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„The Bony Pelvis: Macroscopic Analysis of the Frequency and Morphology of the so-called Scars of Parturition and their Relationship with Sex, Age, Body Mass and Pelvic Dimensions“

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Abstract

The theory behind the formation and manifestation of the so-called „scars of parturition“ and particularly their possible use in determining parity history is still a debated issue among anthropologists. In spite of large amounts of studies, the results are in part contradictory and hence, a true relationship between the pelvic scars and pregnancy and childbirth could not be conclusively shown yet. Since skeletal collections with information about the parity history of female individuals are rare, the best approach is to investigate the relationship of scarring with other potential factors influencing its formation and manifestation.

The aim of the present study was to measure and observe the variability of morphology and frequency of the parturition scars, namely the dorsal pubic pits, the pubic tubercle, and the preauricular sulcus, in a Lithuanian skeletal collection provided by the University of Vilnius comprising 170 males and 130 females. The body mass was estimated and measurements of the pelvic girdle were taken. The pelvic scars, pelvic dimensions, and body mass estimates were compared according to sex and age at death. Further, the relationship between scarring, pelvic measurements, and body mass was examined.

The statistical analysis showed that pelvic scarring was present in both sexes, however, the degree and frequency was significantly greater in females. The scar features were also found among all age groups, whereby the incidence and manifestation of the imprints either increased or remained unchanged with advancing age. The correlation test revealed a significant positive relationship between pubic length and pubic tubercle diameter and the anterior upper spinal breadth and the tubercle height in females. A significant negative association was found between the distance of the ischial spines and the extension of the pubic tubercle and the pubic length and sulcus width in women. Body mass correlated significantly negatively with the tubercle height, sulcus length and sulcus width in the female sample. In the youngest age group, the body mass estimate showed a positive relationship with pit length, whereas in middle-aged adults it was negatively correlated with the preauricular sulcus length and width.

The results indicate that pregnancy and childbirth cannot be the primary factors that cause pelvic scarring. Also, body mass does not affect scar formation substantially. Instead, pelvic architecture and the weight-bearing function of the pelvis might contribute primarily to its formation. Females exhibit a more flexible pelvic girdle with greater mobility, which increases the strain acting on the pelvic ligaments and hence, causes scar formation.

Chapter 1: Background

1.1. Introduction

In the last century, scientists addressed the question whether pregnancy and childbirth leave visible imprints on the female bony pelvis. Angel (1969) was one of the first who proposed that parity and parturition lead to alterations on the bony pelvis, which can be used to assess the birth history of a female individual. In 1970 the term "scars of parturition" was introduced by Stewart and a number of studies followed investigating the relationship between parturition scars and pregnancy and delivery (Stewart, 1970; Houghton, 1975; Putschar, 1976; Holt, 1978; Kelley, 1979; Andersen, 1986; Cox and Scott, 1992). The associated areas comprise the dorsal pubic surface with its pubic pits, the pubic tubercle, the preauricular sulcus, and the interosseous groove.

The cause of formation and manifestation of the bony imprints on the aforesaid areas possibly underlies physiological and anatomical changes and traumata during pregnancy and childbirth (Angel, 1969; Stewart, 1970). Such physiological changes are induced by hormones such as relaxin and estrogen during pregnancy. The hormone relaxin is responsible for the widening of the sacroiliac joint and induces together with estrogen the loosening of the pelvic ligaments (Houghton, 1975; Albert et al., 1997). Relaxin is also responsible for the widening of the pubic cleft (Ritchie, 2003; Borg-Stein and Dugan, 2007). Wider pelvic joint spaces result in a wider birth canal and represent together with lax pelvic ligaments the preparation of the female body for the birth process (Houghton, 1975; Becker et al., 2010). During pregnancy and particularly during delivery the ligaments are heavily stretched. Ruptures may occur in the course of the birth process and can result in edema and hemorrhage at the attachment site. Bone remodeling and active osteoclastic resorption may occur as a response to traumata of the ligaments. All these factors contribute to the formation and manifestation of the parturition scars. After delivery pelvic ligaments return to their normal state within a few weeks. However, the previous osteoclastic active bone areas take years to disappear (Houghton, 1975).

Until now there is no scientific consensus whether the parturition scars are formed and manifested by pregnancy and delivery. While several studies found a relationship between certain bony imprints and parity and childbirth (Kelley, 1979; Cox and Scott, 1992; Snodgrass and Galloway, 2003; McArthur et al., 2016) other studies found no such relationship (Andersen, 1986; Spring et al., 1989; Cox and Scott, 1992; Snodgrass and Galloway, 2003). Furthermore, investigations showed that parturition scars do not solely occur in parous women but in nullipara and males as well (Stewart, 1970; Holt, 1978; Kelley, 1979; Andersen, 1986; Spring et al., 1989). This implies that other factors must contribute to scar formation and manifestation. Such a factor may include body mass. Holt (1978) found in his study a positive association of the occurrence of the parturition scars and obesity. Also, age, pelvic structure, and pelvic dimensions are regarded as further possible influencing factors (Houghton, 1975; Cox and Scott, 1992; Snodgrass and Galloway, 2003).

1.2. The bony pelvis

The human bony pelvis consists of four bony elements, namely the left and right coxae, the sacrum and coccyx. The hip bone actually consists of three different parts, the ilium, ischium and pubic bones, which fuse around the hip socket, the acetabulum, in early adolescence and form afterwards one irregularly shaped and morphological complex bone (Andersen, 1986; White and Folkens, 2005; Brown, 2015; Verbruggen and Nowlan, 2017). The ilium represents the largest element of the coxae. It is located superior to the acetabulum and has a thin and flat shape (White and Folkens, 2005). The ischium lies posteroinferiorly and with its blunt and massive shape, it is the strongest bone of the pelvis (Andersen, 1986; White and Folkens, 2005). The pubis completes the hip bone and is located anteroinferiorly (White and Folkens, 2005). The sacrum and coccyx are actually counted among the axial skeleton and represent variable fused vertebrae (White and Folkens, 2005). The sacrum is a symmetrical triangular bone, which originally consists of usually five separate vertebrae, that fuse to one piece of bone during adolescence (Andersen, 1986; White and Folkens, 2005; Schünke et al., 2014). The coccyx articulates with the sacrum and is composed of three to four vertebral rudiments (Schünke et al., 2014).

The hip bones connect anteriorly with each other at the cartilaginous pubic symphysis and posteriorly with the sacrum at the sacroiliac joints (Figure 1.1) (Schünke et al., 2014; Verbruggen and Nowlan, 2017). Due to these connections, a stable pelvic ring is formed, which allows only minimal flexibility. This, in turn, results in a highly stable pelvic girdle (Schünke et al., 2014).

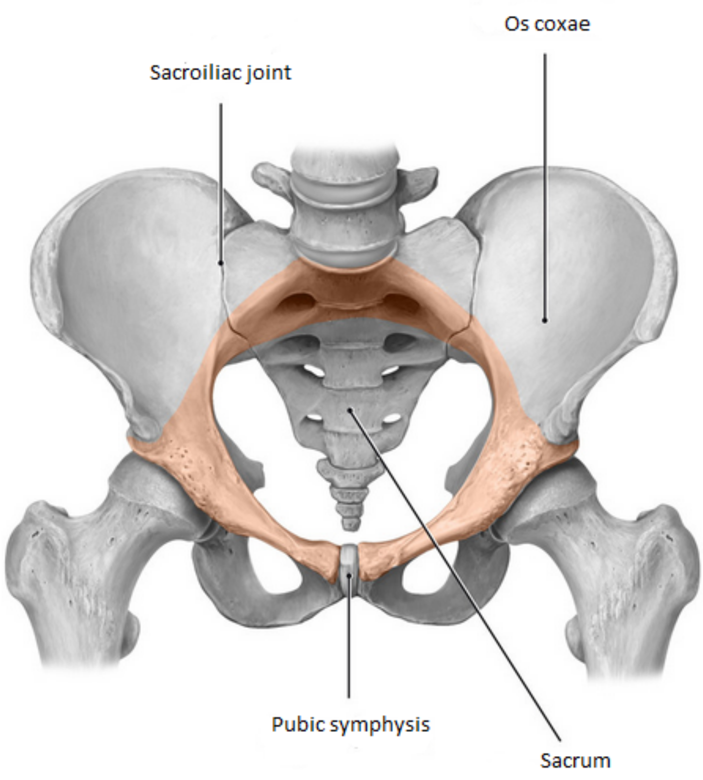


Figure 1.1: Ventral-cranial view of the pelvic girdle and pelvic ring (highlighted in red) consisting of both hip bones and sacrum connected by the pubic symphysis and two sacroiliac joints (Adapted from Schünke et al., 2014).

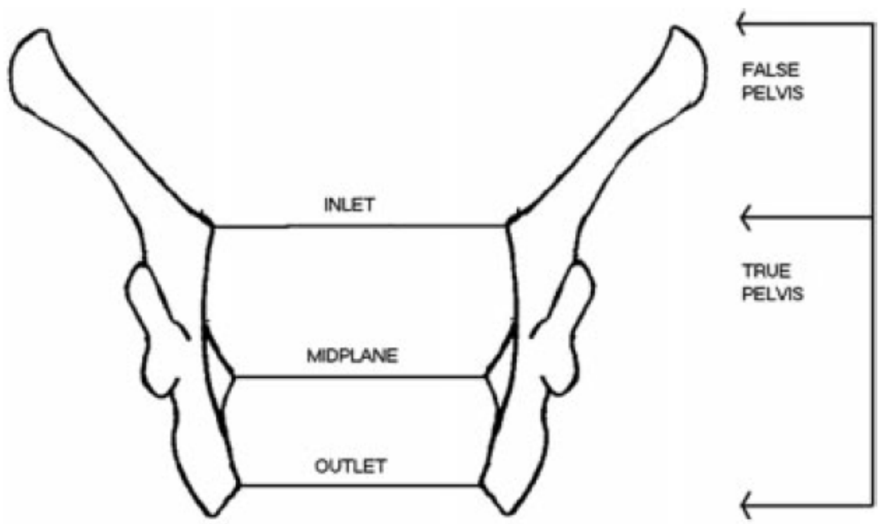


Figure 1.2: The three obstetric planes and major division of the bony pelvis (Adapted from Kurki, 2007).

The bony pelvis is subdivided into two parts: the false pelvis and the true pelvis (Figure 1.2). The false pelvis includes the area above the pelvic brim as well as the superior region of the sacrum. The true pelvis, also known as the pelvic or obstetric canal, consists of the region that lies below the pelvic brim and represents in women the birth canal. The true pelvis, in turn, is divided into three planes: the inlet (at the level of the pelvic brim), the midplane (at the level of the ischial spines), and the outlet (at the level of the ischial tuberosities) (Kurki, 2007). Regarding obstetrics, the midplane is the most delicate plane as the ischial spines protrude in the pelvic canal and produce its greatest constriction (Walrath and Glantz, 1996).

The human pelvis fulfills several important functions. Its primary function lies in the transfer of the upper body weight into the lower limbs during walking, running or standing (DeSilva and Rosenberg, 2017; Verbruggen and Nowlan, 2017). Furthermore, it provides attachment sites for muscles, tendons, and ligaments that enable support and movement (Wobser and Wobser, 2018). It also has a significant role regarding obstetrics, as the human neonate must fit through the maternal birth canal (DeSilva and Rosenberg, 2017). Finally, together with the pelvic floor musculature the bony pelvis holds up the abdominal organs (DeSilva and Rosenberg, 2017).

1.2.1. Sexual dimorphism and the obstetrical dilemma hypothesis

The human pelvic bones are one of the highest sexually dimorphic bony elements in the human body (DeSilva and Rosenberg, 2017). Its anatomy and morphology start to differ between the sexes with the onset of puberty (White and Folkens, 2005; Verbruggen and Nowlan, 2017). While the male pelvis must primarily be suitable for upright posture and bipedal locomotion, the female pelvis additionally must accomplish the demands of reproduction (White and Folkens, 2005; Delprete, 2017). The female pelvis is in general larger and broader, while the male pelvis is more massive, narrower and taller (Figure 1.3). The pelvic inlet of women is oval in shape and larger. Men, however, show a heart-shaped pelvic inlet due to the fact that the promontory protrudes further in the pelvic cave. The left and right inferior pubic ramus form an angle, which is sharp in males and wider in females. Hence, this angle is called pubic arch in women and subpubic angle in men (Schünke et al., 2014). Women show a wider and shorter sacrum and it is also more backward tilted, as well as less curved compared to men (Alderink, 1991; Vleeming et al., 2012).

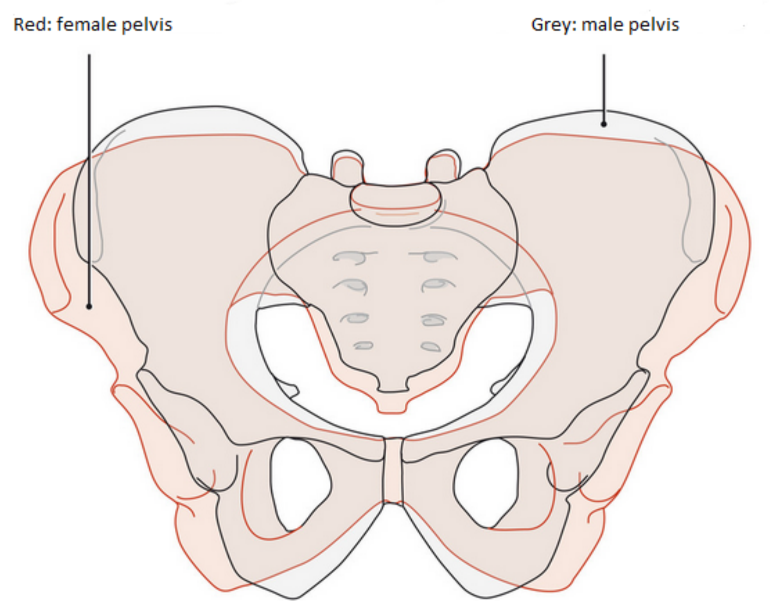


Figure 1.3: Sexual dimorphism of the pelvis. The red outline represents the female and the grey outline the male pelvis (Adapted from Schünke et al., 2014).

Two contrary constraints, namely bipedal locomotion, and childbirth, lead to the so-called "obstetrical dilemma" hypothesis proposed by Washburn (1960). Upright posture and locomotion favor a narrower and shorter pelvis. Consequently, the pelvic and leg joints are closer to the center of gravity and the abductor muscles, which are needed for pelvic stabilization during the single-leg support phase during walking, are less strained and thus less energy is required. This implies that a narrow pelvis improves efficiency in locomotion (Lovejoy, 1988; Warrener et al., 2015; Betti, 2017). However, a narrow pelvis accompanies a narrower birth canal, which leads to a higher risk of feto-pelvic disproportions and obstructed labor. As a consequence, the neonate cannot pass the maternal birth canal (Lovejoy, 1988; Rosenberg, 1992; Betti, 2017). The female pelvis is additionally under selection for a wider pelvis and birth canal due to the constraint of birth of large-brained and large-bodied neonates (Rosenberg, 1992; DeSilva, 2011; Huseynov et al., 2016). These two selective constraints led to a compromise, whereby the female pelvis is larger than the male to enable the passage of the fetus during childbirth, even if bipedal locomotion is less efficient (Rosenberg, 1992; DeSilva and Rosenberg, 2017).

The obstetrical dilemma hypothesis is currently increasingly challenged on biomechanical, metabolic and biocultural grounds (Warrener et al., 2015; Kurki, 2017). Although there is no doubt that locomotion and obstetrics have an impact on the evolution of pelvic morphology and anatomy, the strength of its influence and its opposing nature is unclear (Kurki, 2017).

1.2.2. Joints of the pelvic girdle

The pelvic girdle is connected by three joints, namely the pubic symphysis and the two sacroiliac joints. The pelvic joints fulfill two major tasks, namely the weight transfer of the upper body weight to the lower limbs and it further functions as a buffer to minimize the force of sudden jars and impacts from the lower limb (Brooke, 1924).

1.2.2.1. The pubic symphysis

The pubic symphysis is a joint that is composed of two medial articular surfaces of the pubic bones, which are covered with hyaline cartilage and an intervening fibrocartilaginous disc (Ibrahim and El-Sherbini, 1961; Becker et al., 2010). The pubic symphysis generally resists tension, shearing and compressing forces and is reinforced by four ligaments (Becker et al., 2010). The anterior pubic ligament represents the strongest one (Demirkale et al., 2008). It bridges the left and right pubic bones anteriorly, whereby its fibers blend with the fascia of the rectus abdominis muscle and supports the symphysis in its stability (Gamble et al., 1986; Becker et al., 2010). The anterior pubic ligaments consist of multiple differently oriented layers of collagen fibers. While the deep layers are transversally aligned, the superficial fibers show an oblique alignment. The posterior pubic ligaments connect the pubic bones posteriorly (Becker et al., 2010). Putschar (1976) found that this ligament tends to be thicker in multiparous women. The superior and inferior pubic ligaments complete the ligament connection. The superior pubic ligament attaches the superior margins and the pubic tubercle, whereas the inferior counterpart bridges the inferior pubic rami (Gamble et al., 1986; Hinrichsen, 2008; Becker et al., 2010). Due to the ligamentous reinforcement movement is significantly restricted in the pubic symphysis (Becker et al., 2010). However, the mobility of the symphysis in women is slightly greater than in men. Due to changes in hormonal balance during pregnancy, this mobility is even increased (Gamble et al., 1986).

1.2.2.2. The sacroiliac joint

The sacroiliac joint is a highly specialized joint, which provides stable and yet flexible support to the trunk (Vleeming et al., 2012). It is an amphiarthrosis, whereby the auricular surface of the sacrum and ilium articulate. On the inside of the pelvis are the anterior sacroiliac ligaments and dorsal the posterior sacroiliac, interosseous sacroiliac and the iliolumbar ligaments (Figure 1.4). The ligaments help to anchor the sacrum in an upright posture in the pelvic ring and prevent slipping of the sacrum into the pelvic cave. Additionally, the sacrotuberous ligament and sacrospinous ligament prevent a dorsal tilting movement of the pelvis and reinforce the sacroiliac joint (Schünke et al., 2014). The reinforcement of the posterior region of the joint is greater due to a higher amount of surrounding muscles (Walker, 1992).

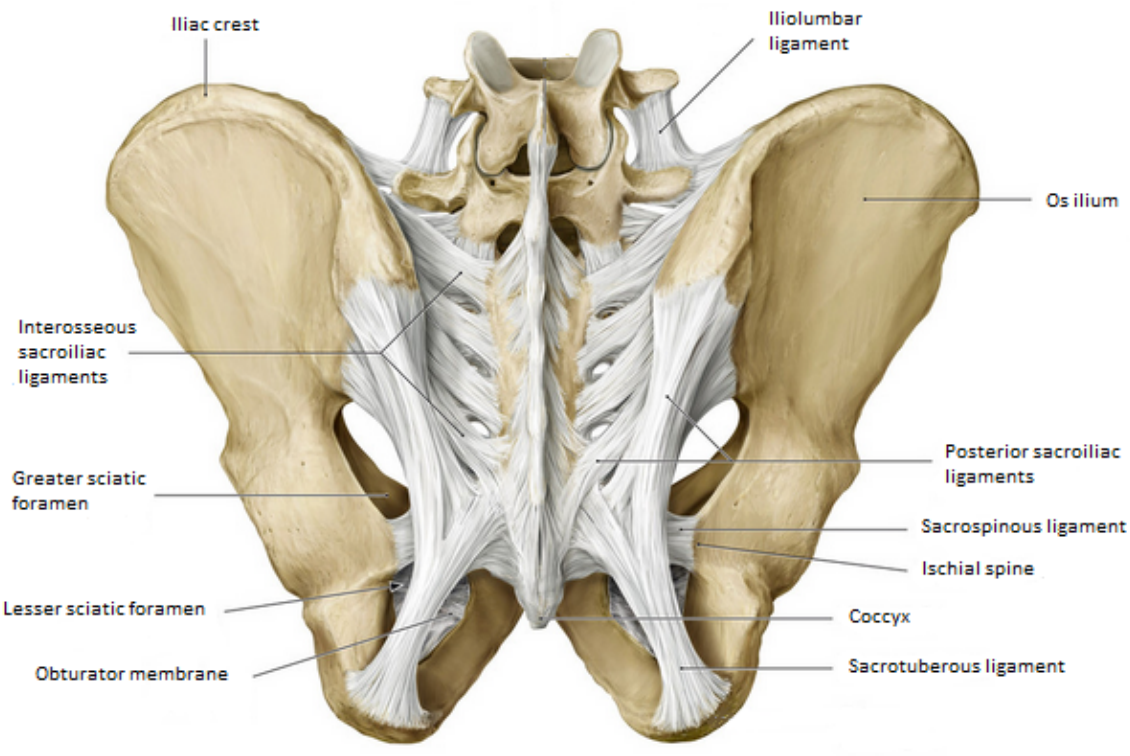


Figure 1.4: Posterior view of the sacroiliac joints and its associated ligaments (Adapted from Schünke et al., 2014).

Shape and size of both articular surfaces vary among individuals and its cartilage coverage differs anatomically. The cartilage on the side of the sacrum is uneven and twice as thick compared to the ilium. Because of the tight joint capsule and strong ligaments, movement is significantly restricted in the sacroiliac joint. However, its range varies individually and sex-specific (Schünke et al., 2014). In males, the ligaments are stronger and thicker, while the ligaments and the soft parts remain comparatively lax in females. Due to the stronger and thicker ligaments, the mobility in the joint is diminished in men compared to women (Brooke, 1924).

Although the movement is significantly restricted in the sacroiliac joint minimal rotational and translational movements are still possible (Alderink, 1991; Schünke et al., 2014). These movements affect the diameter of the pelvic outlet, more precisely the conjugata recta, and are particularly important during delivery. If the sacrum moves forward, the promontory shifts in a caudal-ventral and the coccyx in a cranial-dorsal direction, which results in a larger diameter of the conjugata recta but a shorter diameter of the pelvic inlet. However, if the sacrum moves backward the diameter of the conjugata recta gets smaller and the pelvic inlet larger (Schünke et al., 2014). During pregnancy, the range of movement is even increased by about 2.5 times above the maximum degree in non-pregnant women (Brooke, 1924). This increase in mobility facilitates childbirth since the sacrum rotates during delivery when the fetal head passes the bony birth canal (Houghton, 1975; Alderink, 1991). After delivery, the joint returns slowly to its normal condition, it takes however at least three months until the stability has been completely re-established (Brooke, 1924).

