur lengths of each of the time period samples of this study fell within the ranges reported for samples from similar time periods (Lundy, 1986; Steyn & İşcan, 1997; Correia *et al.*, 2005; Tague, 2005; Kurki, 2007; Dayal *et al.* 2008).

The modern samples had the largest mean femur lengths of the three time period samples. This was not unexpected, since these modern individuals would have had better nutritional and health conditions which have been reported to result in secular increases in stature and thus femur length (Tobias, 1975 and 1985; Dayal *et al.*, 2008). The expectation that the archaeological samples would have the smallest mean femur lengths was not met, since the historical samples had the smallest means. The historical sample also had the least dimorphism between the sexes (as reflected in the low dimorphic index), which according to Wolfe and Gray (1982) reflects the poor nutritional and health conditions reported for these individuals (Friedling, 2007). The difference between the three time period samples may also have been due to the genetic make-up of the individuals of these samples. The individuals of the archaeological sample were biologically Khoisan and are expected to have had little, if any, genetic contributions from other populations (Sealy & Pfeiffer, 2000). The historical individuals are reported to be of mixed European, African and Khoisan descent (Apollonio, 1998; Friedling, 2007). The Khoisan genetic contribution to the archaeological and historical samples may be partially responsible for the shorter stature (and thus femur length) of these individuals, since Khoisan individuals have been reported to generally be of short stature, irrespective of other environmental influences such as nutrition and health conditions (Smith *et al.*, 1992; Wilson & Lundy, 1994; Sealy & Pfeiffer, 2000; Pfeiffer & Sealy, 2006). The modern individuals of this study were mostly of European descent due to the composition of South African cadaveric collections, though some individuals of this sample were also of African or mixed descent (Dayal *et al.*, 2009) and are expected to be genetically pre-disposed to be taller than the other samples examined (Cole, 2003; Kurki, 2011b).

5.4.1.4. Summary

The mean femur length of males was larger than that of females due to normal differences in growth patterns between the sexes. Association between age and femur length was detected in the pooled female data, the archaeological female sample and the historical male and female samples. This was in direct contrast with the expectation that femur length remains constant after skeletal maturity is reached and suggested that the observed associations may have been the result of sampling bias, rather than true association between age and femur length. The modern individuals had the largest mean femur lengths, as expected due to their improved nutritional and health

conditions. The mean femur lengths of the other two samples were smaller and may be due to the combined effects of genetic make-up and poor living conditions. The historical samples whose individuals are expected to have experienced very harsh living conditions had the shortest mean femur length and least dimorphism of this measurement.

5.4.2. Femur head diameter

5.4.2.1. Sex

The mean femur head diameter was larger in males than in females of the same time period sample (c.f. Table 4.17 and Figure 4.10), though the difference was not significant in the historical sample due to its small size (n= 13 and 17 for females and males, respectively). The degree of sexual dimorphism was, however, similar for the three time period samples and also similar to the degree of dimorphism reported in the literature (Table 5.2), with the exception of the LSA sample of Kurki (2007) which was less than those of the other studies. While the degree of sexual dimorphism of the femur head diameter (11%-14%) was larger than that of the femur length, it was still relatively small, which indicates that while males did have larger femoral head diameters than females, the difference between sexes was relatively small. This larger diameter in males was not unexpected, since higher levels of testosterone production tends to result in greater muscle development and bone robusticity in males (Lieberman, 1982; Buikstra & Ubelaker, 1994; Drake *et al.*, 2005), both of which would reflect in increased body mass and the femur head diameter as its proxy.

Table 5.2: Comparison of mean femur head diameter.*

Sample	Females (mm)	Males (mm)	Degree of sexual dimorphism (%) **	Source
South African individuals				
Archaeological sample	37	42	14	This study
Historical sample	38	42	11	“
Modern sample	41	46	12	“
Pooled data	40	45	13	“
Black South African individuals				
Cape Nguni	41	45	9	Lundy (1986)
Venda	39	44	14	“
South African individuals	43	48	11	Steyn & İşcan (1997)
Later Stone Age foragers	37	40	8	Kurki (2007)
Coimbra Identified Skeletal Collection ***	40	46	15	“
Hamann-Todd Collection (mixed) ***	42	47	12	“
Hamann-Todd Collection (mixed) ***	43	49	14	Tague (2009)

* Sample sizes are given in Appendix C

** Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

*** For a brief description of these collections, see Appendix D.

5.4.2.2. Age

The mean femur head diameter increased with age in the archaeological male sample and both the modern male and female samples. The lack of change in the remaining samples might have been due to the small number of older individuals in these samples. Since the size of the femur head was not expected to increase with age due to bone growth (Scheuer & Black, 2000), the observed change in the head diameter was likely due to remodelling. Such remodelling of the femur head may have been the result of increases in body mass with age, as reported for various South African and international samples (Galloway *et al.*, 1998; Puoane *et al.*, 2002; Savona-Ventura *et al.*, 2008), which may have been due to either reduced physical activity or increased fat storage associated with age (Forbes & Reina, 1970; Deurenberg *et al.*, 1991; Ruff *et al.*, 1991).

5.4.2.3. Time period

Body mass, and thus femur head diameter as its proxy, is influenced by several genetic and environmental influences and may also be subject to secular changes (Cole, 2003; Ruff *et al.*, 1991). It was thus expected that, similar to femur length, the temporal and cultural differences between time period samples would cause the mean femur head diameters of these samples to differ.

The mean femur head diameter of each of the time period samples of this study fell within the ranges reported for samples from similar time periods (Lundy, 1986; Steyn & İşcan, 1997; Kurki, 2007; Tague, 2009).

The mean femur head diameters of the archaeological and historical samples were similar to each other, but significantly smaller than those of the modern samples. Similar to the differences in mean femur lengths between these samples, the difference in femur head diameter may have been the result of improved nutritional and health conditions experienced by the modern individuals, but also the reduced physical activity of these individuals compared to the more active archaeological and historical individuals (Sealy & Pfeiffer, 2000; Puoane *et al.*, 2002; Cole, 2003; Friedling, 2007; Driscoll, 2010). Also similar to the differences in femur lengths, the genetic make-up of the archaeological and historical samples may have pre-disposed these individuals to have smaller body masses, while the modern individuals may have been pre-disposed to have larger body masses, as discussed above.

5.4.2.4. Summary

The mean femur head diameter of males was larger than that of females due to normal differences in robusticity between the sexes. The femur head diameter was positively associated with age in the archaeological male and modern male and female samples. Since the size of the femur head was not expected to change due to bone growth, this association was likely due to remodelling of the femur head as a result of age-related changes in body composition or activity patterns that could affect an individual's body mass. The mean femur head diameters of the modern samples were larger than those of the archaeological and historical samples, possibly due to similar genetic and environmental influences as those that cause differences in the mean femur length between the three time period samples.

5.5. Relationship between body size estimates

The femur length and the maximum diameter of its head were strongly correlated in all samples ($r > 0.45$), except the historical male and female samples, possibly due to their small sample sizes. These correlations suggested that an increase in stature tended to coincide with an increase in body weight. This was expected since both measurements are often used to estimate either stature or body mass (Ruff *et al.*, 1991; McHenry, 1992; Grine *et al.*, 1995), and similar correlation between these two measurements have been reported by Savona-Ventura *et al.* (2008).

5.6. Relationship between body size estimates and pelvic measurements

Both the femur length and its head diameter were significantly correlated to several of the pelvic measurements, as previously reported by Holland *et al.* (1982), Rosenberg (1988), Tague (2000), Savona-Ventura *et al.* (2008) and Ridgeway *et al.* (2011). The observed correlations showed that femur length is a better predictor of pelvic capacity, since it was correlated to more of the pelvic measurements than the femur head diameter. Examination of the correlations of the femur measurements to the three most obstetrically significant pelvic measurements (anteroposterior inlet, interspinous and transverse outlet diameters) showed that the strength of the correlations of the femur length and its head diameter were similar for the anteroposterior inlet and transverse outlet diameters. The most obstetrically important dimension, the interspinous diameter, was, however, correlated to the femur length but not its head diameter, which suggested that the femur length was a better indicator of obstetric adequacy than its head diameter. This was the opposite of the results

of Tague (2000), who found that the correlation of the femur length to the pelvic measurements was limited and that body size or mass were better predictors of obstetric capacity. The results of this study did, however, support Tague's (2000) observation that the correlations of the femur and pelvic measurements were not uniform, with correlation strength between these measurements ranging from 0.20 to 0.81 in this study. This meant that the influence of either stature or body mass may have strongly influenced some of the pelvic measurements, but not others and thus the predictive value of these measurements on overall pelvic capacity was limited. These results thus suggested that while shorter or smaller-bodied individuals are more likely to have small pelves than taller or larger-bodied individuals, other developmental influences such as physical activity or nutrition may also play an important role in determining the capacity of the pelvic canal, as shown by Ruff *et al.* (2005). The body size variables thus serve only as risk factors, rather than diagnostic factors, as suggested by Van Bogaert (1999), Awonuga *et al.* (2007) and Benjamin *et al.* (2011). It is also important to remember that mean body size differs between populations, and that a single threshold stature or body mass may not be applicable to all populations (Kurki, 2011b).

5.7. Variation in pelvic measurements

5.7.1. Anteroposterior diameter of the pelvic inlet

5.7.1.1. Sex

The mean anteroposterior diameter of the pelvic inlet was larger in the females than the males of each sample (c.f. Table 4.22 and Figure 4.11), despite the fact that males had larger body size estimates. The difference was significant in the modern sample only, but the lack of significance in the archaeological and historical groups may have been due to the small sizes of these samples, with the archaeological sample consisting of only 14 females and 20 males and the historical sample consisting of only two females and four males. The degree of sexual dimorphism of the anteroposterior inlet diameter was, however, similar for the three time period samples. Similar differences between the sexes have also been reported in the literature (Table 5.3). These differences were likely due to differences between the sexes in terms of the functional requirements of the pelvic girdle. Males only have the requirements of bipedalism that restrict pelvic size and thus have smaller pelves (and thus smaller anteroposterior inlet diameters) to optimize the efficiency of weight transmission through the pelvic girdle (Rosenberg, 1988; Bruzek & Murail, 2006; Kurki, 2007). Females have these biomechanical requirements as well as the requirements for obstetric adequacy that act on the girdle (Andersen, 1986; Walrath, 1997; Scheuer & Black, 2000; O'Connell, 2004; Bruzek & Murail, 2006; Nuger, 2008). The larger anteroposterior inlet diameter

in females is thus indicative of its obstetric importance, since it is the first plane through which the delicate biparietal diameter of the foetal head has to pass and thus has to be sufficiently large to allow the foetus to pass without obstruction (Correia *et al.*, 2005). Studies have shown that the magnitude of the influence of body size and climate is less severe on the anteroposterior inlet diameter than the other pelvic dimensions, suggesting that this diameter is “protected” in females in order to ensure obstetric sufficiency (Kurki, 2007; Nuger, 2008; Steyn & Patriquin, 2009).

Table 5.3: Comparison of the anteroposterior diameter of the pelvic inlet. *

Sample	Females (mm)	Males (mm)	Degree of sexual dimorphism (%) **	Source
South African individuals				
Archaeological sample	105	95	-10	This study
Historical sample	100	89	-11	“
Modern sample	111	102	-8	“
Pooled data	110	101	-8	“
Terry Collection: White individuals ***	116	109	-8	İşcan & Cotton (1985)
Terry Collection: Black individuals ***	111	101	-6	“
Combined historical sample	105	99	-6	O’Connell (2004)
Coimbra Identified Skeletal Collection ***	108	100	-7	Correia <i>et al.</i> (2005)
Later Stone Age foragers	101	91	-10	Kurki (2007)
Coimbra Identified Skeletal Collection ***	110	101	-8	“
Hamann-Todd Collection (mixed)	113	104	-8	“
Greek individuals	113	103	-9	Steyn & İşcan (2008)

* Sample sizes are given in Appendix C

** Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

*** For a brief description of these collections, see Appendix D.

5.7.1.2. Age

The size of the anteroposterior inlet diameter was not significantly associated with age, in agreement with the results of Moerman (1981), who reported that pelvic measurements increase by less than 2 mm after skeletal maturity. This lack of age-related change indicated that other age-related changes such as those to body size and activity patterns did not significantly affect the magnitude of this diameter.

5.7.1.3. Time period

The mean anteroposterior inlet diameters of the archaeological and modern samples of this study were similar to those reported in previous studies (İşcan & Cotton, 1985; Tague, 1989; Kurki, 2007; Steyn & İşcan, 2008). The mean of the historical sample was less than that reported for other historical samples (O’Connell, 2004; Correia *et al.*, 2005; Kurki, 2007), possibly due to the small size of these samples (n= 2 and 4 for females and males, respectively).

The means of the modern samples were significantly larger than those of the other two samples. It was shown above that body size is correlated to the pelvic measurements, thus since the individuals of the modern sample of this study had larger body sizes than those of the other two samples, the larger anteroposterior inlet diameter was not unexpected. Differences in the activity patterns of the three samples may also have played a role by affecting the amount of strain on the muscle and tendon insertions of the pelvic girdle. It has been shown in both osteological samples (Emmons, 1913) and living individuals (Vaughan, 1931; Beck, 1973) that individuals such as those of the modern sample of the present study that are less active and are submitted to prolonged periods of sitting tend to develop larger anteroposterior diameters of the pelvis. On the other hand, activities such as walking from a younger age, as expected for the archaeological individuals of this study, or carrying of heavy burdens before adulthood, as expected for the historical individuals, may cause an increase in this diameter (Cook, 1984; Abitbol, 1996). Nutritional stress, which is expected to be more common in the archaeological and historical individuals, may also have led to flattening of the pelvic girdle (Angel, 1976, 1978 and 1982). Despite the differences in the mean diameter of the samples, their ranges showed large areas of overlap which again suggested that the anteroposterior inlet diameter was “protected” in order to ensure obstetric adequacy (Kurki, 2007).

5.7.1.4. Summary

The mean anteroposterior diameter of the pelvic inlet was significantly larger in females than in males. This was likely due to the differences between the sexes regarding the functional requirements of the pelvic girdle with males having only the requirements of bipedalism to accommodate while females have to balance the requirements of bipedalism with those of obstetric adequacy. The larger anteroposterior inlet diameter in females reflects the obstetric importance of this diameter. The diameter did not change with age, indicating that age-related changes in body size or activity patterns did not significantly affect its size. The means of the modern samples were larger than those of the archaeological and historical samples, possibly due to the larger body size and less active lifestyles of the modern individuals. The genetic make-up of the archaeological and historical samples may also have pre-disposed them to having smaller means.

5.7.2. Transverse diameter of the pelvic inlet

5.7.2.1. Sex

The mean transverse diameter of the pelvic inlet was larger in the females than the males of each sample, though the difference was only significant in the modern sample (c.f. Table 4.22 and Figure 4.12). The lack of significance in the archaeological and historical groups may have been due to the

small sizes of these samples, with the archaeological sample consisting of only 14 females and 20 males and the historical sample consisting of only two females and three males. The degree of sexual dimorphism was, however, similar for the three time period samples. Similar differences between the sexes have also been reported in the literature (Table 5.4). The larger diameter in females suggested that selection pressure related to obstetric adequacy did have some influence on the magnitude of this diameter. This pressure was, however, less than the pressures acting on the other pelvic measurements, since the transverse inlet diameter was the least dimorphic of these measurements (Table 4.23). This may have been a reflection of the reduced obstetric importance of the transverse inlet diameter, since it accommodates the fronto-occipital diameter of the foetal head during labour, not the delicate biparietal diameter (Rosenberg, 1988; Correia *et al.*, 2005; Driscoll, 2010; Kurki, 2011b). The fronto-occipital diameter is, however, still important, as it is the largest of the two diameters of the foetal head, and thus some regulation of the magnitude of the transverse inlet diameter is required to ensure obstetrical adequacy.