1.2.3. Pregnancy-related changes

Significant anatomical and physiological changes occur during pregnancy to nourish and nurture the developing fetus. Pregnancy accompanies two major changes in the pelvis, namely widening of the pubic symphysis and sacroiliac joints and relaxation of the ligaments (Soma-Pillay et al., 2016). These changes are particularly induced by the hormone relaxin. It is produced in the corpus luteum and represents a polypeptide hormone, which affects not only the pelvic joints and ligaments, but also the myometrium, cervix, placenta, and breasts (Walker, 1992; Borg-Stein and Dugan, 2007). During pregnancy, relaxin reaches its peak at the 12^{th} week and is followed by a decline. Afterward, the stable hormone level is about half of the peak value (Borg-Stein and Dugan, 2007). Relaxin induces the widening of the pubic cleft during the 10^{th} and 12^{th} week of pregnancy, which can be accompanied by pain (Ritchie, 2003; Borg-Stein and Dugan, 2007). On average the symphysis widens 7-8mm and normally does not exceed 10mm (Thorp and Fray, 1938; Borg-Stein and Dugan, 2007). Relaxin induces a widening of the sacroiliac joints as well (Houghton, 1975; Albert et al., 1997; Becker et al., 2010).

Moreover, both relaxin and estrogen have major effects on the tensile strength of the ligaments. Under its influence, the ligaments become lax during pregnancy (Walker, 1992; Ritchie, 2003; Borg-Stein and Dugan, 2007). With increasing weight of the fetus during late pregnancy the lumbar hyperlordosis increases and the pelvic ligaments, as well as the rectus abdominis muscle and the obliquus abdominis muscle, get furthermore heavily stretched and as a result, become hypertrophic (Putschar, 1976; Bergfelder and

Herrmann, 1980; Tague, 1988; Borg-Stein and Dugan, 2007). Also, the anterior pubic ligament is weakened. This is probably the case due to the fact that it is strengthened and blended with the fascia of the rectus abdominis muscle (Ibrahim and El-Sherbini, 1961). As a result, lax ligaments result in more flexible joints, which allow an expansion of the birth canal during childbirth (Houghton, 1975). All these factors combined lead to increased mechanical strains on the pelvis and its joints and cause active bone resorption adjacent to the ligaments attachment sites (Houghton, 1975; Borg-Stein and Dugan, 2007). During delivery, the ligaments are stretched even further, which may result in ruptures, edema, and hemorrhage on the attachment sites (Houghton, 1975; Bergfelder and Herrmann, 1980).

Stretched ligaments together with the wider pelvic joint spaces and a more flexible pelvic girdle represent the preparation and facilitation of the female pregnant body for the birth process (Houghton, 1975; Wurdinger et al., 2002; Becker et al., 2010). It takes only a few weeks after childbirth when the ligaments and the widened pelvic joint spaces return to their original state (Ibrahim and El-Sherbini, 1961; Houghton, 1975; Wurdinger et al., 2002). Putschar (1976) however states that each delivery leaves the pelvic joints to some extent substantially loosened.

1.3. Scars of parturition

For decades anthropologists have discussed if and to what extent pregnancy and childbirth can affect the human skeleton. Angel (1969) was one of the first scientists who proposed that pregnancy leaves visible alterations on the female bony pelvis. Shortly afterward Stewart (1970) introduced the term “scars of parturition”. Both scientists believed that these changes can be used to assess the birth history of female individuals (Angel, 1969; Stewart, 1970). Numerous studies have been conducted to investigate these imprints and to figure out if pregnancy is a responsible factor for its development (Kelley, 1979; Andersen, 1986; Cox and Scott, 1992; Maass and Friedling, 2016; McArthur et al., 2016).

1.3.1. Formation of the parturition scars

Although the process of scar formation is complex and still not entirely understood, it is generally accepted that among other factors, the hormonal change during pregnancy is the trigger of the development of these imprints (Cox and Mays, 2006). There is an increased release of relaxin during pregnancy, which induces relaxation of the pelvic ligaments and pelvic joints (Borg-Stein and Dugan, 2007). Other pregnancy related changes such as weight gain and lumbar hyperlordosis during late pregnancy, lead to increased stretching of the ligaments, which results in cysts and knots of fibrocartilage and haemorrhages and oedema on its attachment sites as well as greater muscle insertions (Angel, 1969; Houghton, 1975; Bergfelder and Herrmann, 1980; Cox and Mays, 2006; Borg-Stein and Dugan, 2007). During the birth process, the pelvic ligaments are heavily stretched and may tear. To counteract these stresses and strains cortical reorganization and active osteoclastic resorption occur on the attachment sites of the ligaments and lead to pits or even grooves on the bone, commonly known as the scars of parturition. (Houghton, 1975; Ullrich, 1987).

After labor, the pelvic ligaments return slowly to its normal condition within a few weeks. However, the reorganization and repair processes of the previous active bone resorption areas are slow and it takes years that the scars become shallower until they disappear completely (Houghton, 1975).

1.3.2. Areas of occurrence

The areas of occurrence of the parturition scars comprise the pubic bone with the dorsal pubic pits and pubic tubercle on the ventral side, as well as the ilium with the preauricular sulcus and interosseous groove. Especially the pubic bone with its imprints and extended tubercles has been of great interest as an indicator of pregnancy and childbirth (Snodgrass and Galloway, 2003).

1.3.2.1. Dorsal pubic surface

Adjacent to the pubic symphysis on the dorsal pubic surface depressions and cavities, also known as dorsal pubic pits can be found. Its manifestation can either be circular looking like a crater or elongated like a groove. There can be one or several pits varying in size and depth (Houghton, 1975). The dorsal pubic pits are the attachment site of the puborectal muscle, which is a component of the levator ani muscle. The levator ani muscle in turn, belongs to the pelvic floor muscles. During pregnancy, the pelvic floor muscles are massively strained due to the extreme increase of the intraabdominal pressure, particularly towards the end of gestation. This can lead to the weakening of the connective tissue or even to the damage of the pelvic floor muscles (Schünke et al., 2014).

Dorsal pubic pitting is one of the most examined areas of the parturition scars (Ubelaker and De La Paz, Jade S, 2012). Angel (1969) stated that these pits are a consequence of the hemorrhages, which occur after several pregnancies and deliveries. After a sufficient number of births, the pits may even fuse to a deep groove (Angel, 1969). However, only one year later a study by Stewart (1970) showed the contrary of Angel's statement, namely that also women with known parity exhibited no birth scars. Holt (1978) supported that view with the same exact findings as Stewart. This means that pregnancy and parturition are not solely attributed to the scars, however, they may represent one of many influencing factors (Holt, 1978).

1.3.2.2. Pubic tubercle

The pubic tubercle is located on the ventral aspect of the pubic bone laterally to the pubic symphysis. In association with pregnancy and parturition, its extension is examined. The pubic tubercle is the attachment site of the Rectus abdominis muscle and the inguinal ligament (Cox and Mays, 2006). The rectus abdominis muscle extends superiorly from the fifth to seventh costal cartilages and from the Processus xiphodeus of the sternum along the abdomen to the pubic bone inferiorly (Schünke et al., 2014). There it attaches the pubis by two tendons, whereby the larger one attaches the pubic crest and the pubic tubercle and the smaller one is attached to the opposing pubic crest (Cox and Mays, 2006). The main function of the rectus abdominis muscle represents ventral flexion but it is also responsible in containing the anterior abdomen (Cox and Mays, 2006; Schünke et al., 2014). During pregnancy, the muscle elongates with increasing size of the fetus (Coldron et al., 2008). The inguinal ligament attaches the pubic tubercle and extends to the supero-anterior iliac spine and is also involved in the anterior abdomen containment. Both, the rectus abdominis muscle and the inguinal ligament are stressed during the later stages of pregnancy due to the growing abdomen (Cox and Mays, 2006).

During pregnancy and childbirth, the pubic tubercle extends. This is explained by the increasing weight and size of the fetus towards the end of the pregnancy that stress and stretch muscles and ligaments, which consequently results in pulling and extending the attachment site, namely the pubic tubercle (Cox and Mays, 2006). Cox and Scott (1992) supported the association of extension of the pubic tubercle and parity status suggesting multiparous women had longer tubercles on average than nullipara. Other studies, however, found no such relationship (Bergfelder and Herrmann, 1980; Snodgrass and Galloway, 2003).

1.3.2.3. Preauricular sulcus

The preauricular sulcus is a grooved area located inferior and slightly anterior to the auricular surface on the ilium (Holt, 1978). It is the attachment site of the anterior sacroiliac ligament, that connects the sacrum with the ilium (Andersen, 1986). Due to similar strain processes during pregnancy and delivery that cause the formation of the pubic pits, also lead to the development of the preauricular sulcus (Houghton, 1975). However, the more distinct changes of the sulcus may be also a result of the additional strain of the weight transfer of the upper body on the sacroiliac joints during pregnancy (Derry, 1909; Houghton, 1975). Therefore, changes on the ilium can be amplified due to the increased weight during pregnancy on the lax ligaments for several months (Houghton, 1975). Houghton (1975) stated that men and women who had not given birth before, show normally a shallow sulcus of constant depth. Women who had been pregnant however, exhibit a different kind of sulcus. Its manifestation is deeper and the floor of the preauricular sulcus has several pits or craters thus, making an irregular floor (Houghton, 1975). Nonetheless, the study of Cox and Scott (1992) and Andersen (1986) found no such relationship between preauricular sulcus and pregnancy.

1.3.2.4. Interosseous groove

The interosseous groove is situated superior to the auricular surface and inferior to the iliac tuberosity on the ilium. It is the attachment site of the interosseous sacroiliac ligament and the dorsal sacroiliac ligaments (Andersen, 1986). Only a few studies examined this area in association with pregnancy and parturition. Perhaps this is due to its difficulty to ascertain and observe the imprint (Andersen, 1986). Kelley (1979) however, was one of the few scientists who investigated and also found a relationship between the formation of an interosseous groove and pregnancy.

1.3.3. Factors influencing the parturition scars

Pregnancy and parturition are not the single ones causing factors of the parturition scars. Studies showed that men and nulliparous women can exhibit those bony imprints, as well suggesting that further influences must be involved in its formation and manifestation and thus, need to be considered when examining these bony imprints (Snodgrass and Galloway, 2003). Such influences may include, among other things age, body size, pelvic flexibility and pelvic dimensions (Houghton, 1975; Andersen, 1986; Cox and Scott, 1992; Snodgrass and Galloway, 2003).

1.3.3.1. Age

A frequently discussed factor influencing the manifestation of the parturition scars represents age. The study of Suchey et al. (1979) found out that older individuals are having more severe dorsal pitting than younger females. Their study even showed that nulliparous women, who died befor the age of 30 were more frequently associated with absent dorsal pubic pits, while those older than 30 years, exhibited more often pubic pitting (Suchey et al., 1979). On the contrary, Kelley (1979) and Bergfelder and Herrmann (1980) do not support Sucheys findings. They considered an increasing age as a potential factor that reduces the degree of manifestation of the parturition scars through remodeling and age-atrophical restructuring (Kelley, 1979; Bergfelder and Herrmann, 1980). Snodgrass and Galloway (2003) found a strong relationship between age and pitting and suggested that the hormonal change at the end of childbearing years, which possibly has directly an effect on the stability of the pelvis or due to bone loss in the pubic joint.

1.3.3.2. Body mass

The body mass is considered as another potential influencing factor however, its impact has been rarely tested yet. The idea is that physical conditions of pregnant women and overweight individuals seem to be slightly similar. During pregnancy, the circumference of the anterior abdomen increases particularly in the last months of pregnancy, which is also associated with an increased weight gain. As a consequence, the ligaments and muscles of the pelvis get increasingly stretched and strained and this leads in the end to the formation of the parturition scars on the pelvis.

The same principle can be applied to overweight people as they also tend to have an increased abdominal circumference, which affects the pelvic ligaments and muscles and the bony pelvis itself. One of the few studies testing this relationship represented the study of Snodgrass and Galloway (2003). They found a positive association between dorsal pubic pitting and individuals over 50 years with a higher BMI. A similar association was found by Holt (1978), where four women exhibited medium to severe scarring who had not given birth but were obese.

1.3.3.3. Other possible influences

Another further influence of pelvic scar formation represents pelvic dimensions. Pelvic dimensions determine how obstetric efficient the bony pelvis is. If the parturition scars are related to pregnancy and childbirth someone would expect that delivery in smaller pelves is associated with greater ligamentous stress and thus tend to be more severely scarred than wider pelves. Cox (1989) however, found actually the opposite. In her study, wider pelves in females were more frequently associated with alterations suggesting that the imprints are not solely related to pregnancy and delivery. Furthermore, a study by Snodgrass and Galloway (2003) showed that females with longer pubic bones also tend to have an extended pubic tubercle, while those with smaller pubic bones were associated with no extension.

Another alternative explanation for the formation of the parturition scars represents pelvic flexibility. Females have a broader pelvis but at the same time, smaller articular surfaces of the pelvis and a resultant more flexible pelvic architecture. The flexible female pelvis needs more ligamentous stabilization, which results in increased pelvic scarring, while men exhibit less scarring due to their tighter articulated pelvis architecture (Andersen, 1986; Snodgrass and Galloway, 2003).

Furthermore, Houghton (1975) stated that modern western societies show less severe scarring that prehistoric populations or individuals from developing countries and that this may be a result of fewer deliveries, better obstetrical care, less trauma occurring during the birth process and less physical activity during pregnancy. Stewart (1970) suggested a similar influencing factor, namely prenatal care. Multiple pregnancies, without or lacking obstetrical care, damages the pubic symphysis repeatedly and as a result, can lead to degenerative changes on the bony pelvis (Stewart, 1970).

Pathologies like rickets or osteomalacia also have an impact that directly affects the bone. Both diseases are mostly caused due to vitamin D deficiency and a lack of solar irradiation and can lead to deformations of the bony pelvis. As a consequence, the anteroposterior diameter can be decreased and the sacral promontory can be shifted forward or downwards, which both can lead to a smaller inlet diameter and hence, to feto-pelvic disproportions (Cox, 1989).

An unknown, however, major influencing factor represents the size and cranial circumference of the baby (Putschar, 1976). A large infant will increase the traumata that occurs during delivery especially for women with smaller pelves. This influence, however, is not possible to investigate with archaeological samples but a modern sample with an intense amount of information is required (Cox, 1989).

1.3.4. Previous studies

Angel (1969) was one of the first who suggested that childbirth leads to macroscopic changes on the bony pelvis. In his study, he did not focus solely on the scars of parturition but examined multiple demographic indicators. To assess fecundity he used those macroscopic changes on the pelvis. He claimed that these indicators of pregnancy are clearest visible around the pubic symphysis and are caused by the stress and stretching of the rectus abdominis and obliquus externus abdominis muscle and the inguinal ligament during pregnancy and childbirth. These muscles and ligaments are stretched and stressed, which results in cysts of the fibrocartilages and tears and hemorrhages under the ligaments. Angel suggested that after a sufficient amount of deliveries multiple pubic pits might fuse to one deep groove. According to him, the severity of scaring is directly associated with the number of born children.

In 1970 the term “scars of parturition” was introduced by Stewart who examined the dorsal pubic pits of 170 female skeletons from the Terry collection. Information about sex, age at death and cause at death was available however, not about parity history. Stewart assessed the severity of the pubic pits and classified them either as “trace to small” or “medium to large”. He found out that about 50% of all individuals had absent pits, while 17% showed distinctive scars. He suggested that only medium to large, hence, major developed cavities appear to be a clear indicator of childbirth. Stewart also recognized a decline of pits with increasing age, which he argued that in the course of time the pubic pits are eliminated by bone remodeling. However, unlike Angel (1969) Stewart stated that an accurate assessment of the true number of pregnancies on the basis of these imprints is not possible.

Four years later Houghton (1974) investigated the preauricular sulcus in relation to parity and delivery. He was one of the first who presumed that not only the dorsal pubic pits are related to pregnancy and childbirth, but also the preauricular sulcus. Houghton even suggested that the sulcus is a more sensitive indicator of parity than the pubic pits. Houghton examined 119 pelves, 68 from the Maori and Moriori collection of the University of Otago and further 51 single hip bones of unknown provenance. In this study, he distinguished between two forms namely the preauricular groove of the ligament and the preauricular groove of pregnancy. The groove of pregnancy form was solely found in women and thus must be an indicator of pregnancy. He suggested that the sulcus is a more sensitive indicator of parity compared to the dorsal pubic pits due to the direct line of weight bearing. Furthermore, he considered that age may affect and obscure the manifestation of the parturition scars. Houghton further noted that in modern populations pubic pitting is less distinctive, which may be probably a result of better health and prenatal care and reduced physical activity during pregnancy.

In 1978, the Hamann-Todd Collection from the Cleveland Museum of Natural History was examined by Holt. The collection offered information about soft tissue analyses and was used to assess the parity history of women. Holt investigated the dorsal pubic surface of 68 female pelves with definite information about their pregnancy status, using the classification system of Stewart (1970). No correlation was found between parturition and scarring and parturition and the size of the configuration of the pubic pits. His study showed females with known parity but without any evidence of scar formation and vice versa. Holt found out that nulliparous women with heavy scarring were either obese without any pathology or they showed a high incidence of pathologies like chronic inflammatory processes of the pelvis, femoral hernia or severe edema of the legs. Thus, Holt stated that childbirth may be one factor that causes dorsal pubic pits. However, there must be a multiplicity of other influencing factors that cause its formation. To attribute solely parturition to scarring is misleading.

One year later Suchey et al. (1979) studied 486 skeletons of modern American females also with known parity history. The authors examined dorsal pubic pitting and used the classification system of Stewart (1970). They found a weak correlation between the number of full-term pregnancies and the degree of pitting and also that scarring increased with age. Nevertheless, there were nulliparous women who showed severe pitting and parous women showing absent pits. The authors claimed that age and the number of full-term pregnancies are the most important factors that predict the degree of dorsal pubic pitting.

In 1980, Bergfelder & Herrmann examined 49 pairs of pubic bones of a dissecting room sample regarding its pubic pits and pubic tubercles using the classification system proposed by Ullrich (1975). The sample offered information about the number of birth as well as miscarriages. The authors found out that the size of dorsal pubic pitting increases with the number of births and that the extension of the pubic tubercle can be an indicator of more than three childbirths. Still, they did not found an unequivocal relationship between dorsal pubic pitting and pregnancy and childbirth. Also, the association between pubic tubercle extension and parity status was not strong. Here too, the authors noted that pits can be present in women who had not given birth and conversely there can be absent pitting in multiparous women. Interestingly, Bergfelder & Herrmann could show that females with miscarriages showed pubic pits as well, which indicated that not only parturition caused the imprint but the stress that occurred during pregnancy. Furthermore, the authors stated that with increasing age the pregnancy- and childbirth-caused alterations on the pubic bone are formed back due to age-atrophical restructuring. It was also emphasized, that the pelvic constitution, particularly in regard to the anteroposterior diameter of the pelvic inlet, represents an important influencing factor concerning the formation of the pelvic imprints.

Like Holt in 1978, Andersen (1986) examined in her dissertation 226 remains, both males and females, from the Hamann-Todd Collection. She investigated not only the dorsal pubic pits and preauricular sulcus but also the interosseous groove as well as certain pelvic dimensions. The parity history was available from medical records. Andersen found no significant association between parity and the parturition scars. Nulliparous women and men could show pelvic scarring, while multiparous women could have no pelvic scars at all. Hence, Andersen emphasized that fertility cannot be assessed by the analysis of the bony pelvis. Rather, pelvic flexibility and sex are significantly associated with pelvic scarring. According to the author, scars are formed at the attachment sites of stabilizing ligaments adjacent to the pelvic girdle joints as a result of excess motion, which is enabled in a flexible pelvis. The pelvic girdle of men is much more tightly articulated and allows less movement compared to the one of women. The female pelvic girdle exhibits a more loosely articulation. Andersen (1986) showed that males with more flexible pelves tend to show more scarring than men with tighter articulations. The same applies to females.

One year later Tague (1988) examined both the dorsal pubic pits and the preauricular sulcus. However, parity history of the majority of the sample was unknown and hence, the relationship between pregnancy and pelvic scarring was not tested. The result of his study showed a significant association between pubic pitting and age at death in females. No significant relationship was found between pitting and the preauricular sulcus. Tague suggested that pelvic scarring is unrelated to parturition because males and nulliparous women exhibit those imprints as well. He presumed that the hormone estrogen may play a direct role in the formation of the scars. Tague referred to mammalian studies in which it was shown that estrogen alone can induce resorption at the pubic bone by stimulation of the synthesis of osteoclastic enzymes.

In 1989, Spring et al. examined the preauricular sulcus using abdominal radiographs from 190 females with known parity history and 110 males. They found no significant association between parity and a deep sulcus but rather an association with sex. 10% of the nulliparous women and 17% of the parous women exhibited a preauricular sulcus however none of the men showed deep sulci. Spring et al. also examined six primigravid women with radiographs before and after childbirth but they could not detect any changes at the ilium. Thus, the authors concluded that the presence of deep sulci is not necessarily an indicator of pregnancy.

Cox and Scott (1992) studied female pelves with definite information regarding their parity history from the Christ Church, Spitalfields Collection. They examined the presence, typology, severity as well as the length and width of the preauricular sulcus. Presence of the dorsal pubic pits and its number were noted as well. Lastly, the extension of the pubic tubercle was investigated. The authors found a relationship between the extension of the pubic tubercle and parity status and between the degree of the extension of the tubercle and the number of born children. The greater the extension of the tubercle, the greater is the number of childbirths. Still, the authors noted that an extended tubercle is not conclusive evidence of pregnancy because also nulliparous women and men showed an extension of the pubic tubercle. No significant association was found between either the dorsal pubic pits and the preauricular sulcus and parity. There was also no significant relationship between the pelvic scars and age at death. According to their results, Cox & Scott claim that the theory behind the formation of the scars of parturition, which result from the traumata occurring during pregnancy and delivery, is unlikely to be correct.