5.7.2.2. Age

The size of the transverse inlet diameter increased with age in the modern samples and pooled data only. The weak nature of these associations and lack of association in the other samples suggested that the observed association was possibly the result of the large size of these samples ($n \geq 97$ in all four cases), as suggested by O'Connell (2004). No reports of similar association between age and the transverse inlet diameter of osteological samples were found in the literature. An increase in the transverse inlet diameter has been demonstrated in living individuals (Johanson-Unnérus, 1957; Hulth *et al.*, 1995) and may be related to weakening of the pelvic ligaments with age, possibly due to hormonal changes associated with menopause or andropause (Johanson-Unnérus, 1957; Salazar & Tan, 2005). The weakening of the ligaments may have reduced the tightness of articulation of the girdle, causing an increase in the transverse diameter. These changes, however, were only expected to affect the soft tissues and the attachment sites of the affected ligaments. Since the reference points for measurement of the transverse inlet diameter were not ligamentous attachment sites, changes to ligamentous strain does not explain the observed age-related increase in size. The reference points of the other two transverse diameters that were examined in this study, the transverse outlet and the interspinous diameters, were, however, ligamentous attachment sites, thus changes to ligamentous strain may have affected the size of these dimensions. Since the three transverse diameters of the pelvic girdle were strongly correlated to each other, as will be discussed later, the observed age-related increase in the transverse inlet diameter may thus simply have been a by-product of the increase in the other two diameters, which also will be discussed later.

Table 5.4: Comparison of the transverse diameter of the pelvic inlet. *

Sample	Females (mm)	Males (mm)	Degree of sexual dimorphism (%) **	Source
South African individuals				
Archaeological sample	117	106	-9	This study
Historical sample	121	115	-7	“
Modern sample	124	115	-7	“
Pooled data	123	114	-7	“
Terry Collection: White individuals ***	133	124	-7	İşcan & Cotton (1985)
Terry Collection: Black individuals ***	121	112	-7	“
Hamann-Todd Collection (mixed) ***	131	125	-5	Tague (2000)
Combined historical osteological sample	131	123	-6	O’Connell (2004)
Coimbra Identified Skeletal Collection ***	131	123	-6	Correia <i>et al.</i> (2005)
Later Stone Age foragers	111	96	-14	Kurki (2007)
Coimbra Identified Skeletal Collection ***	126	119	-6	“
Hamann-Todd Collection (mixed) ***	132	123	-7	“
Greek individuals	131	125	-5	Steyn & İşcan (2008)

* Sample sizes are given in Appendix C

** Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

*** For a brief description of these collections, see Appendix D.

5.7.2.3. Time period

The mean transverse inlet diameters of the archaeological samples were less than those reported for LSA foragers (Kurki, 2007), while the means of the historical sample were less than those of similar populations (O’Connell, 2004; Correia *et al.*, 2005; Kurki, 2007). In both these cases the difference was likely due to the small sample sizes in the present and comparative studies. The mean diameters of the modern samples were similar to those reported for Black individuals of the Terry Collection (İşcan & Cotton, 1985), but less than those of mixed samples of the Hamann-Todd Collection (Tague, 2000; Kurki, 2007), White individuals of the Terry Collection (İşcan & Cotton, 1985) and Greek individuals (Steyn & İşcan, 2008). The differences between these samples were possibly due to the differences in body size between the sample populations.

The mean diameters of the archaeological samples were significantly smaller than those of the modern samples. Again, the larger body size of the modern individuals may have been responsible for this difference, as also suggested by Holland *et al.* (1982), Rosenberg (1988) and Kurki (2007). Since the magnitude of the temporal difference between the modern and historical samples was less than that between either of these samples and the archaeological sample, the similarity between these two samples was not unexpected. On the other hand, the means of the historical samples were also not significantly different from those of the archaeological samples, possibly due to the similarity in genetic origins of these two samples. Similarity in activity patterns of these samples

may also have contributed to their similarity in the size of the transverse inlet diameter, since active lifestyles, as reported for the individuals of both these samples, have been shown to be associated with larger transverse diameters (Vaughan, 1931; Beck, 1973; Abitbol, 1996). Despite the differences in the means of the three samples, their ranges showed large areas of overlap, suggesting that the combined influences of weight-bearing and obstetric requirements of the pelvic girdle remained fairly similar over time.

5.7.2.4. Summary

The mean transverse diameter of the pelvic inlet was significantly larger in females than in males, indicating that selection for obstetric adequacy may have influenced the magnitude of this diameter. The transverse inlet diameter was, however, the least dimorphic of the pelvic measurements, which reflected the fact that it is not as obstetrically important as, for example, the anteroposterior inlet diameter. The transverse inlet diameter increased with age in the modern samples and the pooled male and female data. This may have been due to either large sample sizes causing non-significant associations to be detected as significant or possibly as a by-product of the age-related increases in the other transverse pelvic diameters due to changes to the strain on the ligamentous attachment sites which also served as the reference points for these measurements. The transverse inlet diameter was significantly larger in the modern samples than in the archaeological samples, with the mean diameters of the historical samples being intermediate to both. The similarities and differences between the three time period samples was likely due to similarities and differences in genetic origins, body size and activity patterns between these samples.

5.7.3. Interspinous diameter

5.7.3.1. Sex

The mean interspinous diameter of females was significantly larger than that of males in each of the time period samples, with the degree of sexual dimorphism being similar for the archaeological and modern samples, but greater in the historical sample (c.f. Tables 4.22 and 4.23, and Figure 4.13). This greater dimorphism in the historical sample was likely due to the fact that the sample consisted of only two female and four male individuals. The interspinous diameter was the most dimorphic of the pelvic measurements with the narrowest ranges in this and previous studies (Table 5.5), suggesting that the size of the diameter was tightly regulated in both sexes. In males, the regulation of the interspinous diameter simply relates to the biomechanical requirements of bipedalism, with smaller pelves being more biomechanically efficient than larger ones (Andersen, 1986; Walrath, 1997; Bruzek & Murail, 2006; Nuger, 2008). In females, similar requirements of bipedalism restrict the maximum size of this diameter while the requirements of obstetric adequacy restrict the minimum size of it. The interspinous diameter is usually the smallest dimension of the pelvic canal

and therefore the most common site of obstruction during labour (Correia *et al.*, 2005; Basavanthappa, 2006; Cunningham *et al.*, 2010). The midplane in which the diameter occurs is also important, since the foetus has to rotate in its descent from the pelvic inlet plane so that the long fronto-occipital diameter of its head aligns with the widest diameter of the midplane, which is at a right angle to that of the inlet (Walrath, 2003; Correia *et al.*, 2005; Driscoll, 2010). This means that the delicate biparietal diameter of the foetal head has to move through the plane of the interspinous diameter. The female pelvis, and the interspinous diameter in particular, is thus regulated by a tightly regulated compromise between the obstetric and biomechanical requirements of the pelvic girdle.