In 2003, 148 modern female pairs of pubic bones from an autopsy at the Los Angeles County Department were examined by Snodgrass and Galloway (2003). Information about parity history, weight, and age at death was available. The authors studied the dorsal pubic pits and the pubic tubercle elongation. The result of their study showed no correlation of extension of the pubic tubercle and the number of births but an association with the tubercles distance from the pubic symphysis. Thus, women with longer pubic bones were more likely to extend the tubercle. Further, the study revealed a strong relationship between the dorsal pubic pits and the number of births, particularly in younger individuals. In women over 50 years, pitting was associated with BMI but not with the number of births. Thus Snodgrass & Galloway claimed that alterations of the pubic area are probably caused by the interplay of several factors and not solely a consequence of parity. There are probably multiple factors that affect the formation of dorsal pubic pits such as relaxin synthesis, weight gain, interval since last pregnancy, size of the infant and physical activity during pregnancy. They supported the view of Andersen

(1986) and also suggested that pelvic instability might have an influence on pit development.

In a very recent study, McArthur et al. (2016) examined 482 pelvic CT scans of females regarding their dorsal pubic surface. They found a significant relationship between the presence of dorsal pubic pitting and vaginal delivery. Furthermore, the authors could show that more prominent dorsal pubic pits were related to a greater number of vaginal births. McArthur et al. suggest that their study indicates that pubic pits are indeed related to childbirth.

1.4. Summary

Not all scientists believe that pregnancy and childbirth lead to the scars of parturition. Andersen (1986) for example proposed that pelvic flexibility is responsible for the formation of the pelvic imprints. Snodgrass and Galloway (2003) suggested that body size plays another important role in pelvic scarring. Cox and Scott (1992), Spring et al. (1989) and Tague (1988) found out that pregnancy and parturition do not cause the formation of parturition scars. The latter author suggested that estrogen might contribute to pelvic scarring. Estrogen thereby has a direct effect on the bone, which induces resorption processes by the stimulation of the production of osteoclastic enzymes (Tague, 1988). Bergfelder and Herrmann (1980) added that pelvic constitution might also play a role in the development of the scars.

Still, several studies found a significant relationship between parity history and manifestations of parturition scars. Stewart (1970) proposed that the traumata of childbirth cause the parturition scars and that with increasing age those imprints are eliminated in the course of remodeling processes. Houghton (1975) emphasized that the preauricular sulcus represents an indicator of parity and supports Stewart that increasing age might obscure the manifestation of scars. He mentioned that improved prenatal care and reduced physical activity during a pregnancy diminishes pelvic scarring (Houghton, 1975). Suchey et al. (1979) found out that the number of full-term pregnancies and age are the most important predictors of pitting. Finally, McArthur et al. (2016) showed in their study that dorsal pubic pitting is related to childbirth.

In spite of multiple studies investigating parturition scarring, none of the imprints was an indisputable indicator of pregnancy and childbirth. Only a few studies were able to examine pelvic scarring with individuals with known parity history because collections with information about birth history are rare. As a consequence, this issue makes the investigation of the relationship between parity and scars naturally difficult. Furthermore, the different methods in assessing the scars and the partially insufficient description of how measurements were taken may account for some of the conflicting results. Still, some anthropologists and archaeologists continue to use pelvic scarring due to the great potential value of assessing the fertility and parity history of an individual (Ubelaker and De La Paz, Jade S, 2012).

1.5. Importance of the study

Despite conflicting results of previous studies that investigated the relationship between pregnancy and childbirth and the bony imprints the method is still widely accepted and used by anthropologists and archaeologists (Andersen, 1986). However, the different methodological approach and to some extent insufficient description of how measurements and observations were conducted may account for some of the conflicting data (Ubelaker and De La Paz, Jade S, 2012). Furthermore, only very few amounts of skeletal collections are available in which the parity history is known. A lack of known obstetric history in turn, makes an examination of the relationship between pregnancy and delivery and the parturition scars clearly more difficult. Despite all that, the assessment of parity can have significant implications in anthropological and bioarchaeological research but also in forensic issues. To bypass the obstacle of unknown parity history an examination of a number of possible influencing factors such as sex, age, body size and certain pelvic dimensions regarding the formation, manifestation, and morphology of the parturition scars is needed to test the true nature of the relationship between parity history and the bony pelvic imprints.

1.6. Aims and hypotheses of the study

The aim of this study is to measure and observe the variability of morphology and frequency of the so-called “scars of parturition” at the dorsal pubic surface with its pits, the pubic tubercle, and the preauricular sulcus. The data will be used to investigate the relationship between the bony imprints with sex and age at death of the individuals.

Furthermore, the influence of body size and pelvic dimensions on the severity of pelvic scarring is examined.

The hypotheses of this study are:

Hypothesis 1: The scars of parturition are more severe and more frequently found in females than males.
Hypothesis 2: The scars of parturition are less severe and rarer found in older individuals.
Hypothesis 3: Larger pelvic dimensions are associated with more severe scarring in females.
Hypothesis 4: A larger body mass is associated with more severe scarring.

Chapter 2: Material and Methods

2.1. Data collection

In April 2018, shortly before the present study, a pilot study was performed by the author at the Department of Evolutionary Anthropology at the University of Vienna to practice the procedure of data collection and to gain more reliable results. The pilot study made clear that the observation and measuring of the pitting of the interosseous groove were found to be not sufficiently explained in the literature, which made a reliable data collection difficult. Furthermore, pitting is generally hard to ascertain (Andersen, 1986). Thus, it was decided to not collect data regarding the interosseous groove.

Following the pilot study, the data collection of the present study was performed at the Department of Anatomy, Histology, and Anthropology, Faculty of Medicine, at the University of Vilnius for a total of three weeks in May 2018. All measurements were assessed by the author alone apart from sex and age at death estimation, which was taken from the collection catalog from the Department of Anatomy, Histology, and Anthropology of the University of Vilnius.

A data sheet (see Appendix B) was completed for every single individual. All measurements were taken in centimeters. The present study combined osteometric and morphological analyses. While the metric approach was conducted with the help of a GMP sliding caliper with nonius and an anthropometer, the morphological approach was based on observations of the areas of interest to determine the presence, absence, typology, and severity of scarring. This combination provided accurate, reliable and sufficient information regarding the areas of interest. Irrespective of age and sex, every individual was measured and observed in a uniform manner. If possible, both the left and right side were examined.

2.1.1. Dorsal pubic surface

The maximum length, the length of the largest single pit and the width of the broadest pit were measured together with a classification of the dorsal pubic surface whether it is made of single pits or a groove. An elongated cavity or fusing pits that were not separated by a ridge were considered as a groove. In case of the single pubic pits, their number was noted. Finally, the pitted area was observed, which followed the classification of four categories according to McArthur et al. (2016): absent, faintly perceptible, present and prominent (Figure 2.1). The grading system according to McArthur et al. (2016) represented a subjective measure of the size of the pits that takes length, width as well as depth into account.

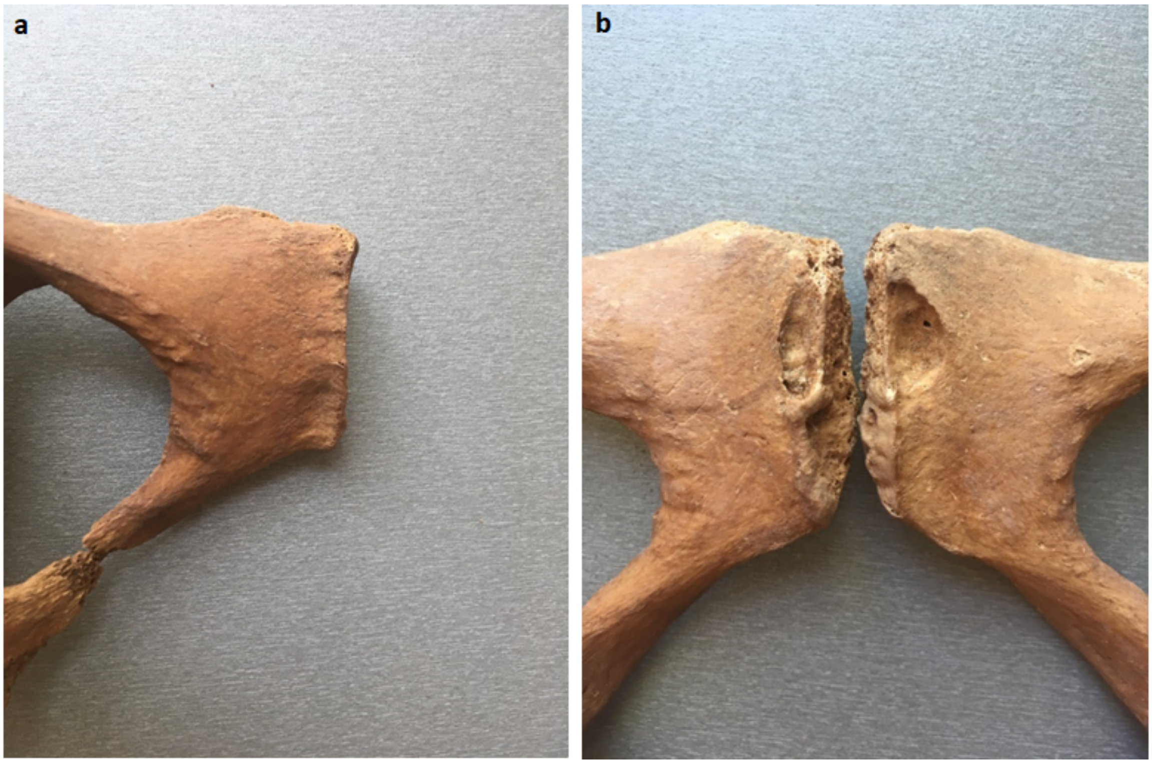


Figure 2.1: Dorsal views of the pubic bone showing examples of the appearance of the dorsal pubic pits: a. present pits on the left side from a 50 – 55 year-old-woman, and b. prominent grooves on both sides from a 35 – 40-year-old woman (© Elisa-Maria Praxmarer, 2018).

2.1.2. Pubic tubercle

The maximum height measured from the base of the Ramus superior ossis pubis to the top of the pubic tubercle was performed according to Snodgrass and Galloway (2003). Usually, every individual shows a pubic tubercle on the ventral pubic surface. According to Bergfelder and Herrmann (1980), the extended tubercle protrudes superiorly. The pilot study of this work however, indicated that the tubercle may extend in a ventral direction as well (Figure 2.2). Therefore, not only cranial but also ventral extended pubic tubercles were measured, whereby the direction was determined as well. Due to the measurement of ventrally oriented tubercles, the classification system of Cox and Scott (1992) was regarded as inappropriate since the ventral unextended pubic tubercle commonly accounted already for 1 mm. Thus, it was decided that a tubercle height larger than 2 mm counted as present, while a height below 2 mm counted as absent.

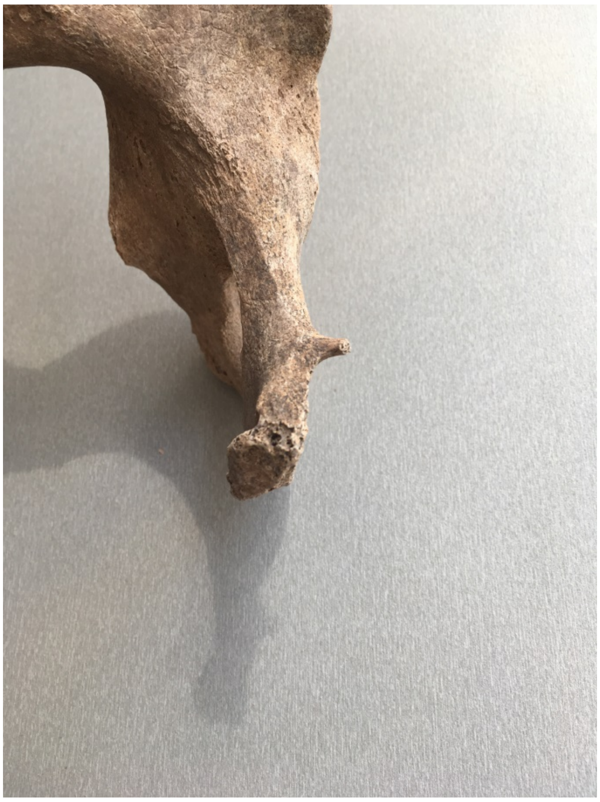


Figure 2.2: Medial view of the left hip bone showing a ventrally oriented pubic tubercle from a >55-year-old woman (© Elisa-Maria Praxmarer, 2018).

2.1.3. Preauricular sulcus

The maximum length and width of the preauricular sulcus were measured. Furthermore, the appearance of the preauricular sulcus was divided into four stages: broad-shallow, narrow-shallow, defined and complex. Lastly, a grading system was used to categorize the preauricular sulcus into five grades according to Canty et al. (2016):

- Grade 0: Absent preauricular sulcus
- Grade 1: The sulcus is shallow and the floor has a consistent depth with no pits or grooves. The edges are usually undefined and the sulcus itself is faintly visible
- Grade 2: The floor of the sulcus is slightly uneven and not completely smooth
- Grade 3: The sulcus consists of more than one pit and its floor differs in depths. The edges of the sulcus are typically more defined

- Grade 4: The floor of the sulcus is very inconsistent and has deep pits and grooves. This grade is very easy to observe on the bone

Additionally, the floor of the sulcus was overall classified either as pitted or smooth. Unfortunately, it was not possible to measure the depth of the sulcus. Hence, a combination of different classification systems was used in order to gain as much information as possible about the sulcus' morphology. It represents a subjective measure of length, width as well as depth. Various examples of preauricular sulci are shown in Figure 2.3.

Figure 2.3: Medial views of the ilium showing examples of the appearance of the preauricular sulcus: **a.** narrow-shallow sulcus with a smooth floor on the right coxae from a 35 – 40-year-old woman, **b.** smooth broad-shallow sulcus on the left coxae from a 40 – 45-year-old man, **c.** defined sulcus with a pitted floor on the left coxae from a 40 -45-year-old woman, and **d**. pitted complex sulcus on the left coxae from a >55-year-old woman (© Elisa-Maria Praxmarer, 2018).

2.1.4. Pubic bone

Measurements of the pubis and the pubic symphysis were performed according to Bräuer (1988) and Schultz (1930) and are defined as follows:

- Pubic length: Linear distance between Point A of the acetabulum to the superior margin of the symphyseal surface (Figure 2.4). Schultz' Point A represents the fusion point of the three pelvic elements in the acetabulum.
- Pubic symphysis length: Linear distance between the superior and inferior margin of the symphyseal surface.

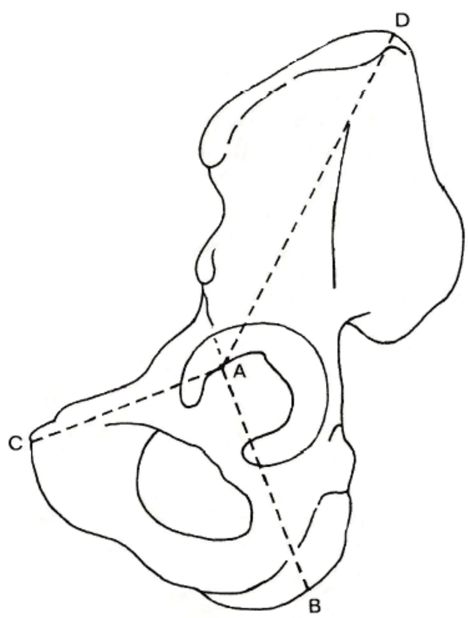


Figure 2.4: Left coxae with the pubic length measure (Adapted from Schultz, 1930).

2.1.5. Measurements of the articulated pelvic girdle

The articulation of the pelvic girdle was done with the help of elastic bands and an insertion of a 5mm rubber at the pubic symphysis (Figure 2.5). The rubber functioned as the pubic symphysis to account for the absence of soft tissue. Several studies confirmed an average thickness of the pubic symphysis of 5 mm for which a 5 mm thick rubber was chosen (Sequeira, 1986; Garagiola et al., 1989; Schoellner et al., 2001). The measurements of the articulated pelvic girdle were performed according to the descriptions of Dauber and Feneis (2008) and Bräuer (1988) and are defined as follows: Particularly the anteroposterior inlet diameter, transverse inlet and outlet diameter, as well as the left and right oblique diameter, represent important pelvic dimensions in obstetrics (Schünke et al., 2014).

- Intercristal distance: Maximum linear distance between the outer margins of the iliac crests
- Transverse diameter of pelvic inlet: Maximum linear distance between the arcuate lines
- Transverse diameter of pelvic outlet: Maximum linear distance between the posterior parts of the ischial tuberosity
- Distance between ischial spines: Linear distance between the ischial spines
- Right and left oblique diameter: Maximum linear distance between the intersection of the arcuate line with the anterior margin of the auricular surface to the opposite side of the arcuate line around the iliopubic eminence
- Right and left anteroposterior diameter of inlet: Distance between the intersection of the promontory with the medial sagittal plane to the posterior margin of the pubic crest
- Right and left anatomic conjugate: Distance between the intersection of the promontory with the medial sagittal plane to the anterior margin of the pubic crest
- Anterior upper spinal breadth: Maximum linear distance between the anterior superior iliac spines
- Inter-obturatum breadth: Linear distance between the most medial located points of the anterior margins of the obturator foramen

Figure 2.5: Articulated pelvic girdle using elastic bands and the rubber insertion at the pubic symphysis from a 25 – 30-year-old man (© Elisa-Maria Praxmarer, 2018).

2.1.6. Body mass estimates

The superior-inferior head breadth of the left and right femur was measured according to Bräuer (1988). Femoral head diameter (FH) was used for the reconstruction of body mass (BM). If the values of both the left and right head breadth of an individual were provided, the mean was calculated to account for side-specific changes and further used for the estimation. If only unilateral measurements were available the side-specific value was used for the BM estimation. Ruff et al. (1991), McHenry (1992) and Grine et al. (1995) supplied equations for estimating the body mass of the femoral head diameter. For the present study the sex-specific formula of Ruff et al. (1991) was found to work best and hence used:

$$\text{Female BM} = (2.426\ \text{FH} - 35.1)0.90$$
$$\text{Male BM} = (2.741\ \text{FH} - 54.9)0.90$$

The Ruff equations are based on a modern living North American sample and are therefore suitable particularly for modern samples with a higher prevalence for adiposity. Because large proportions of the individuals in the Ruff et al. (1991) were overweight the body mass equations are likely to overestimate the body mass in preindustrial populations. To account for this overestimation Ruff et al. (1991) suggested subtracting 10% from the estimate when calculating body mass in preindustrial specimens. The majority of the present study sample date from the 14th to the 17th century and hence, 10% were subtracted because it was believed that it will provide more reliable BM estimates.

2.2. Study sample

A total of 300 individuals (170 males and 130 females) from the Department of Anatomy, Histology, and Anthropology, Faculty of Medicine, of the University of Vilnius were examined. The majority, namely 267 skeletal remains belong to the collection of Alytus (see Chapter 2.2.1.). The residual skeletons are members of further archaeological collections (see Chapter 2.2.2.). Only skeletal mature individuals with a relative complete pelvis were included. Furthermore, skeletons showing any pathology regarding the areas of interest were excluded from this study. It was decided not to use the age group classification according to Buikstra and Ubelaker (1994) with its three adult age ranges but rather to divide age at death into four categories to gain narrower age ranges. This was believed to enhance the sensitivity to detect possible relationships between age and pelvic scarring. Broader age ranges would reduce this sensitivity.

Therefore, the individuals were divided into the following four age groups: young adults (20-30 years), middle-aged adults (30-40 years), old adults (40-50 years) and very old adults (>50 years). 20-year-old individuals were regarded already as skeletal mature in this study, however, skeletal remains below 20 years were excluded. Age groups were not separated by sex as it would have led to tad small sample sizes, particularly concerning females, which was regarded to be inappropriate for the statistical analyses. Table 2.1 gives information about the age and sex group distribution of the sample. Age at death is missing in four individuals. Data about sex and age at death of the individuals were used from the collection catalog from the Department of Anatomy, Histology, and Anthropology of the University of Vilnius.

Table 2.1: *Sample composition and age at death group classification.*

		Age group				Total
		Young adult	Middle adult	Old adult	Very old adult	
Sex	Male	27	36	70	34	167
	Female	29	20	51	29	129
Total		56	56	121	63	296

2.2.1. Collection of Alytus

The majority of skeletons, namely 267 individuals examined in this study are part of the collection of Alytus. The excavation of this former cemetery in Alytus was conducted in 1984 - 1986 and represents the biggest ever excavated cemetery in Lithuania. 1152 undisturbed graves were opened that are dating back between the 14^{th} to the 17^{th} century (Svetikas, 2003). The collection of Alytus now belongs to the University of Vilnius.

2.2.2. Further archaeological collections

A minor part of 33 individuals was examined from additional archaeological collections. The residual skeletons are counted among the collections of Mažeikiai, Ponkiškiai, Plinkaigalis, Mankūnai, Makrickai, Pupasodis, Obeliai, Alovė, Skovagaliai, Akalyčia, Paežeriai, Rokėnai, Norkūnai, Laičiai, Gaidžiai Molėtų, Tursučiai, and Vilnius Cathedral. All listed collections above represent excavated cemeteries. Information about the date of the collections is given in Table 2.2.

Table 2.2: *Date of archaeological collections.*

Collection	Date	Collection	Date
Mažeikiai	16^{th} – 17^{th} century	Ponkiškiai	18^{th} century
Plinkaigalis	5^{th} – 6^{th} century	Mankūnai	18^{th} century
Makrickai	16^{th} – 17^{th} century	Pupasodis	18^{th} century
Obeliai	15^{th} – 16^{th} century	Alovė	15^{th} – 17^{th} century
Skovagaliai	17^{th} – 18^{th} century	Akalyčia	18^{th} century
Paežeriai	17^{th} century	Rokėnai	3^{rd} – 5^{th} century
Norkūnai	6^{th} – 7^{th} century	Laičiai	17^{th} – 18^{th} century
Gaidžiai Molėtų	16^{th} – 17^{th} century	Tursučiai	17^{th} century
Vilnius cathedral	15^{th} – 18^{th} century		

2.3. Data analysis

Statistical analyses of the collected data were performed using the SPSS for Windows Program Version 25 (IBM SPSS Statistics 25, 2017).

2.3.1. Intra-observer error testing

The intra-observer error was tested using the statistical methods proposed by Bland & Altman (1986). During data collection, the second measurement was usually performed the following day after the conduction of the first measurement.