Table 5.5: Comparison of the interspinous diameter. *

Sample	Females (mm)	Males (mm)	Degree of sexual dimorphism (%) **	Source
South African individuals				
Archaeological sample	104	82	-21	This study
Historical sample	106	78	-26	“
Modern sample	105	86	-18	“
Pooled data	105	85	-19	“
Hamann-Todd Collection ***	101	86	-15	Tague (2000)
Combined historical sample	103	89	-14	O’Connell (2004)
Coimbra Identified Skeletal Collection ***	104	89	-14	Correia <i>et al.</i> (2005)
Later Stone Age foragers	96	81	-16	Kurki (2007)
Coimbra Identified Skeletal Collection ***	100	87	-13	“
Hamann-Todd Collection ***	105	86	-18	“

* Sample sizes are given in Appendix C

** Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

*** For a brief description of these collections, see Appendix D.

5.7.3.2. Age

The size of the interspinous diameter increased with age in the modern samples and the pooled data only. The weak nature of these associations and lack of association in the other samples suggested that it is possible that the observed association was the result of the large size of these samples ($n \geq 93$ in all four cases), as suggested by O’Connell (2004). It is also possible that the observed association was related to weakening of the pelvic ligaments with age, as discussed with regards to the transverse inlet diameter above. The reference points for measurement of the interspinous diameter, the ischial spines, are the attachment sites of the sacrospinous ligaments and were thus expected to be affected by age-related changes in the strains of these ligaments, possibly resulting in an increase in the interspinous diameter. If this was the case, the lack of association with age in the other samples of this study may have been due to the combined effects of the weakness of the association and the small sizes of these samples ($n \leq 20$).

5.7.3.3. Time period

There was no significant difference in the interspinous diameter between the three time period samples of this study. Comparison of the mean interspinous diameter of previous studies of samples from similar time periods agree with this finding (Sibley *et al.*, 1992; O'Connell, 2004; Correia *et al.*, 2005). This indicated that the temporal and cultural differences between the samples did not significantly affect this diameter and suggests that the size of the diameter was “protected” over time in order to ensure obstetric adequacy.

5.7.3.4. Summary

The mean interspinous diameter of females was larger than that of males in all of the samples. This diameter was also one of the most sexually dimorphic measurements of the pelvic canal in this and previous studies, highlighting its great obstetric significance. The interspinous diameter increased with age in the modern samples and pooled male and female data. While this may have been due to the large sizes of these samples, it is also possible that the association of this diameter with age was related to age-related changes in the strain acting on the sacrospinous ligaments at the ischial spines, which were the reference points for measuring of the interspinous diameter. There was no significant difference in the mean interspinous diameter between the three time period samples of this study, which suggested that the obstetric importance of this diameter was great enough to restrict the potential effects of temporal and cultural differences between the samples.

5.7.4. Anteroposterior diameter of the pelvic outlet

5.7.4.1. Sex

Similar to the other measurements already discussed, the anteroposterior diameter of the pelvic outlet was larger in the females than the males of the same time period sample (c.f. Table 4.22 and Figure 4.14). The difference was significant in all samples except the historical sample, but the lack of significance may have been due to the small size of these samples (n= 2 and 4 for females and males, respectively). The greater degree of sexual dimorphism of the anteroposterior outlet diameter in the historical sample compared to the other two samples may also have been due to these small sample sizes. The larger diameter in females than males have been reported in the literature (Table 5.6). The degree of sexual dimorphism in the present study was similar to those of these comparative studies, with the exception of that of LSA foragers, as reported by Kurki (2007), which may have been due to the small sizes of the samples investigated (n= 15 for both males and females). The larger diameter in females suggested that selection for obstetric adequacy played some role in regulating the magnitude of the diameter, since it accommodates the long fronto-

occipital diameter of the foetal head. The anteroposterior outlet diameter was, however, one of the least dimorphic pelvic measurements (c.f. Table 4.23), which may have been due to the reduced obstetric importance of this diameter, since it does not accommodate the delicate biparietal diameter of the foetal head. The outlet plane is also less important than the inlet and midplanes, since no rotation of the foetus is necessary and if these two planes are adequate, it is expected that the outlet plane would also be adequate (Correia *et al.*, 2005). The anteroposterior outlet diameter was thus less restricted by its obstetric requirements and was allowed to vary more freely than the other pelvic measurements.

Table 5.6: Comparison of the anteroposterior diameter of the pelvic outlet. *

Sample	Females (mm)	Males (mm)	Degree of sexual dimorphism (%) **	Source
South African individuals				
Archaeological sample	118	106	-10	This study
Historical sample	121	100	-17	“
Modern sample	118	107	-9	“
Pooled data	118	107	-9	“
Hamann-Todd Collection ***	121	112	-7	Tague (2000)
Combined historical sample	114	102	-11	O’Connell (2004)
Coimbra Identified Skeletal Collection ***	116	109	-6	Correia <i>et al.</i> (2005)
Later Stone Age foragers	122	102	-17	Kurki (2007)
Coimbra Identified Skeletal Collection ***	114	108	-5	“
Hamann-Todd Collection ***	115	105	-9	“

* Sample sizes are given in Appendix C

** Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

*** For a brief description of these collections, see Appendix D.

5.7.4.2. Age

Similar to the anteroposterior inlet diameter, the size of anteroposterior outlet diameter was not associated with age, which was in agreement with the results of Moerman (1981), who reported an increase of less than 2 mm in the pelvic measurements after skeletal maturity. The lack of change indicated that age-related changes to body size and activity patterns did not affect the magnitude of this diameter.

5.7.4.3. Time period

There was no significant difference in the anteroposterior outlet diameter between the three time period samples of this study, suggesting that the temporal and cultural differences between samples did not significantly affect this diameter. It is, however, possible that the inherently large range of

this diameter may have reduced any effect such changes could have had on its magnitude. Comparison of the reported mean diameters of previous studies supported the results of this study (Sibley *et al.*, 1992; Tague, 2000; O'Connell, 2004; Correia *et al.*, 2005). Kurki (2007) was the only study that did find a significant difference between time periods, with the LSA forager females in her study having a larger mean diameter than those of the historical or modern samples, though the small size of the LSA samples (n= 15 for both females and males) may have influenced this result.

5.7.4.4. Summary

The mean anteroposterior diameter of the pelvic outlet was larger in females than in males, though the degree of sexual dimorphism of this diameter was less than most of the other pelvic measurements. This indicated that though selection pressure for obstetric adequacy does influence the minimum size of this diameter, the relatively low obstetric importance of it allows it to vary more freely than those diameters of greater obstetrical importance. The diameter did not change with age, indicating that age-related changes in body size or activity patterns did not significantly affect this diameter. There was no significant difference in the anteroposterior outlet diameter between the three time period samples of this study, which suggested that the temporal and cultural differences between these samples did not significantly influence this diameter.

5.7.5. Transverse diameter of the pelvic outlet

5.7.5.1. Sex

The mean transverse diameter of the pelvic outlet was larger in the females than the males of the each sample, except in the historical sample (c.f. Table 4.22 and Figure 4.15). The lack of difference in the historical sample may have been due to the fact that the sample consisted of only two females and four males. The degree of sexual dimorphism was, however, similar for the three time period samples. Similar differences between the sexes have also been reported in the literature (Table 5.7). The transverse outlet diameter was one of the most dimorphic of the pelvic canal measurements in this study, similar to the studies of O'Connell (2004) and Correia *et al.* (2005). This diameter is of some obstetric importance, since it is the final plane through which the delicate biparietal diameter of the foetal head has to pass during labour. Thus maintenance of the obstetric adequacy of this diameter does influence its magnitude. The diameter is, however, not as restricted by its bony margins as the other pelvic dimensions, since the ischial tuberosities are easily separated during labour (Ohlsén, 1973), which may explain the large range of this diameter reported in the literature.

Table 5.7: Comparison of the transverse diameter of the pelvic outlet.

Sample	Females (mm)	Males (mm)	Degree of sexual dimorphism (%) **	Source
South African individuals				
Archaeological sample	119	94	-21	This study
Historical sample	119	93	-22	“
Modern sample	124	103	-17	“
Pooled data	123	102	-17	“
Hamann-Todd: White individuals ***	120	102	-15	Tague (1989)
Hamann-Todd: Black individuals ***	113	95	-16	“
Combined historical sample	84	62	-26	O’Connell (2004)
Coimbra Identified Skeletal Collection ***	112	100	-11	Correia <i>et al.</i> (2005)
Later Stone Age foragers	99	77	-23	Kurki (2007)
Coimbra Identified Skeletal Collection ***	113	99	-12	“
Hamann-Todd Collection (mixed) ***	118	99	-16	“

* Sample sizes are given in Appendix C

** Note: Positive values indicate that males are larger than females, negative values indicate that females are larger than males

*** For a brief description of these collections, see Appendix D.

5.7.5.2. Age

The transverse outlet diameter increased with age in the modern male sample and pooled male and female data only. The weak nature of these associations and lack of association in the other samples suggest that it is possible that the observed association was the result of the large size of these samples ($n \geq 102$ in all three cases), as suggested by O’Connell (2004). Similar to the interspinous diameter, it is possible that the observed association with age was due to age-related weakening of the pelvic ligaments. The reference points for measurement of the transverse outlet diameter, the ischial tuberosities, are attachment sites for the sacrotuberous ligaments and were thus expected to be affected by age-related changes in the magnitude of the strain on these ligaments. If this was the case, the lack of similar associations in the remaining samples may have been due to the combined effect of the weakness of the association and the small number of older individuals in these samples.

5.7.5.3. Time period

The mean transverse outlet diameters of the archaeological samples were larger than those reported for LSA foragers (Kurki, 2007), but still fell within the range reported for these individuals. The mean of the historical female sample was larger than that reported for other historical samples by Correia *et al.* (2005) and Kurki (2007), and the means of both sexes of this sample were larger than the combined historical sample of O’Connell (2004). In both cases the difference was expected to be due to small sample sizes in the present and comparative studies. The mean diameters of the modern samples were larger than those of Black individuals of the Hamann-Todd collection (Tague,

1989), but similar to those of White individuals and a mixed sample of the same collection (Tague, 1989; Kurki, 2007).

The mean transverse outlet diameters of the modern samples were significantly larger than those of the archaeological samples, with the means of the historical samples being intermediate to both. The larger diameter of the modern sample may be due to the improved nutritional and health conditions experienced by the modern individuals, which would have improved the growth potential of their bones (Cole, 2003; Driscoll, 2010; Kurki, 2011b). The smaller means of the archaeological and historical individuals may also have been related to their genetic make-up, which may have predisposed these individuals to have smaller body sizes, which in turn have been shown to be associated with smaller pelvic sizes, as previously discussed. Differences in activity patterns may also have influenced the size of the transverse outlet diameter, since the ischial tuberosities that form the margins of this diameter are also the attachment sites of the hamstring muscles. Derry (1911) and Merry (2005) reported that active lifestyles that involve a lot of walking, as expected for the archaeological and historical individuals of this study, causes increased development of the hamstring muscles and increases the strain of the muscle attachments on the ischial tuberosities, bringing them closer together and thus reducing the transverse outlet diameter.

5.7.5.4. Summary

The transverse diameter of the pelvic outlet was one of the most sexually dimorphic dimensions of the pelvic canal, with females having larger mean diameters than males. This reflected the obstetric importance of this dimension of the pelvis, as it is the last plane through which the delicate biparietal diameter of the foetal head has to pass during labour. The transverse outlet diameter increased with age in the modern male sample and the pooled male and female data. Similar to the other transverse diameters of the pelvic canal already discussed, the reason for this increase may have been either simply statistical in nature or due to age-related changes to the magnitude of the strain acting on the ligaments that attach to the ischial tuberosities that form the margins of the transverse outlet diameter. The mean diameter was largest in the modern sample and smallest in the archaeological sample, with the mean of the historical sample being intermediate to these two samples. The similarities and differences between the three time period samples were likely due to the similarities in genetic origins, activity patterns and environmental conditions experienced by these individuals.

5.8. Relationship between pelvic measurements

The pelvic measurements examined were generally positively correlated to each other. Particularly strong correlations existed between the transverse diameters of the inlet and outlet and the interspinous diameter, and to a lesser extent between the anteroposterior diameters of the inlet and outlet. The positive nature of the correlations suggested that these dimensions were tightly regulated to maintain a functional compromise between the obstetric and biomechanical requirements of the pelvis. Thus a change in the magnitude of one of these measurements tended to coincide with a similar change in one or more of the other measurements.

The anteroposterior diameter of the pelvic inlet was correlated to all of the other pelvic measurements, except the interspinous diameter. This supports the preferential use of this diameter by obstetricians as an assessment of the overall capacity of the pelvis (Rosenberg, 1988), though as Ridgeway *et al.* (2011) suggested, caution should be applied when using the anteroposterior inlet diameter for such assessments, since it does not predict the vitally important interspinous diameter.

5.9. Relationship between body and pelvic size and scar manifestation

Based on the eigenvalue-one criterion (Kaiser, 1960), only the first three principal components were retained for analysis. Together, these three components accounted for approximately 60% of the observed variance (c.f. Table 4.24). Typically, the first two to four principal components account for about 90% of the observed variance (Hatcher, 1994). The lower proportional representation in this study may have been due to the fact that other factors that are not accounted for by this study are responsible for the variance. It is also possible that the use of discrete, rather than continuous, variables such as those used to describe the scar features in this study may have reduced the power of the analysis by making the data set less variable (Kolenikov & Angeles, 2004).

The first principal component could be interpreted as representative of the relative sizes of the body and the pelvis to each other and represented approximately a third of the observed variation (c.f. Table 4.25a and Figures 4.16 and 4.17). The remaining components, which represented variation in shape, accounted for the remaining two-thirds of the variation. Thus while size was the most important determinant of the variation in this study sample, it did not overwhelm the effect of shape

on the overall variance. All of the scar components, with the exception of the pubic tubercle, were positively loaded on this component. This suggested that the development of these scars tended to occur in individuals with small body but large pelvic sizes. On the other hand, the pubic tubercle was negatively loaded on the first principal component, which suggested that extension of the tubercle tended to occur in individuals of large body but small pelvic sizes. The separation of the sexes according to the first principal component showed that females tended to have smaller bodies but larger pelvic sizes and thus greater scar development (c.f. Figure 4.12). Males on the other hand tended to have larger body sizes but smaller pelvic sizes and less developed scarring, except in the case of the pubic tubercle. These results agree with the earlier results of this study which showed that females tended to have more developed scarring, smaller body sizes and larger pelvic sizes than males. The tendency of smaller-bodied females to have proportionately larger pelves while larger-bodied males have proportionately smaller pelves has also previously been reported by Rosenberg (1988), Tague (2005), Kurki (2007) and Nuger (2008). The reason for the differences between the sexes may have been due to the different requirements of the pelvic girdle in males and females, as discussed earlier. Males tend to have small pelves despite their larger body size, which makes them specifically adapted for the biomechanical requirements of bipedal locomotion (Aiello & Dean, 1990; Campbell, 1998; Kurki, 2007). The larger body size of males does, however, result in increased strain on the rectus abdominis muscle (and thus its attachment at the pubic tubercle) either as a result of increased action of the muscle in containment of the anterior abdomen or simply due to increased muscle development. On the other hand, females have the added requirements of maintaining an obstetrically adequate pelvic canal, which is especially vital in smaller individuals which may have naturally smaller pelves (Rosenberg, 1988; Scheuer & Black, 2000; Kurki, 2007). The relationship between scar development and pelvic size was similar to that reported by Cox (1989) and O'Connell (2004), which both showed that scarring tends to occur more commonly in individuals with proportionately larger pelves. Cox (1989) suggested that the reason for this is that larger pelves are less stable in the transmission of weight from the trunk to the lower limbs, thus creating the need for more ligamentous stabilization of the girdle. Such ligamentous stabilization would result in increased remodelling of the attachment sites of these ligaments and scar formation. This need for ligamentous stabilization is further amplified in females due to the more flexible articulation of their pelvic girdles (Derry, 1911; Emmons, 1913; İşcan & Derrick, 1984). The relationship between scar development and body and pelvic sizes also explains the occurrence of scarring in some males, with those males that present with scarring potentially having larger or more flexible pelves than average, which would lead to scar formation in a similar manner as in females.