2.3.2. Variation in pelvic measurements and body mass estimates

A Kolmogorov-Smirnov test was conducted to testify the distribution of the data within the sexes and each age group. Either the means of normally distributed data or the medians of non-normally distributed data were compared between both sex and age groups. In the case of sex differences, normally distributed data were analyzed using the independent *t*-test, whereas non-normally distributed data were assessed using the Mann-

Whitney *U*-test to detect differences between the samples. In the case of age group differences normally distributed data were analyzed with a One-way ANOVA and non-normally distributed data using the Kruskal-Wallis *H*-test. If differences were found regarding the Kruskal-Wallis test, the post-hoc Dunn-Bonferroni test was conducted to determine in which of the samples the differences occurred. In all cases, the two-tailed *p*-value with less than 0.05 was considered as significant. Regarding the Dunn-Bonferroni analysis, the Bonferroni corrected *p*-value was used.

2.3.3. Scar manifestation according to sex and age at death

A Chi-squared and Fisher-exact test was conducted to investigate the association of the scar manifestation of either sex or age of the individuals. A Kolmogorov-Smirnov analysis was used to testify the distribution of the data. Non-normally distributed data were analyzed either with a Mann-Whitney *U*-test or a Kruskal-Wallis to detect differences between the samples. If such differences were found the Post-hoc Dunn-Bonferroni test was conducted to figure out between which samples the differences occurred. A two-tailed *p*-value with less than 0.05 was considered as significant and regarding the Dunn-Bonferroni test, the Bonferroni corrected *p*-value was used.

2.3.4. Relationship between parturition scars, pelvic measurements, and body mass estimates

The Pearson correlation was conducted to test the relationship between the parturition scars, pelvic measurements, and body mass estimates in both the female and male sample as well as in the age groups. It was decided that the utilization of the mean of bilateral measurements of the parturition scars and pelvic measurements represents the best way for analyzing the relationship. If only one side was available this single value was used for the correlation. Metric data of the parturition scars, namely the mean length and mean width or mean height and mean diameter, were used to conduct the Pearson correlation test. A two-tailed *p*-value with less than 0.05 was considered as significant. Positive correlation coefficients indicated a positive relationship, while negative coefficients indicated a negative association.

Chapter 3: Results

3.1. Intra-observer error testing

The differences between first and repeated measurements of every fifth individual were not significant for almost all measurements. The only exceptions represented the maximal left and right length of the pubic pits. In the case of the maximal left pit length, the absolute mean difference between the two measurements was -0.07 cm (Figure 3.1). The graph shows that four measurements clearly fell outside the 95% confidence interval. The Bland-Altman plot of the maximal right pit length with an absolute mean difference of -0.08 cm shows three measurements outside the 95% confidence interval (Figure 3.2). Measurements of the length of the pubic pits, especially of faintly perceptible pits, were proved to be tricky, which most probably led to the discrepancy between the two measurements. Thus, the maximal left and right pubic pit length were excluded from further analysis.

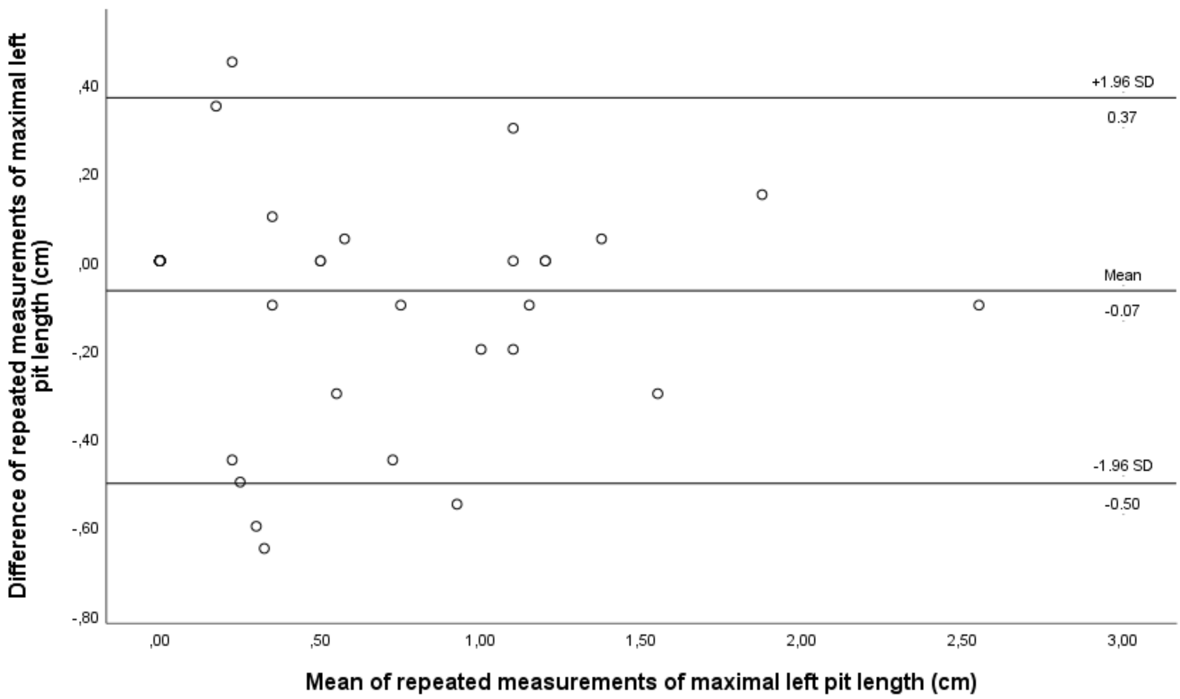


Figure 3.1: Results of the Bland-Altman repeatability analysis of the maximal left pit length showing four measurements outside the 95% confidence interval.

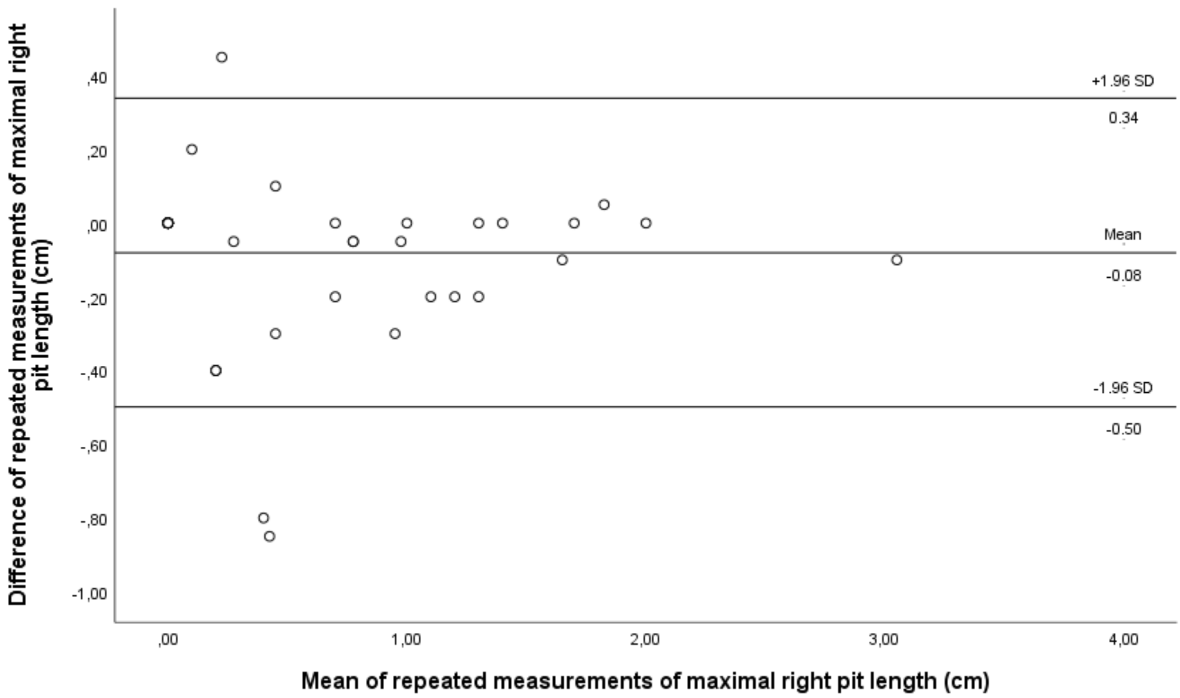


Figure 3.2: Results of the Bland-Altman repeatability analysis of the maximal right pit length showing three measurements outside the 95% confidence interval.

3.2. Variation in pelvic measurements

3.2.1. Intercristal distance

3.2.1.1. Sex

The *t*-test showed no significant difference in the intercristal distance means between the sexes (p=0.239, t=1.18, n=141). A comparison of the means showed that the male and female sample had similar mean values. Men had an intercristal distance mean of 26.73 and a *SD* of 1.40, while women had a mean of 26.42 and a *SD* of 1.70.

3.2.1.2. Age

The One-way ANOVA showed a significant difference in the intercristal distance means between the age groups (p<0.001, n=140) (Table 3.1). A Post-hoc Bonferroni analysis revealed that young adults and old adults (p=0.022) and young adults and very old adults (p<0.001) differed significantly from each other. Furthermore, a significant difference was shown between middle-aged and very old adults (p<0.001) and old and very old adults

(p=0.003). The result indicated that the youngest age group had the shortest intercristal distances, while the eldest age group tended to have the largest.

Table 3.1: *Mean, standard deviation and sample size of the intercristal distance according to age group.*

	n	*Mean*	*SD*
Young adults	22	25.71	1.44
Middle adults	29	26.13	1.15
Old adults	59	26.73	1.47
Very old adults	30	27.62	1.40

3.2.2. Transverse diameter of the inlet

3.2.2.1. Sex

The t-test showed a significant difference in the transverse diameter of the inlet between the sexes (p<0.001, t=-4.65, n=155). A comparison of the means suggested that the female sample tended to have larger transverse inlet diameters ($\bar{x}$=13.24, SD=0.76) on average than the male sample ($\bar{x}$=12.64, SD=0.77).

3.2.2.2. Age

The conduction of the One-way ANOVA revealed a significant difference in the transverse diameter of the inlet between the age groups (p=0.029, n=154) (Table 3.2). The Post-hoc Bonferroni analysis showed that middle-aged adults differed significantly from the eldest age group (p=0.029). Middle-aged adults tended to have the smallest transverse diameters of the inlet, while the eldest age group had the largest diameters.

Table 3.2: *Mean, standard deviation and sample size of the transverse diameter of the inlet according to age group.*

	n	*Mean*	*SD*
Young adults	26	12.71	0.74
Middle adults	31	12.57	0.82
Old adults	63	12.89	0.76
Very old adults	34	13.13	0.88

3.2.3. Transverse diameter of the outlet

3.2.3.1. Sex

The Mann-Whitney *U*-test showed a significant difference in the transverse diameter outlet medians between the sexes ($p<0.001$, $U=278.50$, $r=0.66$, $n=115$). A comparison of the medians (*mdn*) indicated that the female sample tended to have a larger dimension of the transverse diameter of the outlet (*mdn*=11.80) than the male sample (*mdn*=10.20).

3.2.3.2. Age

The Kruskal-Wallis test revealed no significant differences in the transverse diameter outlet medians between the age groups ($p=0.161$, $df=3$, $n=115$) (Figure 3.3). According to the medians, the eldest age group had the shortest transverse diameter of the outlet (*mdn*=10.45), while young and middle-aged adults had the largest transverse outlet diameter (*mdn*=10.90), followed by old adults (*mdn*=10.80).

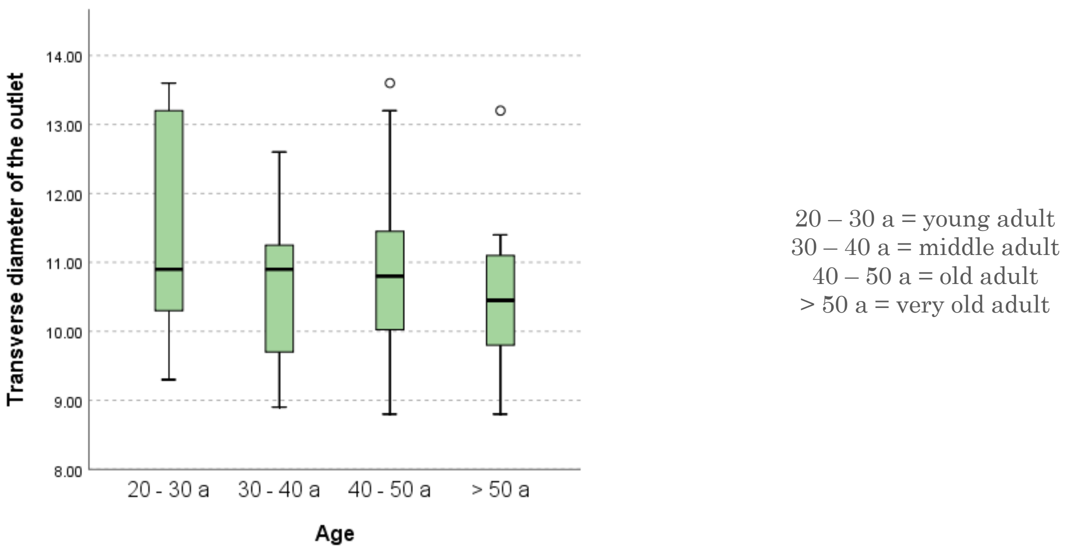


Figure 3.3: Median plot of the transverse diameter of the outlet according to age group.

3.2.4. Distance between the ischial spines

3.2.4.1. Sex

The *t*-test showed a significant difference in the means between males and females (p<0.001, t=-6.57, n=29). A comparison of the means indicated that the female sample tended to have larger distances between the ischial spines ($\bar{x}$=10.96, *SD*=0.93), while the male sample had smaller means ($\bar{x}$=8.85, *SD*=0.67).

3.2.4.2. Age

The result of the One-way ANOVA showed no significant difference in the ischial spine distance means between the age groups (p=0.562, df=3, n=29) (Table 3.3). The youngest age group tended to have the largest distance between the ischial spines, followed by middle-aged adults. The eldest age group had the shortest ischial spine distance.

Table 3.3: *Mean, standard deviation and sample size of the distance between the ischial spines according to age group.*

	n	*Mean*	*SD*
Young adults	6	9.65	1.63
Middle adults	5	9.02	0.68
Old adults	11	9.62	1.05
Very old adults	7	8.96	1.23

3.2.5. Oblique diameter

3.2.5.1. Sex

The Mann-Whitney *U*-test showed a significant difference in the left and right oblique diameter between the sexes (Table 3.4). The result indicated that the female sample had on both sides larger oblique diameters (left *mdn*=12.80, right *mdn*=12.90), while the males had shorter diameters (left *mdn*=12.10, right *mdn*=12.20).

Table 3.4: *Results of the Mann-Whitey U-test showing p-, U- and r-values of the left and right oblique diameter between sexes.*

	p	*U*	*r*	*n*
Left oblique diameter	<0.001	1295.50	0.44	156
Right oblique diameter	<0.001	1093.50	0.50	156

3.2.5.2. Age

The Kruskal-Wallis test showed no significant differences in the right (p=0.678, H=1.52, df=3, n=155) and left (p=0.923, H=0.48, df=3, n=155) oblique diameter between the age groups. The medians indicated that all age groups had similar values (Table 3.5).

Table 3.5: *Comparison of the medians of the left and right oblique diameter according to age group.*

	Left		**Right**	
	n	***Median***	***n***	***Median***
Young adults	26	12.38	26	12.35
Middle adults	32	12.20	32	12.35
Old adults	63	12.40	63	12.40
Very old adults	34	12.60	34	12.28

3.2.6. Anteroposterior diameter of the inlet

3.2.6.1. Sex

The Mann-Whitney U-test showed a significant difference in the right anteroposterior diameter of the inlet between the sexes (p=0.035, U=1427.50, r=0.19, n=129). However, no such difference but a trend was found regarding the left anteroposterior diameter between the sexes (p=0.053, U=1202.50, r=0.18, n=118). A comparison of the medians indicated that the male sample had shorter anteroposterior diameters of the inlet on average (left and right mdn=10.10), while the female sample tended to have a longer dimension of the anteroposterior inlet (left mdn=10.50, right mdn=10.60).

3.2.6.2. Age

The One-way ANOVA revealed no significant differences in the left and right anteroposterior inlet diameter between the age groups (left p=0.878, df=3, n=117, right p=0.511, df=3, n=128) (Table 3.6). The youngest age group tended to have the largest dimensions of both the left and right anteroposterior diameter of the inlet, while middle-aged adults had the shortest diameters on average. Nevertheless, all age groups had similar mean values.

Table 3.6: *Mean, standard deviation and sample size of the left and right anteroposterior inlet diameter according to age group.*

		n	***Mean***	***SD***
Left	**Young adult**	20	10.28	0.86
	Middle adult	26	10.11	0.88
	Old adult	48	10.26	0.89
	Very old adult	23	10.22	0.65
Right	**Young adult**	25	10.33	0.85
	Middle adult	26	9.99	0.82
	Old adult	48	10.20	0.85
	Very old adult	29	10.19	0.64

3.2.7. Anatomic conjugate

3.2.7.1. Sex

The *t*-test showed no significant difference in the left (*p*=0.152, *t*=-1.45, *n*=113) and right (*p*=0.245, *t*=-1.17, *n*=120) anatomic conjugate between the sexes (Table 3.7). A comparison of the means showed that the female sample had on average slightly larger left and right anatomic conjugates compared to the male sample.

Table 3.7: *Mean, standard deviation and sample size of the left and right anatomic conjugate according to sex.*

		Left			**Right**	
	n	***Mean***	***SD***	***n***	***Mean***	***SD***
Males	77	11.12	0.72	82	11.13	0.74
Females	36	11.40	1.07	38	11.33	0.92

3.2.7.2. Age

The results of the One-way ANOVA showed no significant differences in the left (*p*=0.403, n=112) and right (*p*=0.680, *n*=119) anatomic conjugate between the age groups (Table 3.8). Very old adults tended to have the largest anatomic conjugate on both sides, while middle-aged adults had on average the smallest dimensions of the anatomic conjugate.

Table 3.8: *Mean, standard deviation and sample size of the left and right anatomic conjugate according to age group.*

		n	***Mean***	***SD***
Left	**Young adult**	18	11.24	0.93
	Middle adult	25	10.95	0.82
	Old adult	47	11.28	0.92
	Very old adult	22	11.31	0.66
Right	**Young adult**	22	11.27	0.82
	Middle adult	22	11.02	0.76
	Old adult	46	11.18	0.91
	Very old adult	29	11.28	0.65

3.2.8. Anterior upper spinal breadth

3.2.8.1. Sex

The *t*-test showed no significant difference in the anterior upper spinal breadth between the sexes (p=0.218, t=1.25, n=115). However, a comparison of the means indicated that the male sample had slightly larger interspinous distances ($\bar{x}$=22.11, SD=1.26) compared to the female sample ($\bar{x}$=21.62, SD=2.13).

3.2.8.2. Age

The results of the Kruskal-Wallis test indicated a significant difference in the anterior upper spinal breadth between the age groups (p=0.024, H=9.44, df=3, n=115). However, after the conduction of a post-hoc Dunn-Bonferroni analysis the Bonferroni corrected *p*-values were above the significance level of 0.05 and, thus, no significant difference between the age groups was found.

3.2.9. Inter-obturatum breadth

3.2.9.1. Sex

The *t*-test showed a significant difference in the inter-obturatum breadth between the sexes (p<0.001, t=-5.24, n=156) (Table 3.9). A comparison of the means indicated that females tended to have larger inter-obturatum breadths than males.

Table 3.9: *Mean, standard deviation and sample size of the inter-obturatum breadth according to sex.*

	n	***Mean***	***SD***
Male	101	5.23	0.49
Female	55	5.67	0.50

3.2.9.2. Age

Results of the One-way ANOVA revealed no significant differences in the inter-obturatum breadth between the age groups (p=0.180, n=155) (Table 3.10). However, a comparison of the means showed that the youngest age group had the smallest inter-obturatum breadths, while old adults had the largest breadths on average.

Table 3.10: *Mean, standard deviation and sample size of the inter-obturatum breadth according to age group.*

	n	***Mean***	***SD***
Young adult	26	5.26	0.57
Middle adult	32	5.27	0.57
Old adult	63	5.47	0.52
Very old adult	34	5.44	0.49

3.2.10. Pubic length

3.2.10.1. Sex

The Mann-Whitney U-test showed a significant difference in the left (p=0.027, U=2797.00, r=0.17, n=176) and right (p<0.001, U=2115.50, r=0.29, n=171) pubic length between the sexes. Females tended to have larger pubic lengths on the left (mdn=7.30) and right side (mdn=7.40) than men (left mdn=7.10, right mdn=7.00).

3.2.10.2. Age

Results of the Kruskal-Wallis test showed a significant difference in right pubic length between the age groups (p=0.008, H=11.76, df=3, n=168), but no such difference was found regarding the left pubic length (p=0.292, H=4.19, df=3, n=173) (Table 3.11). A post-hoc Dunn-Bonferroni analysis revealed a significant difference between young and old adults (p=0.046) and young and very old adults (p=0.021). The comparison of the medians indicated that the eldest two age groups tended to have larger right and left pubic lengths, while the youngest two age groups had the smallest dimensions of the pubic length.

Table 3.11: *Median and sample size of the left and right pubic length according to age group.*

	Left		Right	
	n	***Median***	***n***	***Median***
Young adult	29	6.90	35	7.00
Middle adult	38	7.15	29	7.00
Old adult	73	7.20	68	7.20
Very old adult	34	7.20	36	7.40

3.2.11. Pubic symphysis height

3.2.11.1. Sex

The Mann-Whitney U-test showed a significant difference in the left (p<0.001, U=1443.50, r=0.53, n=188) and right (p<0.001, U=1890.50, r=0.47, n=196) pubic symphysis height between the sexes. The male sample tended to have larger symphysis heights (left and right *mdn*=4.20) compared to the female sample (left *mdn*=3.85, right *mdn*=3.90).

3.2.11.2. Age

The Kruskal-Wallis test revealed no significant difference in the left (p=0.059, H=7.46, df=3, n=185) and right (p=0.068, H=7.13, df=3, n=193) pubic symphysis height between the age groups (Table 3.12). All age groups had similar median values, however, the eldest age group tended to have the largest symphysis heights compared to all other age groups. Even though, this was only found to a minor degree.