The second principal component can be interpreted as representative of the combined body and pelvic size and accounted for approximately a sixth of the observed variance (c.f. Table 4.25b and Figures 4.16 and 4.18). The majority of the scar features were positively correlated to this component, suggesting that scar development tended to occur in individuals with larger body and pelvic sizes overall. This appears to be in conflict with the relationships between body and pelvic size and the development of scarring suggested by the correlations to the first principal component, which suggested that smaller bodied individuals tend to present with more developed scars. This conflict may, however, simply indicate that there is a threshold body size above which the weight-bearing strain on the pelvic ligaments becomes so large that it causes scar formation at the ligamentous attachment sites, irrespective of the degree of stability of the pelvic girdle as determined by its size. Dorsal pubic pitting was the only scar feature that was negatively correlated to the second principal component, suggesting that pitting tended to occur more commonly in individuals with smaller body and pelvic sizes. In females, it is possible that this relationship may have been due to the strain acting on the dorsal pubic ligaments when the pubic symphysis separates during labour, the effects of which would be expected to be more severe in smaller pelves than larger ones (Ohlsén, 1973; Heckman & Sassard, 1994; Ritchie, 2003; Borg-Stein *et al.*, 2005; Becker *et al.*, 2010). In both sexes, however, activity patterns may be the simplest explanation. It is possible that individuals with smaller bodies and smaller pelves experience more strain on the dorsal pubic ligaments when performing certain activities. The fact that this strain appears to affect only the dorsal pubic ligaments in this manner suggests that the activities causing the strain acted mostly on the anterior of the pelvic girdle and the adductor muscles which attach to it. The sexes could not be clearly separated according to the second principal component (c.f. Figure 4.13). This may have been due to the large overlap in the ranges of body and pelvic sizes between males and females, with the difference between sexes being less than 10% for the majority of these variables, as well as the tendency of females to have small bodies but large pelves and the tendency of males to have large bodies but small pelves, as indicated by the first principal component.

The third principal component contrasted body and pelvic size with scar development and accounted for 8.5% of the observed variance (c.f. Table 4.25c and Figures 4.17 and 4.18). The dorsal pubic pitting and pubic tubercle were negatively correlated to this component, suggesting that pitting and tubercle extension tended to occur in individuals with larger body and pelvic sizes. In the case of the dorsal pubic pitting, this may have been the result of an increase in either the arcuate or the subpubic angle, both of which would increase the strain on the dorsal pubic ligaments across the pubic symphysis. The extension of the pubic tubercle may have been due to increased strain on the rectus abdominis muscle as the result of either muscle development or increased

abdominal fat deposition, both of which would result in an increased body mass. The preauricular sulcus, interosseous groove and iliac tuberosity were positively correlated to the third principal component, suggesting that the development of these features tended to occur in individuals with smaller body and pelvic sizes. A possible explanation for this is that the pelvic ligaments of individuals with larger body and pelvic sizes may have developed to be stronger and able to absorb more strain than those of smaller individuals, especially if the strains caused by having larger body and pelvic sizes were present over extended periods of time (DonTigny, 1985). The scar features that tended to occur more commonly in individuals with smaller body and pelvic sizes were also the ones located closest to the sacroiliac joint and the direct line of weight transfer through the pelvic girdle (Fraser, 1958), suggesting that weight-bearing strain may be another explanation for these observed relationships. Rosenberg (1988) claimed that shorter individuals tend to be heavier relative to their stature than taller individuals. It is thus possible that the relative weight-bearing strain in short individuals that are heavier may have been greater than that of tall individuals of average body weight, resulting in the increased development of scarring in these shorter individuals. Similar to the second principal component, the sexes could not be clearly separated according to the third principal component (c.f. Figure 4.14). This was again due to the large ranges of overlap in scar development and body and pelvic measurements between males and females.

5.9.1. Summary

Principal Components Analysis has shown that the variation between the individuals examined in this study could be attributed mostly to differences in body and pelvic size. The relative size of the body and the pelvis to each other (principal component 1) accounted for approximately a third of the total variance observed. The correlations of the scar features to this component indicated that scars tended to occur in individuals with small body sizes but large pelves, possibly due to the greater requirement for ligamentous stabilization of these larger pelves. It was found that females tend to present more with these body and pelvic sizes than males, which may explain the greater occurrence of scarring observed in females. The difference between the sexes was likely related to the differences in the functions of the girdle, with females having to balance biomechanical and obstetrical requirements, while males only have biomechanical restrictions to accommodate. The combined size of the body and the pelvis (principal component 2) accounted for approximately a sixth of the total variance observed. The correlations of the scar features to this component suggested that scars tended to be more developed in individuals with both large bodies and pelves. The apparent conflict in the relationship between body and pelvic size in this component and that of the first component may suggest that there is a threshold body size above which the weight-bearing

strain on the pelvic ligaments becomes sufficiently large to cause scar formation, regardless of the size of the pelvic girdle and its associated stability requirements. The sexes could not be clearly separated according to the second principal component, likely due to the large ranges of overlap in body and pelvic sizes between the sexes. The third principal component contrasted body and pelvic size with the scar development. The development of scars on the posterior of the pelvic girdle was associated with small body and pelvic sizes, while the development of scars on the anterior of the girdle was associated with larger body and pelvic sizes. In the former case, the observed relationship may have been due to greater strength of the pelvic ligaments in larger individuals due to prolonged strain applied to the ligaments or due to differences in the magnitude of the strains acting on the ligaments as a result of the combination of small stature with larger body mass. In the case of the scars on the anterior of the pelvic girdle, the relationship to body and pelvic size may simply reflect increased strain on either the rectus abdominis muscle or the dorsal pubic ligaments due to the larger body or pelvic sizes. Similar to the second principal component, the sexes could not be separated according to this component, again due to the large overlap in body and pelvic sizes. The three principal components examined lend further support to the theory that body and pelvic size and the associated stabilization and weight-bearing requirements of the pelvic girdle are the primary causes of scar formation at the attachment sites of the pelvic ligaments.

CONCLUSIONS

Original studies claimed that remodelling of bone at specific sites on the pelvic girdle could be used to assess the parity history of an individual. While it is no longer accepted that the number of children can be determined from such scars alone, very few studies have investigated the relationship between skeletal markers and parity history. The problem with the majority of studies that have done so is that they examine only a few areas at a time or use very small samples. Many studies also neglect to investigate the role of body size and pelvic dimensions on the manifestation of scarring.