Table 3.12: *Median and sample size of the left and right pubic symphysis height according to age group.*

	Left		Right	
	n	***Median***	***n***	***Median***
Young adult	32	4.00	39	4.00
Middle adult	39	4.10	34	4.00
Old adult	73	4.10	80	4.10
Very old adult	41	4.15	40	4.20

3.3. Scar manifestation according to sex and age

3.3.1. Occurrence of the dorsal pubic pits

3.3.1.1. Sex

For testing Hypothesis 1, the statistical analysis revealed a significant association of the occurrence of the dorsal pubic pits on both sides with sex (left side: $p<0.001$, $\chi^2=104.08$, $df=6$, $n=241$; right side: $p<0.001$, $\chi^2=117.65$, $df=5$, $n=244$) (Figure 3.4 and 3.5). The majority of the male sample had absent pits (left: 74.0%, right: 75.7%), while only very small proportions of men showed either more than three single pits or a groove. In the case of the right dorsal pubic pits, not a single male individual showed four or five single pits. However, the majority of women had a groove (left: 41.1%, right: 52%) and only small proportions either absent pits or one and two single pits.

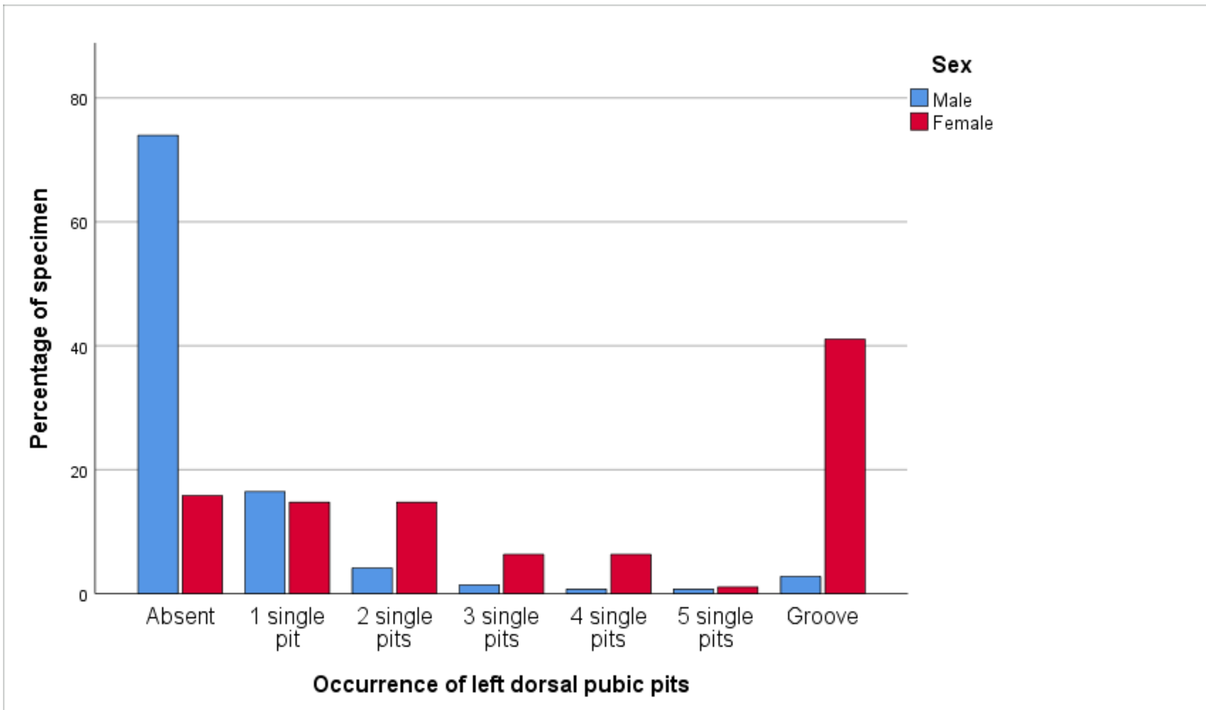


Figure 3.4: Comparison of the occurrence of the left dorsal pubic pits between the sexes.

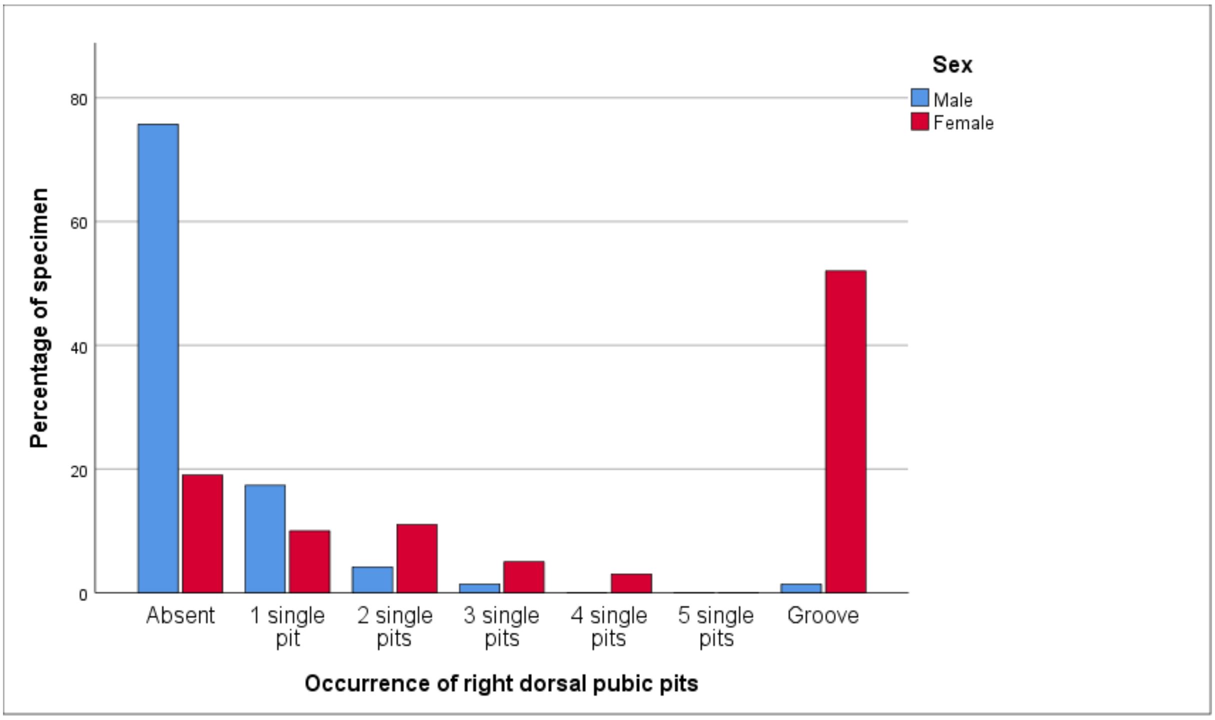


Figure 3.5: Comparison of the occurrence of the right dorsal pubic pits between the sexes.

3.3.1.2. Age

For checking Hypothesis 2, the statistical analysis showed that the occurrence of the right dorsal pubic pits was significantly associated with age (p=0.008, χ^2=31.32, df=15, n=240). However, no such association was found between the occurrence of the left dorsal pubic pits and age (p=0.551, χ^2=16.60, df=18, n=237) (Table 3.13). The majority of each of the age groups had no dorsal pubic pits, followed by a groove and one single pit. Only small proportions of all age groups had two to five single pits, whereas on the right side none of the four age groups exhibited five single pits. Very old adults presented more frequently a groove compared to all other age groups.

Table 3.13: Comparison of the occurrence of the left and right dorsal pubic pits between the age groups.

			Absent	1 single pit	2 single pits	3 single pits	4 single pits	5 single pits	Groove
Left	Young adult	n	23	9	5	0	0	0	5
		%	54.8%	21.4%	11.9%	0%	0%	0%	11.9%
	Middle adult	n	25	7	6	1	2	0	7
		%	52.1%	14.6%	12.5%	2.1%	4.2%	0%	14.6%
	Old adult	n	48	15	6	6	2	1	17
		%	50.5%	15.8%	6.3%	6.3%	2.1%	1.1%	17.9%
	Very old adult	n	23	7	3	1	3	1	14
		%	44.2%	13.5%	5.8%	1.9%	5.8%	1.9%	26.9%
Right	Young adult	n	24	12	6	0	1		6
		%	49.0%	24.5%	12.2%	0%	2.0%	0%	12.2%
	Middle adult	n	21	11	1	2	1	0	7
		%	48.8%	25.6%	2.3%	4.7%	2.3%	0%	16.3%
	Old adult	n	55	10	5	2	1	0	22
		%	57.9%	10.5%	5.3%	2.1%	1.1%	0%	23.2%
	Very old adult	n	25	1	5	3	0	0	19
		%	47.2%	1.9%	9.4%	5.7%	0%	0%	35.8%

3.3.2. Manifestation of the dorsal pubic pits

3.3.2.1. Sex

For testing Hypothesis 1, it was shown that the manifestation of the dorsal pubic pits on both the right and left side was significantly associated with sex (left side: $p<0.001$, $\chi^2=105.63$, $df=3$, $n=239$; right side: $p<0.001$, $\chi^2=111.89$, $df=3$, $n=243$) (Table 3.14). Pitting was absent in the majority of men, the largest proportion of women, however, showed present pubic pits. The category "prominent" pubic pits was solely found in women.

Table 3.14: Comparison of the manifestation of the left and right dorsal pubic pits between the sexes.

			Absent	Faintly perceptible	Present	Prominent
Left	Male	n	108	31	6	0
		%	74.5%	21.4%	4.1%	0%
	Female	n	14	27	30	23
		%	14.9%	28.7%	31.9%	24.5%
Right	Male	n	109	29	6	0
		%	75.7%	20.1%	4.2%	0%
	Female	n	19	16	37	27
		%	19.2%	16.2%	37.4%	27.3%

3.3.2.2. Age

For evaluating Hypothesis 2, the result demonstrated that the manifestation of left dorsal pubic pitting was not significantly associated with age (p=0.380, χ^2=9.69, df=9, n=235). However, the right dorsal pubic pit manifestation was significantly associated with age (p=0.001, χ^2=28.67, df=9, n=239) (Table 3.15). Yet in both cases, the largest part of all age groups presented no pubic pits, while smaller proportions had either faintly perceptible or present dorsal pubic pits. Prominent pits were most commonly found in the eldest age group.

Table 3.15: *Comparison of the manifestation of the left and right dorsal pubic pits between the age groups.*

			Absent	Faintly perceptible	Present	Prominent
Left	Young adults	***n***	23	14	4	1
		%	54.8%	33.3%	9.5%	2.4%
	Middle adults	***n***	25	13	6	4
		%	52.1%	27.1%	12.5%	8.3%
	Old adults	***n***	48	21	15	10
		%	51.1%	22.3%	16.0%	10.6%
	Very old adults	***n***	22	10	11	8
		%	43.1%	19.6%	21.6%	15.7%
Right	Young adults	***n***	24	16	7	2
		%	49.0%	32.7%	14.3%	4.1%
	Middle adults	***n***	21	8	13	1
		%	48.8%	18.6%	30.2%	2.3%
	Old adults	***n***	55	16	13	11
		%	57.9%	16.8%	13.7%	11.6%
	Very old adults	***n***	25	4	10	13
		%	48.1%	7.7%	19.2%	25.0%

3.3.3. Length of the single dorsal pubic pits

3.3.3.1. Sex

For verifying Hypothesis 1, the Mann-Whitney U-test showed a significant difference in the length of a single dorsal pubic pit on the right side between the sexes (p=0.014, U= 671.00, r=0.31, n=63), however, no such difference was detected on the left side (p=0.505, U=740.50, r=0.08, n=74). Comparisons of the medians suggested that the female sample had larger right single dorsal pubic pits (*mdn*=0.50) than the male sample (*mdn*=0.45), whereas on the left side both men and women had the same median value of 0.48.

3.3.3.2. Age

For testing Hypothesis 2, no significant difference in the left and right length of the single dorsal pubic pits was found between the age groups with a Kruskal-Wallis analysis (left: p=0.239, H=4.21, df=3, n=74; right: p=0.873, H=0.70, df=3, n=62). A comparison of the medians showed that all age groups had approximately the same median value on both sides (Table 3.16).

Table 3.16: *Comparison of the medians of the left and right single pit length between the age groups.*

	Left		**Right**	
	n	***Median***	***n***	***Median***
Young adult	14	0.53	19	0.50
Middle adult	16	0.48	15	0.50
Old adult	31	0.45	18	0.48
Very old adult	13	0.50	10	0.48

3.3.4. Width of the dorsal pubic pits

3.3.4.1. Sex

For checking Hypothesis 1, the Mann-Whitney U-test showed a significant difference (p<0.001) in the width of the dorsal pubic pits between the sexes on both the left and right side (Table 3.17). A comparison of the medians indicated that the female sample had on both sides wider pubic pits (left *mdn*=0.45, right *mdn*=0.50) than the male sample (left *mdn*=0.35, right *mdn*=0.30).

Table 3.17: *Results of the Mann-Whitney U-test showing p-, U- and r- and n-values of the left and right pubic pit width.*

	p	***U***	***r***	***n***
Left pubic pit width	<0.001	812.00	0.39	119
Right pubic pit width	<0.001	295.00	0.64	116

3.3.4.2. Age

For testing Hypothesis 2, the Kruskal-Wallis test showed a significant difference in the width of the right dorsal pubic pits between the age groups (p=0.012, H=10.86, df=3, n=115). No such difference was found regarding the left pubic pit width (p=0.391, H=3.00, df=3, n=119). The post-hoc Dunn-Bonferroni analysis detected a significant difference in the right pubic pit width between the youngest and eldest age group (p=0.027) and the middle-aged and very old adults (p=0.034).

A comparison of the medians showed that each of the age groups had a median of 0.40 on the left side, which suggests that they had approximately equal left pit widths. Regarding the right side, very old adults tended to have the widest dorsal pubic pits (mdn=0.50), while all of the residual age groups had the same pit width (young, middle, old adults: mdn=0.40).

3.3.5. Occurrence of the pubic tubercle

3.3.5.1. Sex

For evaluating Hypothesis 1, the statistical analysis revealed a significant association of the left and right pubic tubercle with sex (left: Fisher exact p=0.003, χ^2=8.22, df=1, n=135; right: Fisher exact p=0.017, χ^2=5.23, df=1, n=138) (Table 3.18). The majority of both sexes exhibited a pubic tubercle, although this was shown more frequently in women than in men.

Table 3.18: *Comparison of the occurrence of the left and right pubic tubercle between the sexes.*

			Absent	**Present**
Left	**Male**	***n***	39	54
		%	41.9%	58.1%
	Female	***n***	7	35
		%	16.7%	83.3%
Right	**Male**	***n***	42	58
		%	42.0%	58.0%
	Female	***n***	8	30
		%	21.1%	78.9%

3.3.5.2. Age

For verifying Hypothesis 2, the result showed a significant association of the left and right pubic tubercle with age (left: p=0.007, χ^2=12.18, df=3, n=132; right: p=0.048, χ^2=7.92, df=3, n=135) (Table 3.19). While the majority of young adults showed no pubic tubercle, the majority of the older age groups exhibited a pubic tubercle.

Table 3.19: *Comparison of the occurrence of the left and right pubic tubercle between the age groups.*

			Young adult	Middle adult	Old adult	Very old adult
Left	**Absent**	***n***	15	10	17	3
		%	60.0%	33.3%	31.5%	13.0%
	Present	***n***	10	20	37	20
		%	40.0%	66.7%	68.5%	87.0%
Right	**Absent**	***n***	16	9	15	9
		%	57.1%	40.9%	27.3%	30.0%
	Present	***n***	12	13	40	21
		%	42.9%	59.1%	72.7%	70.0%

3.3.6. Pubic tubercle height

3.3.6.1. Sex

For testing Hypothesis 1 a significant difference in the left pubic tubercle extension was found between the sexes (p=0.010). No such difference was found regarding the right side (p=0.057) (Table 3.20). Still, a comparison of the medians suggested that the female sample had longer pubic tubercles on both sides (left mdn=0.45, right mdn=0.50) than the male sample (left mdn=0.35, right mdn=0.3).

Table 3.20: *Results of the Mann-Whitney U-test showing p-, U- and r- and n-values of the left and right pubic tubercle height.*

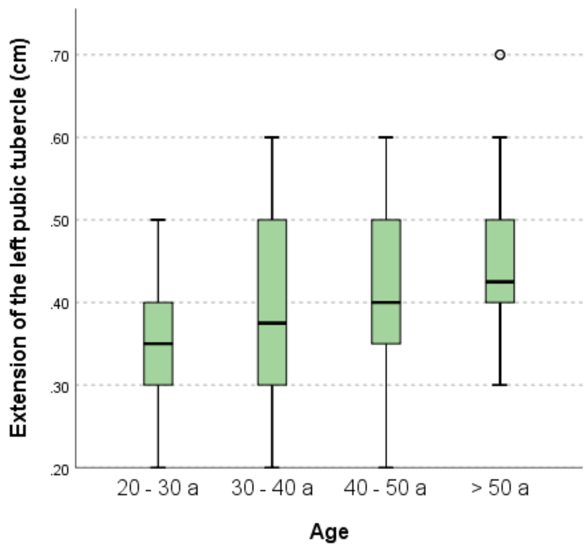
	p	*U*	*r*	*n*
Left pubic tubercle height	0.010	643.00	0.27	89
Right pubic tubercle height	0.057	658.50	0.20	88

3.3.6.2. Age

For checking Hypothesis 2, the Kruskal-Wallis analysis showed a significant difference in the right pubic tubercle extension between the age groups (p=0.002, H=14.78, df=3, n=86) (Figure 3.7). However, no such difference was found in the left tubercle (p=0.173, H=4.98,

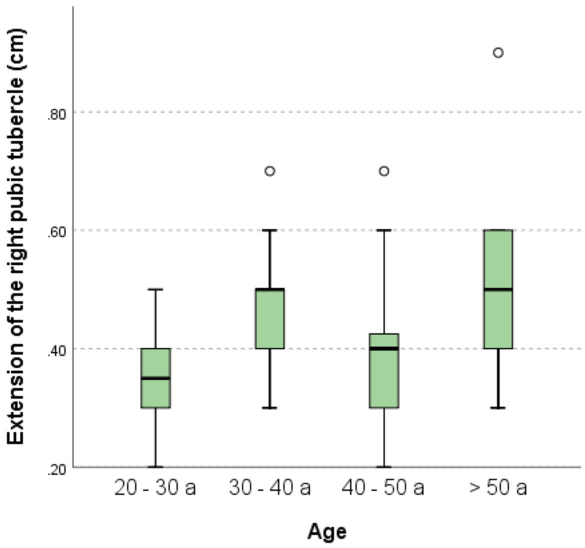
df=3, n=87) (Figure 3.6). A post-hoc test revealed a significant difference in the right tubercle height between young and very old adults (p=0.010) and old and very old adults (p=0.015).

A comparison of the medians indicated that the youngest age group had the shortest pubic tubercles on both sides (left *mdn*=0.35, right *mdn*=0.35), while the eldest age group tended to have the largest tubercles (left *mdn*=0.43, right *mdn*=0.50) together with middle-aged adults regarding the right side (*mdn*=0.50). Compared to the other age groups, old adults had intermediate tubercle extensions (left and right mdn=0.40).



20 – 30 a = young adult
30 – 40 a = middle adult
40 – 50 a = old adult
> 50 a = very old adult

Figure 3.6: Median plot of the left pubic tubercle extension according to age group.



20 – 30 a = young adult
30 – 40 a = middle adult
40 – 50 a = old adult
> 50 a = very old adult

Figure 3.7: Median plot of the right pubic tubercle extension according to age group.

3.3.7. Orientation of the pubic tubercle

3.3.7.1. Sex

For evaluating Hypothesis 1, a significant association of the orientation of the right pubic tubercle was found with sex (Fisher exact p=0.034, χ^2=6.21, df=1, n=87). No such association was shown regarding the left pubic tubercle and sex (Fisher exact p=0.058, χ^2=4.79, df=1, n=89) (Table 3.21). Males had solely ventrally oriented pubic tubercles. The majority of females showed ventrally oriented tubercles and only very small proportions had a cranial orientation of the tubercle.

Table 3.21: *Comparison of the orientation of the left and right pubic tubercle between the sexes.*

		Left		Right	
		Cranial	**Ventral**	**Cranial**	**Ventral**
Male	***n***	0	54	0	58
	%	0%	100%	0%	100%
Female	***n***	3	32	3	26
	%	8.6%	91.4%	10.3%	89.7%

3.3.7.2. Age

For testing Hypothesis 2, the statistical analysis showed a significant association of the orientation of the right pubic tubercle with age (p=0.044, χ^2=8.08, df=3, n=85). No such association was found between the left tubercle orientation and age (p=0.116, χ^2=5.90, df=3, n=87) (Table 3.22). The majority of each of the age groups tended to have a ventrally oriented pubic tubercle on the left and right side. Only small proportions of the youngest and eldest age group had cranially oriented pubic tubercles.

Table 3.22: *Comparison of the orientation of the left and right pubic tubercle betwee the age groups.*

		Left		Right	
		Cranial	**Ventral**	**Cranial**	**Ventral**
Young adult	***n***	1	9	2	10
	%	10.0%	90.0%	16.7%	83.3%
Middle adult	***n***	0	20	0	13
	%	0%	100%	0%	100%
Old adult	***n***	0	37	0	39
	%	0%	100%	0%	100%
Very old adult	***n***	2	18	1	21
	%	10.0%	90.0%	4.8%	95.2%

3.3.8. Maximal diameter of the pubic tubercle

3.3.8.1. Sex

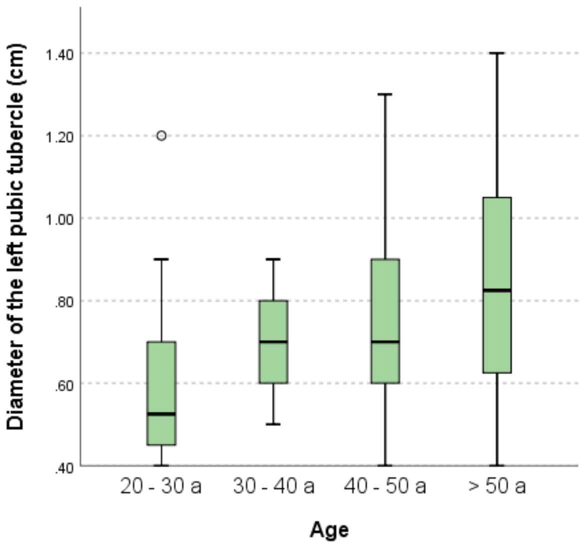
For verifying Hypothesis 1, the Mann-Whitney U-test showed significant differences in the left and right diameter of the pubic tubercle between the sexes (p<0.001) (Table 3.23). A comparison of the medians suggested that men had thicker tubercles both on the left (mdn=0.83) and right (mdn=0.80) side than women (left mdn=0.60; right mdn=0.58).

Table 3.23: *Results of the Mann-Whitney U-test showing p-, U- and r- and n-values of the left and right pubic tubercle diameter.*

	p	***U***	***r***	***n***
Left pubic tubercle diameter	<0.001	493.50	0.41	89
Right pubic tubercle diameter	<0.001	423.50	0.42	88

3.3.8.2. Age

For evaluating Hypothesis 2, the Kruskal-Wallis test showed a significant difference regarding the left pubic tubercle diameter between the age groups (p=0.048, H=7.90, df=3, n=87) (Figure 3.8), while no such difference was found on the right side (p=0.322, H=3.50, df=3, n=86) (Figure 3.9). The post-hoc Dunn-Bonferroni analysis revealed a significant difference in the left tubercle between the youngest and eldest age group with a p-value of 0.049. The youngest age group tended to have the thinnest tubercles (left *mdn*=0.53, right *mdn*=0.65), while the eldest age group had the thickest tubercles (left *mdn*=0.83, right *mdn*=0.80). Middle-aged and old adults on average had pubic tubercles with an intermediate diameter (*mdn*=0.70).



20 – 30 a = young adult
30 – 40 a = middle adult
40 – 50 a = old adult
> 50 a = very old adult

Figure 3.8: Median plot of the diameter of the left pubic tubercle according to age group.

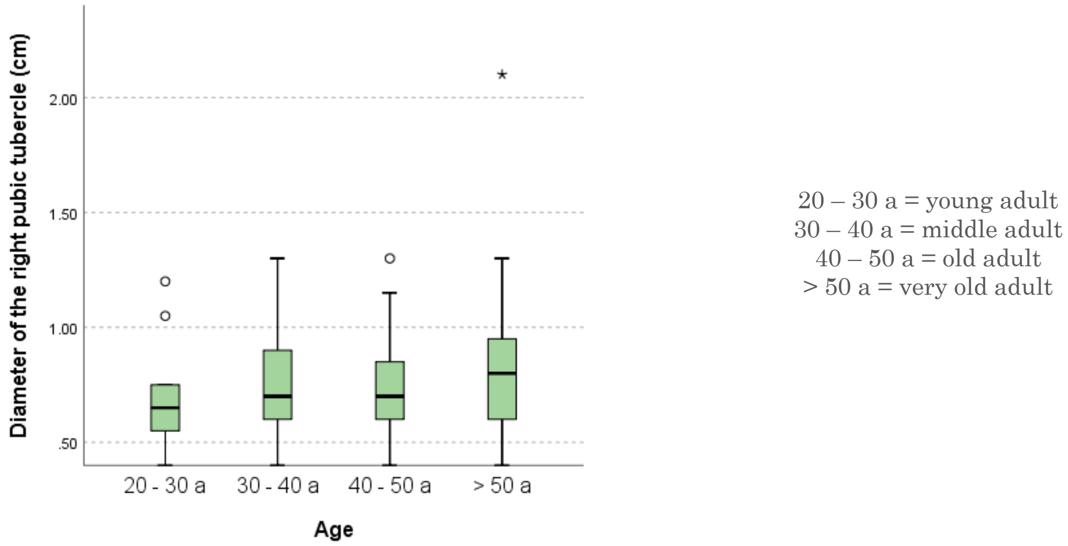


Figure 3.9: Median plot of the diameter of the right pubic tubercle according to age group.

3.3.9. Length of the preauricular sulcus

3.3.9.1. Sex

For testing Hypothesis 1, the Mann-Whitney *U*-test showed a significant difference in the length of the left (p<0.001, U=3012.50, r=0.52, n=245) and the right preauricular sulcus (p<0.001, U=2936.00, r=0.53, n=245) between the sexes (Table 3.24). A comparison of the medians suggested that the female sample had longer preauricular sulci on both sides compared to men.

Table 3.24: *Comparison of the mediasn of the left and right preauricular sulcus length according to sex.*

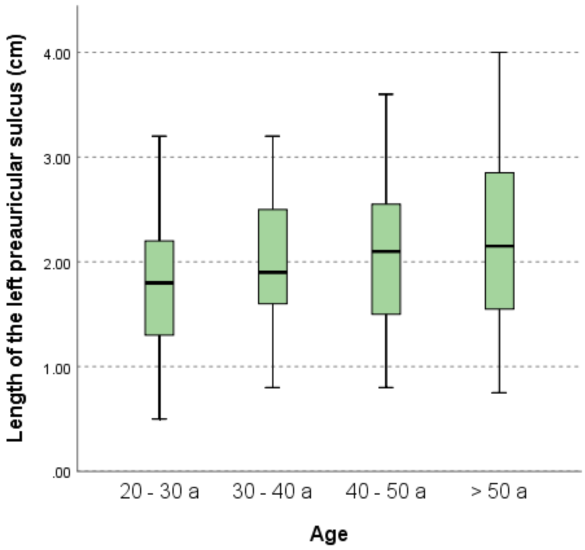
	Female		Male	
	Left length	**Right length**	**Left length**	**Right length**
n	116	121	129	124
Median	2.40	2.50	1.60	1.60

3.3.9.2. Age

For checking Hypothesis 2, the Kruskal-Wallis test showed a significant difference in the left length of the preauricular sulcus between the age groups (p=0.042, H=8.20, df=3, n=242) (Figure 3.10). However, no such difference was found on the right side (p=0.121,

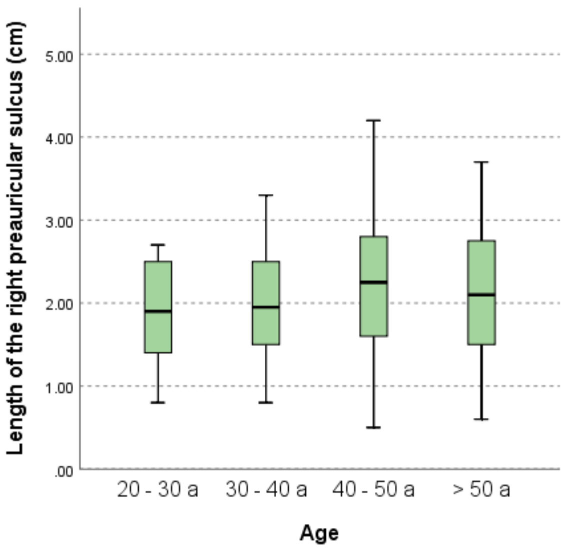
H=5.82, df=3, n=243) (Figure 3.11). A post-hoc analysis revealed that the youngest age group differed significantly from the eldest age group with a p-value of 0.042.

A comparison of the medians suggested that young adults had the shortest left (mdn=1.80) and right sulcus (mdn=1.90,) followed by middle-aged adults (left mdn=1.90, right mdn=1.95). Old adults (left mdn=2.10, right mdn=2.25) and very old adults (left mdn=2.15, right mdn=2.10) had the longest sulci compared to the other age groups.



20 – 30 a = young adult
30 – 40 a = middle adult
40 – 50 a = old adult
> 50 a = very old adult

Figure 3.10: Median plot of the left preauricular sulcus length according to age group.



20 – 30 a = young adult
30 – 40 a = middle adult
40 – 50 a = old adult
> 50 a = very old adult

Figure 3.11: Median plot of the right preauricular sulcus length according to age group.

3.3.10. Width of the preauricular sulcus

3.3.10.1. Sex

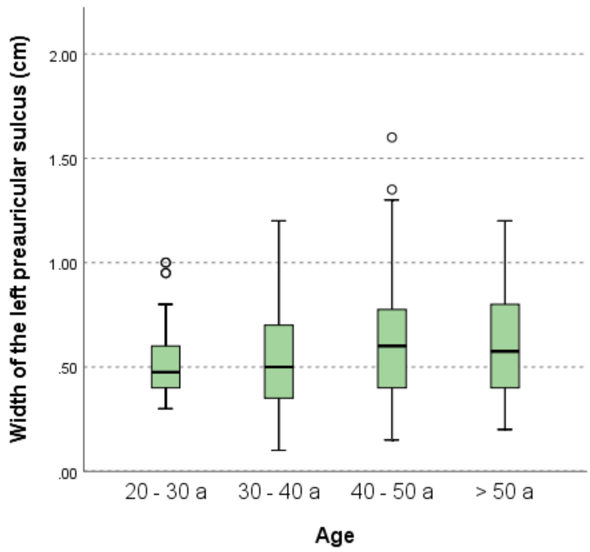
For testing Hypothesis 1, a significant difference in the left (p<0.001, U=2794.50, r=0.54, n=245) and right (p<0.001, U=2853.50, r=0.54, n=247) width of the preauricular sulcus between the sexes was found (Table 3.25). A comparison of the medians suggested that women had on average wider preauricular sulci on both sides than men.

Table 3.25: *Comparison of the medians of the left and right preauricular sulcus width according to sex.*

	Female		**Male**	
	Left width	**Right width**	**Left width**	**Right width**
n	116	121	129	126
Median	0.70	0.70	0.40	0.40

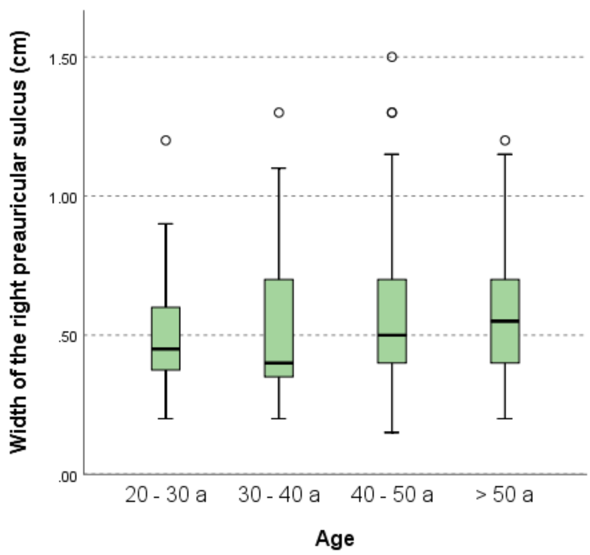
3.3.10.2. Age

For verifying Hypothesis 2, the Kruskal-Wallis test showed no significant difference in the left (p=0.267, H=3.95, df=3, n=242) (Figure 3.12) and right (p=0.429, H=2.77, df=3, n=245) (Figure 3.13) width of the preauricular sulcus between the age groups. Comparisons of the medians indicated that young adults had the narrowest sulci on the left (mdn=0.48) and right side (mdn=0.45), followed by middle-aged adults (left mdn=0.50, right mdn=0.40). Old adults (left mdn=0.60, right mdn=0.50) and very old adults (left mdn=0.58, right mdn=0.55) showed the widest preauricular sulci compared to the other age groups.



20 – 30 a = young adult
30 – 40 a = middle adult
40 – 50 a = old adult
> 50 a = very old adult

Figure 3.12: Median plot of the left preauricular sulcus width according to age group.



20 – 30 a = young adult
30 – 40 a = middle adult
40 – 50 a = old adult
> 50 a = very old adult

Figure 3.13: Median plot of the right preauricular sulcus width according to age group.

3.3.11. Appearance of the preauricular sulcus

3.3.11.1. Sex

For checking Hypothesis 1, the statistical analysis showed a significant association of the appearance of the left and right preauricular sulcus with sex (left: p<0.001, χ^2=118.59, df=4, n=272; right: p<0.001, χ^2=136.35, df=4, n=286) (Figure 3.14 and 3.15). The majority of the male sample showed a narrow-shallow sulcus (left and right side: 62.7%) and just small proportions a broad-shallow sulcus. Solely one male individual exhibited a defined preauricular sulcus, namely on the left side. Only small proportions of women showed no sulcus (left side: 2.5%, right side: 3.2%) and complex sulci were found merely in the female sample (left side: 22.7%, right side: 20%).

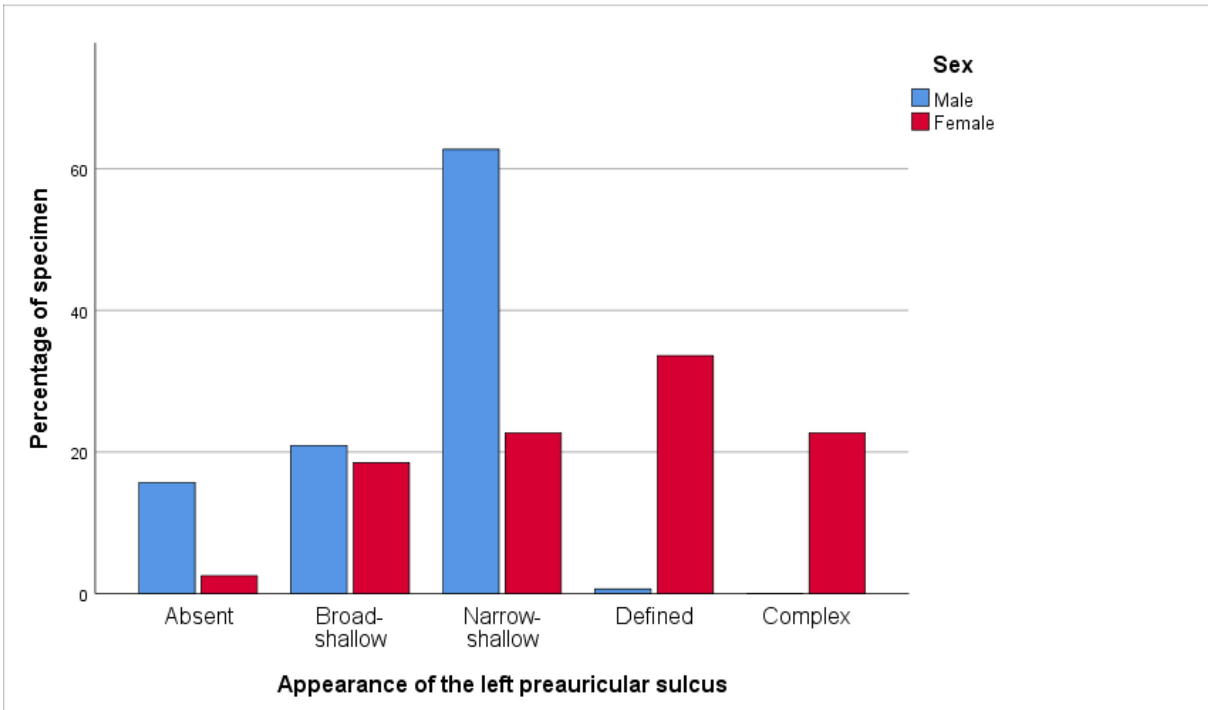


Figure 3.14: Comparison of the appearance of the left preauricular sulcus between the sexes.

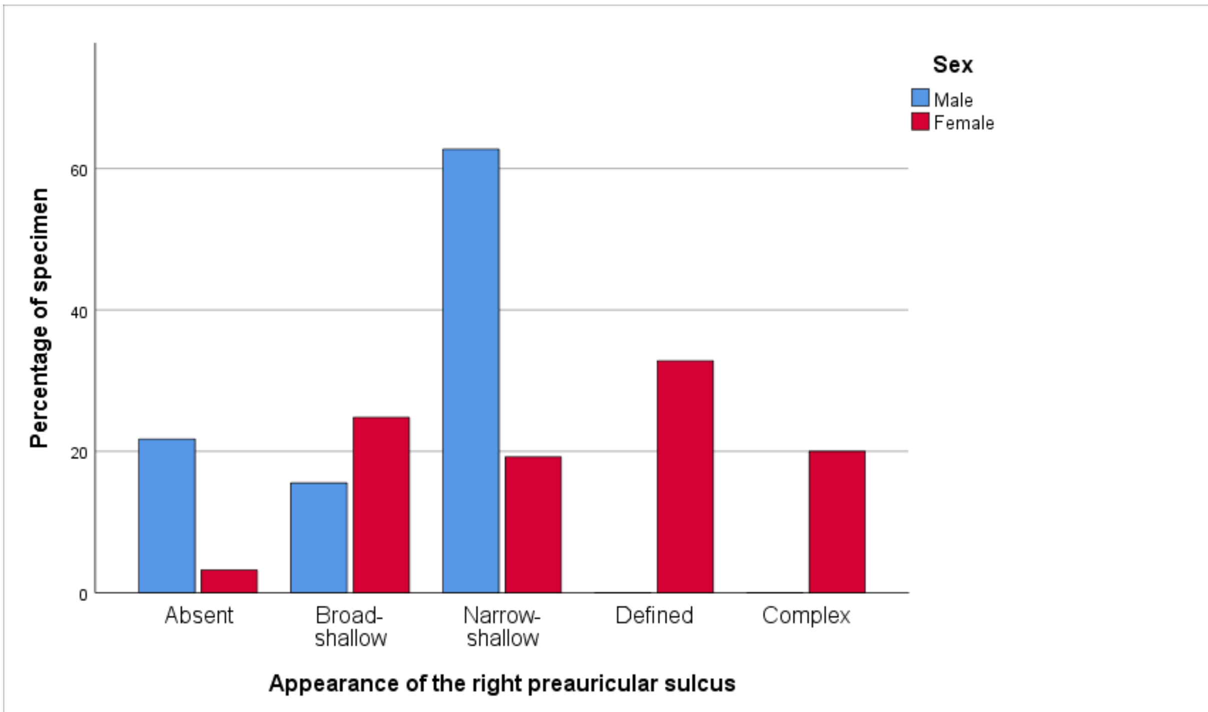


Figure 3.15: Comparison of the appearance of the right preauricular sulcus between the sexes.

3.3.11.2. Age

For testing Hypothesis 2, a significant association of the appearance of the left preauricular sulcus with age was found (p=0.049, χ^2=21.08, df=12, n=269). No such association was shown between the right sulcus and age (p=0.287, χ^2=14.21, df=12, n=282) (Table 3.26). The majority of individuals of each of the four age groups had a narrow-shallow sulcus, while only small proportions of the sample developed either a defined or complex preauricular sulcus.

Table 3.26: *Comparison of the left and right preauricular sulcus appearance between the age groups.*

			Absent	Broad-shallow	Narrow-shallow	Defined	Complex
Left	**Young adult**	***n***	6	10	31	6	1
		%	11.1%	18.5%	57.4%	11.1%	1.9%
	Middle adult	***n***	2	13	28	7	3
		%	3.8%	24.5%	52.8%	13.2%	5.7%
	Old adult	***n***	12	23	45	19	12
		%	10.8%	20.7%	40.5%	17.1%	10.8%
	Very old adult	***n***	7	7	18	8	11
		%	13.7%	13.7%	35.3%	15.7%	21.6%
Right	**Young adult**	***n***	9	12	25	4	2
		%	17.3%	23.1%	48.1%	7.7%	3.8%
	Middle adult	***n***	7	11	27	5	3
		%	13.2%	20.8%	50.9%	9.4%	5.7%
	Old adult	***n***	16	20	47	24	10
		%	13.7%	17.1%	40.2%	20.5%	8.5%
	Very old adult	***n***	5	13	25	8	9
		%	8.3%	21.7%	41.7%	13.3%	15.0%

3.3.12. Grade of the preauricular sulcus

3.3.12.1. Sex

For verifying Hypothesis 1, a significant association of the grade of both the left and right preauricular sulcus with sex was shown (left: $p<0.001$, $\chi^2=128.07$, $df=4$, $n=272$; right: $p<0.001$, $\chi^2=155.27$, $df=4$, $n=286$) (Figure 3.16 and 3.17). The majority of men showed a grade 1 sulcus (left: 72.5%, right: 64.6%), followed by a grade 0 sulcus (left: 15.7%, right: 21.7%). However, not a single male individual showed a grade 4 sulcus. The largest part of the female sample developed a grade 3 sulcus on both the right and left side (left: 30.3%, right: 35.2%). Solely women showed a grade 4 sulcus (left: 26.9%, right: 23.2%).

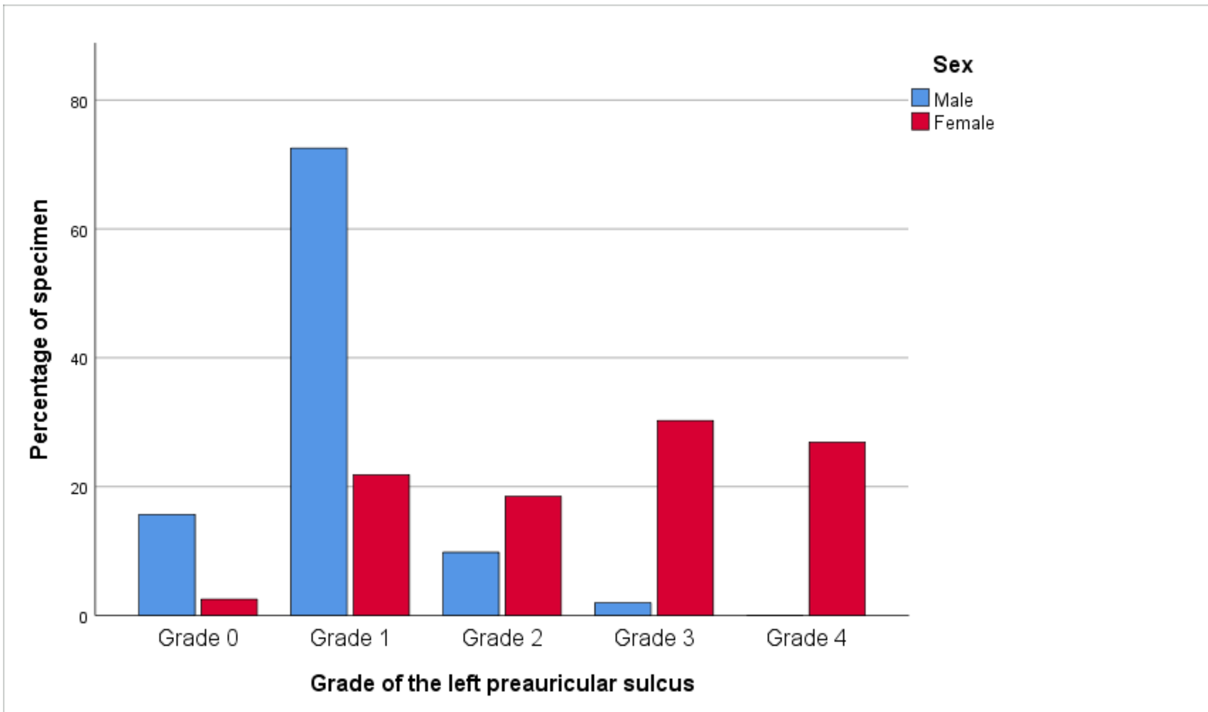


Figure 3.16: Comparison of the left preauricular sulcus grade between the sexes.