This study examined “parturition scar” features at the dorsal pubic surface, pubic tubercle, preauricular sulcus, interosseous groove and iliac tuberosity of a large skeletal sample. The occurrence of scarring in both sexes indicates that the cause of scar formation was shared between the sexes and was likely related to ligamentous stabilization of the pelvic girdle. Since female pelves are more flexible than those of males, the need for this stabilization is greater, hence the increased occurrence and severity of scarring in females. The general lack of age-related changes in scar manifestation suggested that pregnancy and parturition-related strains were not the cause of scar formation, since the transient nature of such strains would have allowed remodelling of the areas of scarring, reducing the appearance of scars with age. Comparison of scarring between different time period samples indicated that body size and activity patterns did not significantly influence scar manifestation. Correlation between scar features showed that the strains acting across the pubic symphysis and the sacroiliac joint balance each other to maintain stability of the pelvic girdle, while the anterior and posterior sacroiliac ligaments balance each other in a similar manner to maintain stability of the joint. Comparison of the body and pelvic dimensions showed that despite having smaller body sizes, females tended to have relatively larger pelves. The transverse measurements of the pelvic girdle showed an unexpected increase with age, which could have been due to either sampling bias or age-related changes to the strain on the ligaments and muscles that attach to the bony areas that form the reference points for these measurements. The modern individuals tended to have larger pelves than either the archaeological or historical individuals, which was indicative of the relationship between body and pelvic size. Assessment of the influence of body and pelvic size on the manifestation of scars revealed that body and pelvic size accounted for approximately a third of the total variance observed, while the shape of the body and pelvis

combined accounted for approximately a quarter of the variance. The fact that these components accounted for only about 60% of the total variance suggested that some other factors not accounted for in this study may be responsible for the remainder of the variance. It was found that scarring occurred more commonly in individuals with either small bodies and large pelves or large bodies and large pelves. Whether scar development was greater on the anterior or posterior aspects of the pelvic girdle appeared to be determined by changes to the body or pelvic dimensions which would have resulted in a reduction in the stability of the girdle at either the pubic or the sacroiliac joints. Lastly, it was found that females tended to have the body and pelvic size combinations most commonly associated with scar development, which explains the greater occurrence of scarring relative to males. This model also explains the occurrence of scarring in males in the absence of indicators of trauma or disease, with those males that presented with scarring likely to have the body or pelvic sizes similar to those of females, thus resulting in similar scar development.

This study has shown that weight-bearing strain and the associated ligamentous stabilization of the pelvic girdle were responsible for the formation of scarring at the ligamentous attachment sites of the pelvic ligaments. Though these results suggested that parturition was not a primary cause of scar formation, the fact that pregnancy is an extreme form of weight-bearing means that pregnancy and parturition-related strains may have had some effect on the severity of scarring. Future studies may be able to test this theory on samples of known parity history. It may also be of interest to examine the magnitudes and directionalities of the strains acting on the pelvic ligaments in living individuals in order to further knowledge of the specific strains acting on each scar location.

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APPENDIX A: DATA COLLECTION FORM

General information

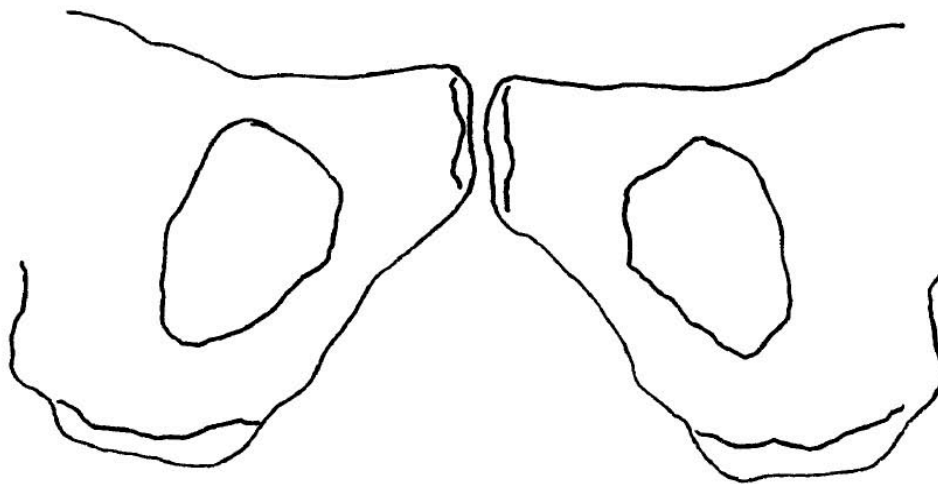
Collection: _____ Accession number: _____
Sex: _____ Age: _____
Pathologies: _____

Femur measurements

Length: _____ Max head diameter: _____

Dorsal pubic pitting

Absent Trace/small (diameter < 2.0 mm) Medium/large (diameter > 2.0 mm)



Pubic tubercle

	LEFT	RIGHT
Height (ventral aspect)	_____	_____
Description	small/medium/large	small/medium/large

Preauricular groove/ sulcus

	LEFT	RIGHT
Depth	_____	_____
Width	_____	_____
Description	1 2 3 4	1 2 3 4

Description:

- 1) *Absent/ Broad-shallow = sulcus < 3.9 mm deep*
- 2) *Narrow-shallow = sulcus is 3.0 mm – 5.0 mm deep*
- 3) *Defined = sulcus > 5.0 mm deep, but < 10.0 mm wide*
- 4) *Complex = sulcus > 5.0 mm deep and > 10.0 mm wide*

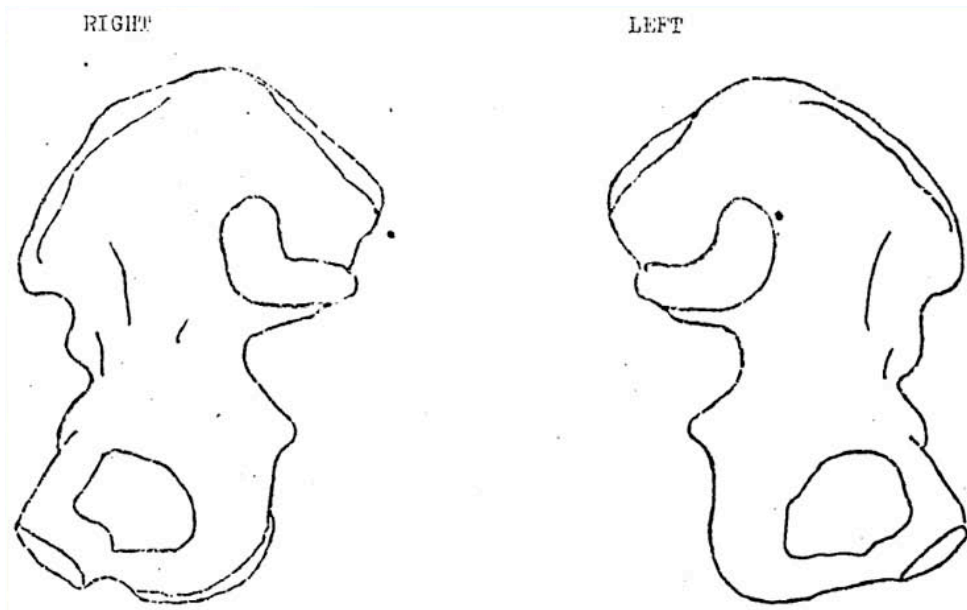
Interosseous groove

Depth: floor of sulcus to highest margin of posterior auricular surface near the posterior inferior iliac spine **LEFT:** _____ **RIGHT:** _____

Width: widest point between superior margin of sulcus to inferior margin between posterior superior and inferior iliac spines **LEFT:** _____ **RIGHT:** _____

Description 1 2 3 1 2 3

- Description:*
- 1) *Shallow* = groove < 3.0 mm deep
 - 2) *Moderate* = groove > 3.0 mm, and 5.0 – 10.0 mm wide
 - 3) *Developed* = groove > 3.0 mm and > 10.0 mm wide.