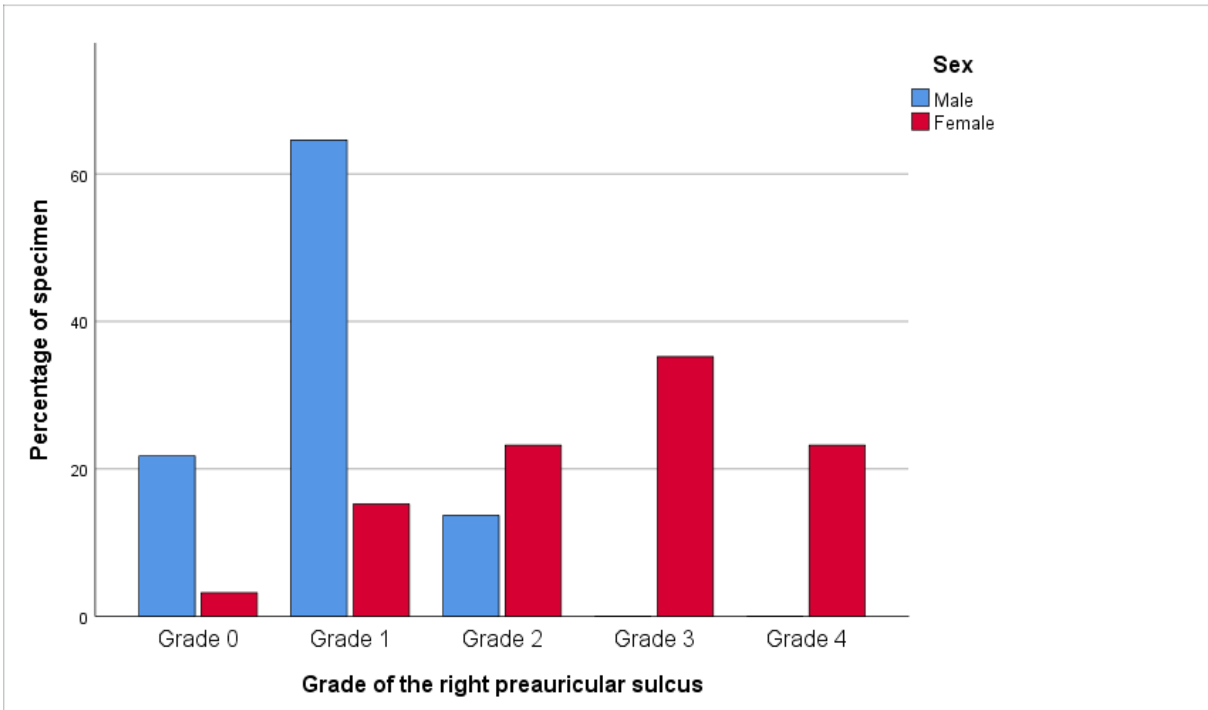


Figure 3.17: Comparison of the right preauricular sulcus grade between the sexes.

3.3.12.2. Age

For evaluating Hypothesis 2, the statistical analysis revealed a significant association of the grade of the left preauricular sulcus with age (p=0.039, χ^2=21.89, df=12, n=269), while no significant association was found between the grade of the right sulcus and age (p=0.540, χ^2=10.88, df=12, n=282) (Table 3.27). The majority of individuals of each of the four age groups had a grade 1 preauricular sulcus, with smaller proportions having a grade 2 or grade 0 sulcus. Very old adults represented most frequently a grade 4 sulcus compared to all other age groups.

Table 3.27: *Comparison of the left and right preauricular sulcus grade between the age groups.*

			Grade 0	Grade 1	Grade 2	Grade 3	Grade 4
Left	**Young adult**	***n***	6	34	9	4	1
		%	11.1%	63.0%	16.7%	7.4%	1.9%
	Middle adult	***n***	2	30	9	9	3
		%	3.8%	56.6%	17.0%	17.0%	5.7%
	Old adult	***n***	12	52	13	17	17
		%	10.8%	46.8%	11.7%	15.3%	15.3%
	Very old adult	***n***	7	19	6	8	11
		%	13.7%	37.3%	11.8%	15.7%	21.6%
Right	**Young adult**	***n***	9	24	12	5	2
		%	17.3%	46.2%	23.1%	9.6%	3.8%
	Middle adult	***n***	7	27	8	8	3
		%	13.2%	50.9%	15.1%	15.1%	5.7%
	Old adult	***n***	16	45	21	21	14
		%	13.7%	38.5%	17.9%	17.9%	12.0%
	Very old adult	***n***	5	26	10	10	9
		%	8.3%	43.3%	16.7%	16.7%	15.0%

3.3.13. Floor of the preauricular sulcus

3.3.13.1. Sex

For testing Hypothesis 1, a significant association of the left and right floor of the preauricular sulcus with sex was found (left: Fisher exact p<0.001, χ^2=83.89, df=1, n=245; right: Fisher exact p<0.001, χ^2=97.48, df=1, n=247) (Table 3.28). While the majority of the male sample showed a smooth floor of the preauricular sulcus on both sides, the majority of the female sample had pitted sulcus floors.

Table 3.28: Comparison of the left and right preauricular sulcus floor between the sexes.

		Left		Right	
		Pitted	**Smooth**	**Pitted**	**Smooth**
Male	***n***	17	112	19	107
	%	13.2%	86.8%	15.1%	84.9%
Female	***n***	82	34	94	27
	%	70.7%	29.3%	77.7%	22.3%

3.3.13.2. Age

For verifying Hypothesis 2, the result demonstrated no significant association of the floor of both the left and right preauricular sulcus with age (left: p=0.233, χ^2=4.28, df=3, n=242; right: p=0.356, χ^2=3.24, df=3, n=245) (Table 3.29). The majority of individuals of each of the age groups had a smooth floor of the left and right sulcus. However, regarding pitted sulci, the largest proportions of old and very old adults showed a pitted floor.

Table 3.29: Comparison of the left and right preauricular sulcus floor between the age groups.

		Left		Right	
		Pitted	**Smooth**	**Pitted**	**Smooth**
Young adult	***n***	15	33	16	27
	%	31.3%	68.8%	37.2%	62.8%
Middle adult	***n***	18	33	18	28
	%	35.3%	64.7%	39.1%	60.9%
Old adult	***n***	43	56	51	50
	%	43.4%	56.6%	50.5%	49.5%
Very old adult	***n***	22	22	27	28
	%	50.0%	50.0%	49.1%	50.9%

3.4. Relationship between parturition scars and pelvic measurements in females

For testing Hypothesis 3, the Pearson correlation test showed a positive significant relationship between the tubercle height and the anterior upper spinal breadth (r=0.49, p=0.024, n=21) and between the tubercle diameter and the pubic length (r=0.31, p=0.032, n=49). The tubercle height was negatively correlated with the distance between the ischial spines (r=-0.95, p=0.014, n=5) and the sulcus width was negatively correlated with the pubic length (r=-0.24, p=0.026, n=84).

3.5. Body mass estimate

3.5.1. Sex

The body mass differed significantly between the sexes (p=0.030, t=2.18, n=277). Males tended to have a larger body mass with a mean of 58.43 (SD=6.12), while women had smaller body masses ($\bar{x}$=56.83, SD=5.94).

3.5.2. Age

The One-way ANOVA showed a significant difference in the body mass between the age groups (p<0.001, n=273). A post-hoc analysis revealed that young and very old adults (p<0.001), middle-aged and old adults (p<0.001) as well as middle-aged and very old adults (p<0.001) differed significantly from each other. A comparison of the means indicated that middle-aged adults had the largest body mass, followed by young adults, while old and very old adults showed the smallest body masses (Table 3.30).

Table 3.30: *Mean, standard deviation and sample size of the body size estimate according to age group.*

	n	*Mean (kg)*	*SD*
Young adult	52	59.28	5.57
Middle adult	52	61.16	5.26
Old adult	113	57.31	6.50
Very old adult	56	54.31	4.21

3.6. Relationship between body mass and parturition scars

3.6.1. Sex

For testing Hypothesis 4, the Pearson correlation test showed no significant relationship regarding the male sample between body mass and the parturition scars. In the case of the female sample a significant but weak relationship between the body mass and tubercle extension (r=-0.31, p=0.030, n=50), sulcus length (r=-0.28, p=0.002, n=120) and sulcus width (r=-0.24, p=0.008, n=120) was found.

3.6.2. Age

For evaluating Hypothesis 4, the Pearson correlation showed no significant relationship between the body size and the parturition scars in the middle-aged and very old adult age group. Regarding young adults, only one significant relationship was found, namely between body mass and pit length (r=0.41, p=0.039, n=26). In the case of the old adult age group, the correlation showed a significant relationship between body mass and sulcus length (r=-0.44, p<0.001, n=106) and sulcus width (r=-0.38, p<0.001, n=107).

Chapter 4: Discussion

4.1. Variation in pelvic measurements

4.1.1. Intercristal distance

4.1.1.1. Differences between the sexes

There was no significant difference regarding the intercristal distance between men and women. Both groups had similar means. This result corresponds with the finding of Purcell (2013). The reason for that lack of sexual dimorphism possibly underlies the fact that the intercristal distance is part of the false pelvis and hence, not relevant regarding obstetrics, which suggests both sexes have similar functional requirements. It was shown that rather than obstetrics, the intercristal distance corresponds with climate. Namely, populations from higher latitudes tend to have broader intercristal distances than populations from lower latitudes (Betti, 2017).

4.1.1.2. Differences between the age groups

The statistical results showed a significant difference between very old adults and each of the other age groups. Furthermore, young and middle-aged adults differed significantly. The youngest age group tended to have the smallest intercristal distance, while the eldest age group had the largest distance (c.f. Table 3.20). This finding can be explained by a study by Berger et al. (2011) who showed that the pelvis enlarges in width even after skeletal maturity and after cessation of longitudinal growth. This increase in width was present in both sexes and is independent of body mass. It suggests that the bony pelvis continues to grow over the course of life.

4.1.2. Transverse diameter of the inlet

4.1.2.1. Differences between the sexes

The statistical analysis revealed a significant difference regarding the transverse inlet diameter between the sexes, namely females tended to have larger dimensions than males. This difference has also been reported in the literature (Tague, 2000; Correia et al., 2005;

Crespo et al., 2015; Maass and Friedling, 2016). It reflects differential selection pressures on the two sexes. Males have the biomechanical acquirements of bipedalism, whereby smaller pelves are biomechanically more efficient than larger ones (Andersen, 1986). The female pelvis additionally must accomplish the demands of reproduction, which in contrast to bipedalism favors large dimensions of the pelvic girdle (White and Folkens, 2005; Delprete, 2017). Large transverse inlet dimensions ensure obstetrical adequacy and enhance reproductive efficiency. Since the fetal head enters the maternal birth canal normally in a transverse or oblique position, a larger transverse diameter of the inlet assures the passage of the head (Rosenberg, 1992). However, other studies claimed that this dimension is of reduced importance regarding obstetrics due to its accommodation of the fronto-occipital diameter of the neonatal head and not the more vulnerable biparietal diameter since there is a tighter fit between the biparietal diameter and the birth canal than between the fronto-occipital diameter (Rosenberg, 2002; Correia et al., 2005). Therefore, one would expect less divergent transverse inlet dimensions between the sexes. In the present study, however, the difference was highly significant.

4.1.2.2. Differences between the age groups

The statistical analysis revealed that middle-aged adults differed significantly from the eldest age group regarding the transverse diameter of the inlet. A comparison of the means showed that this diameter tends to increase with advancing age. Middle-aged adults had the smallest dimensions, followed by young adults, while the eldest age group exhibited the largest dimensions, followed by the old adult age group (c.f. Table 3.21). Since in elderly people, particularly in women, the reproductive stage has already ended, reproduction cannot explain this increase. A study by Kolesova et al. (2017) explained that an expansion of the transverse diameter of the inlet and the decrease of the transverse outlet diameter enhances the efficiency in bipedal locomotion. Thus, it might function as an adaption to increase gait stability in older individuals (Kolesova et al., 2017).

4.1.3. Transverse diameter of the outlet

4.1.3.1. Differences between the sexes

Females showed larger dimensions of the transverse diameter of outlet than males. The difference between the sexes was highly significant. Similar results between the sexes have been reported in the literature as well (Tague, 2000; Correia et al., 2005; Maass and

Friedling, 2016). This sexual dimorphism reflects the different requirements of the male and female pelvis. The male pelvis solely requires bipedal locomotion, while the female pelvis additionally must facilitate childbirth (White and Folkens, 2005; Delprete, 2017). The transverse outlet diameter is of great importance during delivery as it accommodates the delicate biparietal diameter of the fetal head. The tight fit between the neonatal biparietal diameter and the birth canal can be associated with biparietal deformations, which can often lead to the death of the neonate (Correia et al., 2005). A larger transverse diameter of the outlet in females reduces the risk of obstructed labor and ensures obstetrical adequacy.

4.1.3.2. Differences between the age groups

There was no significant difference regarding the transverse diameter of the outlet between the age groups. A comparison of the medians showed that the dimensions decreased with advancing age (c.f. Figure 3.18). This finding is concordant with the study by Kolesova et al. (2017). As already mentioned in the section before (c.f. Section 4.1.2.2.), a decrease in the transverse diameter of the outlet enhances the efficiency in bipedalism and hence, increases the gait stability in elderly people (Kolesova et al., 2017). However, since the present study found no significant differences between the age groups, the decrease in this dimension must be considered with caution.

4.1.4. Distance between the ischial spines

4.1.4.1. Differences between the sexes

The distance between the ischial spines was significantly larger in females than in males. Previous studies showed that this diameter is the most sexually dimorphic dimension of the pelvic girdle and reflects the different demands of the bony pelvis between the sexes (Tague, 2000; Correia et al., 2005; Maass, 2012). The midplane, which is at the level of the ischial spines represents a critical obstetric plane since there is the greatest constriction of the birth canal (Walrath and Glantz, 1996). Hence, a large distance between the ischial spines in women is required for a safe passage of the fetus during childbirth. Similar to the transverse diameter of the outlet the distance between the ischial spines is also of great significance due to its accommodation of the biparietal diameter of the head of the neonate (Correia et al., 2005).

4.1.4.2. Differences between the age groups

There was no significant difference in the distance between the ischial spines between the age groups. Nevertheless, a comparison of the means shows that the eldest age group had the smallest, while the youngest age group exhibited the largest dimension (c.f. Table 3.22). This finding is not concordant with other studies (Maass, 2012; Kolesova et al., 2017). However, it needs to be mentioned that this contradictory result may be due to the small sample size (n=29). According to the present study, the lack of change regarding the distance between the ischial spines indicates that age-related changes do not affect its magnitude.

4.1.5. Oblique diameter

4.1.5.1. Differences between the sexes

Both the left and right oblique diameter was significantly larger in females than in males. This result was also reported in the literature (Correia et al., 2005). Again, it reflects the differential demands of the bony pelvis for males and females. During childbirth, the fetal head enters the birth canal in a transverse or oblique position and hence, larger dimensions ensure the passage of the fetus and reduce the risk of obstructed labor.

4.1.5.2. Differences between the age groups

There was no significant difference in both the left and right oblique diameter between the age groups. This result indicates that age-related changes do not affect the magnitude of the oblique diameter.

4.1.6. Anteroposterior diameter of the inlet

4.1.6.1. Differences between the sexes

The statistical analyses revealed only a significant difference regarding the right side of the anteroposterior inlet diameter between the sexes. However, a trend was observed on the left side. The female sample had longer dimensions of the anteroposterior diameter compared to the male sample. This result is concordant with previous studies (Correia et al., 2005; Crespo et al., 2015; Maass and Friedling, 2016). Again, this sexual dimorphism reflects the different requirements of the male and female pelvis and can be explained that a large anteroposterior diameter of the inlet in women ensures the passage of the fetal head during the birth process as well as a reduction of the risk of possible lethal biparietal deformations of the neonatal head.

4.1.6.2. Differences between the age groups

There was no significant difference regarding the anteroposterior diameter of the inlet between the age groups. This result is concordant with the study by Maass and Friedling (2016) and suggests that age does not significantly affect the magnitude of this dimension.

4.1.7. Anatomic conjugate

4.1.7.1. Differences between the sexes

The female sample tended to have slightly larger dimensions of both the left and right anatomic conjugate than the male sample. However, this difference was statistically non-significant. Since this dimension does not reflect the actual size of the birth canal, like the anteroposterior diameter of the inlet, this result is not surprising. It is not relevant regarding obstetrics, which might explain the non-significant difference between the sexes.

4.1.7.2. Differences between the age groups

The statistical analysis showed that the eldest age group had the largest anatomic conjugate, while middle-aged adults had the smallest ones (c.f. Table 4.29). However, this difference was not significant and, hence, suggests that age does not influence the magnitude of the anatomic conjugate. The result of the present study is not concordant with a previous study by Shah et al. (2017) who reported that the anatomic conjugate decreases with advancing age due to the vertical posture that changes the pelvic bone system with advancing age. This is not the case in the present study, which rather indicates that vertical posture did not affect pelvic bone system with increasing age.

4.1.8. Anterior upper spinal breadth

4.1.8.1. Differences between the sexes

The male sample tended to have slightly larger anterior upper spinal breadths than the female sample, however, this difference was statistically not significant. Due to a lack of literature investigating this relationship the cause can only be presumed. The lack of sexual dimorphism of the anterior upper spinal breadth might explain the reduced importance regarding obstetrics. The anterior upper spinal breadth is part of the false pelvis and hence does not play a significant role during childbirth. The regulation of this diameter appears to be similar in both sexes and is probably related to the biomechanical requirements of bipedalism.

4.1.8.2. Differences between the age groups

There was no significant difference in the anterior upper spinal breadths between the age groups. This result indicates that age-changes do not affect the magnitude of the diameter.

4.1.9. Inter-obturatum breadth

4.1.9.1. Differences between the sexes

Females had significantly larger dimensions of the inter-obturatum breadth than males (c.f. Table 4.30). These differential breadths may be an anatomical by-product of the subpubic angle or subpubic arch. It is more angular in men, possibly resulting in smaller dimensions of the inter-obturatum breadth. In women, however, the subpubic angle is more rounded because it determines the size of the birth canal (Oladipo et al., 2010). The larger inter-obturatum breadth in females may be an anatomical consequence of the wider subpubic angle.

4.1.9.2. Differences between the age groups

There was no significant difference regarding the inter-obturatum breadth between the age groups. The result indicates that age does not influence this pelvic dimension.

4.1.10. Pubic length

4.1.10.1. Differences between the sexes

The female sample had significantly longer left and right pubic lengths than the male sample. This result had been reported in the literature (Chris-Ozoko et al., 2014). Also, Washburn (1948) who investigated sex differences in the pubic bone noted that the pubic length in women is longer than in men. It would be reasonable to assume that longer pubic lengths result in a wider pelvic cavity, whereas shorter lengths would rather restrict the cavity. Women need a large birth canal to assure the safe passage of the fetus during delivery, and longer pubic lengths contribute or are needed to ensure obstetric adequacy. Hence, this result indicates that the length of the pubis reflects the differential requirements of the female and male pelvis.

4.1.10.2. Differences between the age groups

The statistical analysis showed that the youngest age group differed significantly from old and very old adults regarding the right side of the pubic length. Young adults tended to have the shortest pubic length, while the eldest age group had the longest pubic length (c.f. Table 4.33). However, there was no statistically significant difference on the left side.

Unfortunately, there is a lack of data about age changes in the pubic length. Hence, the reason for the increase in pubic length can only be of speculative nature. One potential explanation may represent the pelvic enlargement in width even after skeletal maturity as Berger et al. (2011) claimed. As a result, also the pubic length would increase in length, which leads to a wider pelvis with advancing age. Another possibility could be body mass and the lifelong strain of the upper body weight acting on the pelvis that changes the pelvic bone system with increasing age and as a result, also the length of the pubic bone.

4.1.11. Pubic symphysis height

4.1.11.1. Differences between the sexes

The male sample tended to have larger pubic symphysis heights both on the left and right side than the female sample. This finding is concordant with previous studies (Decker et al., 2011; Lottering et al., 2014). A study by Fischer and Mitteroecker (2017) showed that the height of the pubic symphysis is related to body stature. Tall individuals tend to have a taller and narrower pelvis and consequently a longer symphysis compared to shorter individuals (Fischer and Mitteroecker, 2017). Since men are on average taller than women, stature might explain this sexual dimorphism regarding the pubic symphysis height.

4.1.11.2. Differences between the age groups

The eldest age group had larger pubic symphysis than the younger age groups. Even though, it is worth mentioning that the difference was statistically non-significant. This finding is concordant with those of Lottering et al. (2014) who also reported an increase in height. However, in their study, the 25-34 year age cohort differed significantly from the 55-64 year age cohort in females (Lottering et al., 2014). A division according to sex regarding the age groups was not possible in the present study since it would have led to a smaller sample size. Nevertheless, this result indicates that age does not have major effects on the height of the pubic symphysis.

4.1.12. Summary

The statistical analyses showed that all of the pelvic dimensions which are important in obstetrics were significantly larger in females than in males. Those obstetric dimensions include the transverse diameter of the inlet, the transverse diameter of the outlet, the distance between the ischial spines, the oblique diameter, and the anteroposterior diameter of the inlet. These differences reflect the sexual dimorphism and therefore, the differential requirements of the bony pelvis in males and females. Men only have the requirements of bipedalism, whereby a narrow pelvis is favored due to its greater efficiency in bipedal locomotion (Lovejoy, 1988; White and Folkens, 2005; Warrener et al., 2015). Women, on the other hand, have the requirements of both bipedalism and reproduction. Bipedal locomotion favors a narrow pelvis, while reproduction favors a wider pelvis to ensure obstetric adequacy. These two contradictory constraints led to a compromise, whereby the female pelvis is larger, particularly regarding the pelvic cavity, to enable the passage of the fetus during childbirth, even if bipedal locomotion is less efficient (Rosenberg, 1992; DeSilva and Rosenberg, 2017).