Iliac tuberosity

Thickness: with spreading calipers the anteroposterior thickness at the highest point of iliac tuberosity to posterior of ilium **LEFT:** _____ **RIGHT:** _____

Description: 1 2 3 1 2 3

- Description:*
- 1) *No eminence* = tuberosity < 20.0 mm thick
 - 2) *Depressed mound* = tuberosity is 20.0 – 25.0 mm thick
 - 3) *Pointed mound* = tuberosity > 25.0 mm thick

Articulated measurements

Distance between ischial spines _____
 Distance between ischial tuberosities _____
 Bi-iliac breadth (distance between iliac crests) _____
 Transverse diameter of inlet (between arcuate lines) _____
 Transverse diameter of outlet (ischial tuberosities) _____

LEFT **RIGHT**

Anteroposterior diameter of inlet _____ _____
 Anteroposterior diameter of outlet: _____ _____

APPENDIX B: SAMPLE SIZES FOR MEASUREMENT OF THE ARTICULATED PELVIC GIRDLE

	Archaeological sample		Historical sample		Modern sample		Pooled data	
	Females	Males	Females	Males	Females	Males	Females	Males
Anteroposterior diameter inlet	14	20	2	4	96	158	112	182
Transverse diameter inlet	14	20	2	3	97	158	113	181
Interspinous diameter	13	19	2	4	93	156	108	179
Anteroposterior diameter outlet	13	19	2	4	92	152	107	175
Transverse diameter outlet	11	20	2	4	89	158	102	182

APPENDIX C: SAMPLE SIZES OF STUDIES USED IN COMPARISONS

Table C.1: *Sample sizes for comparison of mean femur length.*

Sample	Females	Males	Source
Black South African individuals			
Cape Nguni	22	32	Lundy (1986)
Sotho	56	61	“
Venda	3	3	“
South African individuals	50	56	Steyn & İşcan (1997)
Hamann-Todd Collection (mixed) **	99	98	Tague (2005)
Later Stone Age foragers	23	28	Kurki (2011a)
Coimbra Identified Skeletal Collection **	40	40	“
Hamann-Todd Collection (mixed) **	40	40	“
South African individuals	71	98	Dayal <i>et al.</i> (2008)

Table C.2: *Sample sizes for comparison of mean femur head diameter.*

Sample	Females	Males	Source
Black South African individuals			
Cape Nguni	22	32	Lundy (1986)
Venda	3	3	“
South African individuals	50	56	Steyn & İşcan (1997)
Later Stone Age foragers	23	27	Kurki (2007)
Coimbra Identified Skeletal Collection **	40	40	“
Hamann-Todd Collection (mixed) **	40	40	“
Hamann-Todd Collection (mixed) **	53	83	Tague (2009)

Table C.3: *Sample sizes for comparison of the anteroposterior diameter of the pelvic inlet.*

Sample	Females	Males	Source
Terry Collection: White individuals **	100	100	İşcan & Cotton (1985)
Terry Collection: Black individuals **	100	100	“
Combined historical sample	33	30	O’Connell (2004)
Coimbra Identified Skeletal Collection **	124	118	Correia <i>et al.</i> (2005)
Later Stone Age foragers	18	16	Kurki (2007)
Coimbra Identified Skeletal Collection **	40	40	“
Hamann-Todd Collection (mixed)	40	40	“
Greek individuals	83	85	Steyn & İşcan (2008)

Table C.4: *Sample sizes for comparison of the transverse diameter of the pelvic inlet.*

Sample	Females	Males	Source
Terry Collection: White individuals **	100	100	İşcan & Cotton (1985)
Terry Collection: Black individuals **	100	100	“
Hamann-Todd Collection (mixed) **	156	176	Tague (2000)
Combined historical osteological sample	40	30	O’Connell (2004)
Coimbra Identified Skeletal Collection **	124	118	Correia <i>et al.</i> (2005)
Later Stone Age foragers	18	14	Kurki (2007)
Coimbra Identified Skeletal Collection **	40	39	“
Hamann-Todd Collection (mixed) **	40	40	“
Greek individuals	86	85	Steyn & İşcan (2008)

Table C.5: *Sample sizes for comparison of the interspinous diameter.*

Sample	Females	Males	Source
Hamann-Todd Collection **	32	55	Tague (2000)
Combined historical sample	7	11	O’Connell (2004)
Coimbra Identified Skeletal Collection	124	118	Correia <i>et al.</i> (2005)
Later Stone Age foragers	10	11	Kurki (2007)
Coimbra Identified Skeletal Collection	21	28	“
Hamann-Todd Collection **	32	40	“

Table C.6: *Sample sizes for comparison of the anteroposterior diameter of the pelvic outlet.*

Sample	Females	Males	Source
Hamann-Todd Collection **	140	156	Tague (2000)
Combined historical sample	21	19	O’Connell (2004)
Coimbra Identified Skeletal Collection **	124	116	Correia <i>et al.</i> (2005)
Later Stone Age foragers	15	15	Kurki (2007)
Coimbra Identified Skeletal Collection **	40	40	“
Hamann-Todd Collection **	40	40	“

Table C.7: *Sample sizes for comparison of the transverse diameter of the pelvic outlet.*

Sample	Females	Males	Source
Hamann-Todd: White individuals **	49	48	Tague (1989)
Hamann-Todd: Black individuals **	50	50	“
Combined historical sample	37	27	O’Connell (2004)
Coimbra Identified Skeletal Collection **	124	118	Correia <i>et al.</i> (2005)
Later Stone Age foragers	16	13	Kurki (2007)
Coimbra Identified Skeletal Collection **	40	40	“
Hamann-Todd Collection (mixed) **	39	40	“

APPENDIX D: OVERVIEW OF COLLECTIONS USED FOR COMPARISON

C1. Hamann-Todd Osteological Collection

The Hamann-Todd collection was started by Carl A. Hamann, who was the professor of anatomy at the medical school at the Western Reserve University in Cleveland, Ohio, from 1893 to 1912. Skeletons were collected from cadavers (of known age and sex) after dissection and consisted mostly of African- or European-American individuals from a low socioeconomic background (Quigley, 2001). Hamann's successor, Thomas W. Todd, continued to enlarge the collection. In 1968, over 3000 skeletons were moved to the Cleveland Museum of Natural History, where they are currently being housed.

C2. Robert J Terry Anatomical Skeletal Collection

Dr Robert J. Terry, the chair of the Anatomy Department of the Washington University Medical School, began collecting the skeletons of cadavers in 1910 (Hunt & Albanese, 2005). The majority of these cadavers were unclaimed bodies from the St Louis morgues and hospitals and were thus represented mostly the lower socioeconomic class of the area. Terry's successor in the department, Mildred Trotter, also played an important role in the growing of the collection by balancing the demographic distribution of the collection thorough adding younger individuals and white females to it. After the Willd Body Law of Missouri was passed in 1956, individuals of the middle and upper socioeconomic classes were also included in the collection. After Trotter's retirement in 1967, the collection was donated to the Smithsonian Institute in Washington DC. The collection currently consists of 1728 individuals of known age, sex, ancestry, cause of death and antemortem pathology.

C3. Christ Church, Spitalfields

Between 1984 and 1986, excavation of burial vaults beneath Christ Church, Spitalfields, in London yielded 968 skeletons of individuals interred between 1729 and 1859 (Cox & Scott, 1992). Of these skeletons, 387 were recovered in association with coffin plates stating the name, age at death and date of death (referred to as the "named sample"). The sample consisted mainly of individuals of French descent. Most were middle class, well-nourished and rarely performed manual labour. The information obtained from the coffin plates, used in combination with historical records such as death certificates and baptism records, allowed reconstruction of the obstetric histories of 94 of the adult female skeletons. The complete collection is currently housed in the National History Museum in London.

C4. Coimbra Identified Skeletal Collection

This collection consists of the skeletal remains excavated from the Cemitério Municipal da Conchada in Coimbra, Portugal, from 1915 to 1942 (Quigley, 2001). The remains individuals buried in the late 19th to early 20th centuries, and for whom age, sex and socioeconomic status is known. The 505 sets of remains are currently housed in the Faculty of Science and Technology at the University of Coimbra in Portugal.

University of Cape Town