Although the larger dimensions of the inter-obturatum breadth and the pubic length in women are not directly relevant for obstetrics, this sexual dimorphism indicates that both may contribute to a larger pelvic cavity. It seems that longer pubic bones increase the pelvic inlet, while shorter pubic bones would rather constrict the inlet. The larger inter-obturatum breadth in women appears to be an anatomical consequence of the wider subpubic angle, which determines the size of the birth canal (Oladipo et al., 2010). In men it is more angular, possibly leading to shorter inter-obturatum breadths and hence to a smaller pelvic cavity. Since women must accomplish the demands of childbirth the longer pubic bones and larger inter-obturatum breadths might truly result in larger dimensions of the pelvic cavity, which is needed for a safe passage of the fetus during childbirth.

There was no sexual dimorphism regarding the intercristal distance, the anatomic conjugate, and the anterior upper spinal breadth. Those diameters represent dimensions that are not important in obstetrics and hence do not influence obstetrical adequacy in women. Therefore, it is not surprising that females and males did not differ significantly in those diameters. Also, the height of the pubic symphysis does not affect the size of the pelvic cavity and therefore obstetrical adequacy, however, the statistical analysis revealed a significant difference between the male and female sample. Men tended to have longer pubic symphyses than women. This finding is probably related to body stature though. Taller individuals have taller pelves which, in turn, would result in larger heights of the symphysis. Since men are on average taller than women they also tend to have longer pubic symphyses than women.

The majority of the measured pelvic dimensions differed not significantly between the age groups in the present study. This involved the transverse diameter of the outlet, the distance between the ischial spines, the oblique diameter, the anteroposterior diameter of the inlet, the anatomic conjugate, the anterior upper spinal breadth, the inter-obturatum breadth, and the pubic symphysis height. This result indicates that age-related changes do not affect the magnitude in these dimensions.

The intercristal distance increased significantly with age. This might be a result of the pelvic enlargement with advancing age, which can be seen even after skeletal maturity and after the cessation of longitudinal growth (Berger et al., 2011). The same outcome was found regarding the pubic length. The youngest age group had the shortest pubic bones, while the eldest age group tended to have the longest pubic bones, indicating an increase with advancing age. Due to a lack of literature investigating age changes in pubic length, the cause for this increase can only be assumed. Pelvic enlargement with advancing age may represent one potential reason. Another possibility could be the body mass and the lifelong strain of the upper body weight acting on the bony pelvis, resulting in changes of the pelvic bone system with advancing age and in turn also leading to longer pubic bones.

The transverse diameter of the inlet also increased significantly with age. According to Kolesova et al. (2017), the increase in the transverse inlet diameter and decrease of the transverse outlet diameter enhances the efficiency in bipedalism and acts as an adaption to increase gait stability in older individuals. The present study found a decrease in the transverse diameter of the outlet, however, it was statistically non-significant. Nevertheless, both results suggest accordance with the claim of gait stability by Kolesova et al. (2017).

4.2. Scar manifestation according to sex and age at death

4.2.1. Effect of sex on scar formation

Pelvic scarring was present in both males and females, however, the presence and the degree of manifestation differed between the sexes. Apart from the tubercle diameter, women generally exhibited more frequently and more developed scars of all types than men, which signifies the support of Hypothesis 1. Occurrence, manifestation, and width of the dorsal pubic pits examined on both sides were all significantly associated with sex (c.f. Figures 3.4, 3.5 and Tables 3.2, 3.5). Females showed more frequently and more severe pitting than men. The only exception represented the left pit length, whereby both sexes tended to have similar long pits. The length, width, appearance, grade and floor of the preauricular sulcus examined on both sides were all significantly associated with sex (c.f. Figures 3.14, 3.15, 3.16, 3.17 and Tables 3.12, 3.13, 3.16). Females tended to have longer, wider and more developed sulci than men.

The statistical results suggest that the strain acting on female pelves is greater than it is on males. Angel (1969), Stewart (1970), Houghton (1975), and Ullrich (1987) claim that this strain originates from pregnancy and childbirth. However, since men exhibited pelvic scarring as well, to a lesser degree than women but still to a relatively high incidence, indicates that parity and delivery cannot be the single causing factor of scar formation. Hence, the name “scars of parturition” represents a rather mistaken terminology and technically should not be used any longer to bypass misconceptions and incorrect assumptions. There must be other influencing factors contributing to its development.

Pelvic architecture may represent one such factor. Andersen (1986) suggested that women’s greater strain on the pelvis might be a result of their pelvic architecture.

Compared to men, females exhibit a more loosely articulated pelvic girdle, which is accompanied by greater mobility. Thus, pelvic scarring is caused by the excess motion that is enabled in a more flexible pelvis. This, in turn, increases the strain acting on pelvic ligaments, leading to bone remodeling at their attachment sites and to the formation of more developed pelvic scars in women (Andersen, 1986). Andersen's suggestion may explain the higher incidence and the more severe scarring events in females.

A possible factor that causes pelvic scarring in men might represent trauma. Andersen (1986) stated in her study that trauma may affect scar formation. This may account for small proportions in men who exhibited pelvic scars. However, more than half of males showed a pubic tubercle and preauricular sulcus, which cannot support this claim. Even the incidence of pubic pitting in men, that accounted for 26% on the left and 24.5% on the right side, still appears too high for an exclusive traumatic origin.

Maass and Friedling (2016) suggested that weight-bearing is the common cause of pelvic scarring in both men and women. Pregnancy-related stresses may enhance the strain in some females, which probably led to the weak relationship between pelvic scarring and parity in other studies. This also might explain the higher incidence of more severe scar formation in women. Furthermore, the fact that the sacroiliac joint with its ligaments is generally under greater stress, due to the transfer of the upper body weight onto the lower limbs, may account for the high incidence of men showing preauricular sulci (Houghton, 1974). Body weight represents another additional factor of weight-bearing that will be discussed in a later section.

The occurrence and diameter of the pubic tubercle revealed significant differences on both sides and regarding the tubercle height on the left side between the sexes (c.f. Tables 3.6, 3.8, 3.11). Women showed on average more often and also longer pubic tubercles. The diameter of the pubic tubercle was the only scar feature that was larger in men than in women. Already Cox and Scott (1992) stated that the morphology of the tubercle is very distinct between men and women, namely men showing a more robust and less fragile pubic tubercle than women. However, they did not mention the possible reason for that difference between the sexes.

A potential explanation could lie in the general sexual dimorphism in skeletal muscles. Men have larger skeletal muscles than women, especially in the upper body and as a result, are stronger (Janssen et al., 2000). Thus, it is presumed that the muscle attachment sites, which are generally more conspicuous in males, reflects the greater strength of men (Benjamin et al., 2002). Interestingly, women showed longer pubic tubercles than men. This suggests that the strain acting on the attachment site was larger in female individuals. Pregnancy and childbirth could indeed explain the greater strain in women with a resultant longer pubic tubercle. As parity history was not available in the present study, this explanation could not be tested directly. Another possibility is that women performed more activities than men that involved flexion of the torso. However, this appears to be rather unlikely as it is shown that normally men are associated with greater physical activity and mobility due to the sexual division of labor (Ruff, 1987).

The orientation of the pubic tubercle was only significantly associated on the right side, indicating that women show in comparison more often cranial orientated tubercle than men (c.f. Table 3.9). Since the orientation of the extended pubic tubercle has not been examined in previous studies, its cause can only be speculated.

One possibility for the ventral extension represents parity. In the last trimester of pregnancy the abdomen increases in size. Due to the growing belly, the attachment of the abdominis rectus muscle is not stretched cranially but ventrally, which would result in a ventrally oriented extended tubercle. In the present study, six females showed one cranially oriented pubic tubercle. This may suggest that these individuals performed more activities that involved flexion of the torso that had led to the cranial extension of the pubic tubercle. However, the origin of the ventral extension of the pubic tubercle in men is unclear. Perhaps the tubercle was not actually extended but rather appeared to be extended due to the general greater attachment sites in men. Unfortunately, the claims behind the orientation of the tubercle could not be tested due to missing information about the individual's lives.

4.2.2. Effect of age at death on scar formation

Pelvic scarring was present in all age groups, however, the presence and degree of manifestation differed between the age classes. The occurrence, manifestation, and width of the dorsal pubic pits on the right side were significantly associated with age, but no such relationship could be shown regarding the left side (c.f. Tables 3.1, 3.3). Younger age groups tended to have absent or only one or two single pits, while the eldest age group showed more often multiple pits. Also, the groove was more frequently present in very old adults and the least frequent in young adults. A faintly perceptive manifestation of the pubic pits was exhibited particularly in the youngest age group, while the prominent manifestation was found commonest in the eldest age group. Very old adults showed wider pits compared to all other age groups. Solely the pubic pit length was not associated with the age at death on both the left and right side (c.f. Table 3.4). In sum, these results indicate a rejection of Hypothesis 2.

This outcome of the present study is the opposite of what was actually expected namely, that parturition related scarring recede over the course of time (Houghton, 1975; Bergfelder and Herrmann, 1980). The results appear to be rather concordant to those of Suchey et al. (1979) who showed that women who died 15 years or later after their last childbirth exhibited more severe pubic pitting than women who died more recently after childbirth. The authors could also show that nulliparous women under 30 years showed more frequently absent dorsal pubic pits than nulliparous women over the age of 30. This suggests that pregnancy and childbirth do not affect the formation of dorsal pubic pits. Normally, it would be expected that the young and middle-aged adults who are in their reproductive stages would exhibit more severe scarring than older individuals, since the scars recede over time according to Houghton (1975). However, the opposite was the case.

One potential factor, which can be related to increased pubic pitting in older individuals may represent the body mass. Snodgrass and Galloway (2003) found in their study that the BMI is correlated to dorsal pubic pitting in females over the age of 50. A larger BMI leads to more severe pubic pitting in older women. Nevertheless, since the influence of body mass was examined in this study, this relationship will be discussed in a later section (see Section 4.5).

The occurrence, orientation, and height of the right pubic tubercle were significantly associated with age. No such relationship was found on the left side (c.f. Figures 3.6, 3.7 and Tables 3.7, 3.10). The majority of young adults exhibited no tubercle, while all other age groups presented tubercles. Regarding the extension, the youngest age group showed the shortest tubercle compared to all other age groups, while very old adults exhibited the longest tubercles. The orientation of the tubercle was in the majority of all cases ventral, however, compared within the age groups very young adults had more often cranial oriented tubercles than the others. The diameter of the pubic tubercle was only associated on the left side with age at death, whereby the youngest age group tended to have the thinnest and the oldest age group the thickest tubercle (c.f. Figures 3.8, 3.9). To summarize, this part of the results signifies the rejection of Hypothesis 2.

The strain acting on the pubic tubercle is greater in elderly individuals than younger individuals. Maass and Friedling (2016) suggested that osteophyte development may cause this increase in tubercle extension. Unfortunately, there are no studies so far that examined osteophytes in relation to the pubic tubercle. However, it was shown that osteophyte formation in the spine is a general indicator of age (Snodgrass, 2004). It is not unreasonable to assume that this could be potentially assigned to the pubic tubercle as well.

The length, appearance, and grade of the left preauricular sulcus were significantly associated with sex, but no such relationship was found regarding the right sulcus (c.f. Figures 3.10, 3.11 and Tables 3.14, 3.15). The youngest age group exhibited the shortest sulcus, while the eldest age group tended to have the longest sulci. Regarding the appearance, the majority of the young, middle-aged and old adults showed a narrow-shallow sulcus. Very old adults, on the other hand, tended to have a complex sulcus. The majority of all age groups had grade 1 sulci, yet a comparison within the age groups indicated that the oldest age group showed more often a grade 4 sulcus compared to the others. The floor and width of the preauricular sulcus were not significantly associated with age at death (c.f. Figures 3.12, 3.13 and Table 3.17). In sum, this part of the results signifies the rejection of Hypothesis 2.

The statistical analyses suggest that the strain acting on the anterior sacroiliac ligament enhances with increasing age. This result is not concordant with those of other studies (Spring et al., 1989; Cox and Scott, 1992; Maass and Friedling, 2016). Thus, the reason for the greater strain is uncertain. Possibly, the lifelong weight transfer of the upper body on the sacroiliac joint may have led to more developed preauricular sulci with advancing age. High levels of physical activity enhance the mechanical stress even further. Although, it does not explain the discrepancy between the results of the present and other studies investigating the relationship between preauricular sulcus and age at death. A potential factor that can be denied in association with age represents pelvic and joint flexibility. Flexibility is reduced with increasing age and would normally have led to less severe pelvic scarring but the contrary was the case (Andersen, 1986).

4.2.3. Summary

Pelvic scarring was present in both sexes, however, the degree and frequency were greater in females, which signifies the support of Hypothesis 1. The common cause of pelvic scarring in both sexes may have been the weight-bearing function of the pelvis, whereby pregnancy-related stress may enhance the strain in some women, which could explain the higher incidence of more developed bony imprints. Pelvic architecture may have contributed to that as well. Females exhibit a more flexible pelvic girdle with greater mobility. The resulting excess motion increases the strain of the pelvic ligaments. This leads to bone remodeling and the development of distinct bony imprints at the attachment sites in women. If pregnancy and childbirth would be the primary cause of pelvic scarring it would be expected that those scars would recede over the course of time after the last child was born. Yet, the statistical results indicate the opposite. The incidence and manifestation of the bony imprints either increased or remained unchanged with age, which signifies the rejection of Hypothesis 2. A possible reason could represent the weight-bearing function of the pelvis, this is, however, of speculative nature.

4.3. Relationship between pelvic scars and pelvic measurements in the female sample

The statistical analysis showed that women with longer pubic bones tend to have thicker pubic tubercles, which signifies partial support of Hypothesis 3. This relationship has not been tested in previous studies and thus, the cause of this relationship can only be presumed. One possibility may represent the anatomy of the pubic bone, whereby longer pubic bones generally accompany by thicker tubercles.

Moreover, the tubercle height was significantly positively correlated with the anterior upper spinal breadth in the female sample, which also signifies partial support of Hypothesis 3. This association was not tested in previous studies, so its cause can only be speculated. The result implies that larger anterior upper spinal breadths enhance the strain acting on the pubic tubercle and leading to its extension. Since this dimension is part of the false pelvis and hence, not relevant in obstetrics, the relationship between the anterior upper spinal breadth and the tubercle height is probably not affected by childbirth. Perhaps, larger upper spinal breadths are either biomechanically inefficient or reduce the stability of the pelvic girdle, whereby the rectus abdominis muscle tries to balance out this inefficiency or instability which, in turn, results in an extension of the pubic tubercle.

Furthermore, women with larger distances between the ischial spines tended to have shorter pubic tubercles and vice versa, which signifies a partial rejection of Hypothesis 3. This result is concordant with a study by Maass and Friedling (2016), who found that extended pubic tubercles tend to occur in individuals with smaller pelves. It suggests that smaller distances between the ischial spines enhance the strain on the pubic tubercle. Since the level at the ischial spines represents a critical obstetric plane and the greatest constriction of the birth canal, the relationship between the pubic tubercle and the distance between the ischial spines could be assigned to childbirth. Thereby, greater dimensions of the ischial spine distance would reduce the risk of obstructed labor and enable an easier birth and resulting in less straining of the pubic tubercle.

Finally, the statistical analyses revealed a negative relationship between sulcus width and pubic length in the female sample, which signifies a partial rejection of Hypothesis 3. This result was not reported in the literature. The finding of the present study suggests that women with longer pubic bones tended to have narrower sulci and vice versa. It implies that larger dimensions of the pubic bone reduces the strain acting on the sacroiliac joint and, consequently, also the preauricular sulcus. This relationship could be assigned to childbirth as well. Longer pubic bones technically accompany by larger dimensions of the pelvic canal which, in turn, enables an easier birth and reduce the risk of obstructed labor. This, again, would result in less strain acting on the preauricular sulcus during childbirth and hence, to less developed and narrower sulci.

4.4. Body mass estimates

4.4.1. Sex

The statistical analysis revealed a significant difference in the body mass between the male and female sample, whereby men tended to have a higher body mass than women. The result is not surprising and has been also reported in the literature (Kiefer et al., 2000; Greil, 2006). This sex difference in body weight is triggered by the action of sex steroid hormones. Men have a greater total lean mass, mineral mass, and lower fat mass, resulting on average in a generally greater body mass than women (Wells, 2007).

4.4.2. Age

The result of the statistical test showed significant differences regarding the body weight between the age groups, namely between young and very old adults, middle-aged and old adults and middle-aged and very old adults. The eldest age group tended to have the smallest body mass, followed by old adults, whereas middle-aged adults had the largest body mass, followed by the youngest age group (c.f. Table 3.39). This weight reduction in the two older age groups can be attributed to the increase of fat mass and the decrease of muscle mass that is occurring with advancing age (St-Onge and Gallagher, 2010).

4.5. Relationship between pelvic scars and body mass

4.5.1. Differences between the sexes

The statistical analysis showed no significant relationship between body mass and any of the scar features in the male sample. In the female sample, body mass correlated negatively with the tubercle height, the sulcus length and sulcus width. The result indicates that a higher body mass in women is associated with less severe developed pubic tubercles and preauricular sulci. This implies that a greater body weight reduces the strain acting on the pubic tubercle and the preauricular sulcus, which signifies a rejection of Hypothesis 4. This finding has not been reported in the literature before and is not concordant with the study by Holt (1978). A possible explanation for the discrepancy between the result of the present study and the study by Holt (1978) may be due to estimating errors in the reconstruction of the body mass.

4.5.2. Differences between the age groups

There was no significant relationship between body mass and any of the pelvic scars in middle-aged and very old adults, which signifies partial rejection of Hypothesis 4. Regarding the youngest age group, body mass correlated positively with pit length, which signifies a partial support of Hypothesis 4. The result implies, that greater body weight in young adults is associated with longer dorsal pubic pits and vice versa. This indicates that the straining on the dorsal pubic surface is greater in individuals with a larger body mass. A similar finding was reported by Snodgrass and Galloway (2003), however, they found a significant relationship between the BMI and dorsal pubic pitting in women over 50 years. Nevertheless, it does not appear counterintuitive that a greater body mass increases the strain acting on the dorsal pubic surface and resulting, in turn, to larger dorsal pubic pits.

In middle-aged adults, body mass was negatively correlated with sulcus length and sulcus width, which signifies a rejection of Hypothesis 4. The result indicates that greater body weight in middle-aged adults decreases the straining on the preauricular sulcus. This negative relationship seems unreasonable and is not concordant with previous studies by Holt (1978) and Snodgrass and Galloway (2003) and may be a result of errors in the reconstruction of the body mass.

4.5.3. Summary

The body mass correlated negatively with the pelvic scars, namely with the tubercle height, sulcus length, and width in the female sample and the old adult age group. This finding signifies a rejection of Hypothesis 4. It appears quite counterintuitive that larger body weights decrease the straining on the pelvis and thus, also on the scar features. This outcome is probably attributable to false estimates of the body mass reconstruction.

The only positive association was found between body mass and pit length in the youngest age group, which signifies partial support of Hypothesis 4. A similar result by Snodgrass and Galloway (2003) confirms this finding, even though their study found the relationship in women over 50 years. Nevertheless, it does not seem counterintuitive that a larger body mass enhances the straining on the pelvic bones, including the dorsal pubic surface and hence, resulting in larger pubic pits.

4.6. Limitations in the present study

The greatest limitation in the present study most probably represents the lack of information regarding the parity history of women. Without this information, the true relationship between pregnancy and childbirth and the formation and manifestation of the pelvic scars could not be tested. Therefore, it was only possible to study the sexual dimorphism of the bony imprints. Someone might assume that there is a high likelihood that all women got pregnant and gave birth in former times. Nevertheless, one can never be sure about this circumstance. Another uncertainty represents the age at which females got pregnant for the first time. The general lack of knowledge related to parturition and delivery in this study made it difficult to study the true relationship regarding pelvic scarring.

Another limitation represents the examination of the effect of body mass on scar formation. The delicate reconstruction of body mass from skeletal traits is popular among anthropologies, however, the different methodologies in estimating the body mass lead to varying outcomes (Myszka et al., 2012). Even though in the present study the method for the body mass estimation was chosen very carefully, one cannot be sure that the estimate matches the true body weight. Thus, estimates of the body mass derived from skeletal individuals and further tests with those estimates need to be considered with caution.

Finally, examinations of the effect of age at death on skeletal material are associated with problems as the age of the individuals can only be estimated. Especially the age estimation of adult individuals is problematic (Milner and Boldsen, 2012). In the present study, errors in age estimation may have led to some significant correlations that are not truly significant or vice versa. To bypass this problem broader age ranges than originally in the collection catalog listed were used. Despite the broader age ranges the sample sizes within the age groups were still rather small.

Chapter 5: Conclusion

The present study examined the manifestation and frequency of the so-called "scars of parturition", namely the dorsal pubic pits, the pubic tubercle and preauricular sulcus in relationship with sex, age at death, pelvic dimensions and body mass estimates. Pelvic scarring was present in both sexes, however, the degree and frequency were greater in women than in men. This result suggests that pregnancy and childbirth cannot be the primary factors causing pelvic scar formation. The occurrence of the pelvic imprints in both sexes might have been caused by the weight-bearing function of the bony pelvis. Pelvic architecture might have contributed to the formation and manifestation as well, resulting in more developed scars in females due to their more flexible pelvic girdle. With advancing age, the incidence and manifestation of pelvic scarring either increased or remained unchanged, which implies that pregnancy and childbirth cannot be the primary cause since it is expected that the pelvic scars recede over the course of time after the last child was born.

The anterior upper spinal breadth and the pubic bone length were the only two pelvic dimensions that were positively associated with pelvic scarring. Since the anterior upper spinal breadth is part of the false pelvis and, therefore, not relevant in obstetrics, its relationship with the tubercle height is probably not affected by childbirth but perhaps rather by biomechanics or the stability of the pelvic girdle. In the case of the pubic bone, the general anatomy might represent the reason for the relationship with the diameter of the pubic tubercle, whereby longer pubic bones accompany by thicker tubercles.

There was no relationship found between the body mass and the pelvic scars in the male sample. However, in the female sample, the body mass was unexpectedly negatively correlated with the tubercle height, the sulcus length and sulcus width. Also, in middle-aged adults, the body mass was negatively associated with pelvic scarring, more precisely the sulcus length and sulcus width. These outcomes are most probably caused by estimating errors in the reconstruction of the body mass. Lastly, there was only one positive relationship between the body mass and the pelvic scars, namely the pubic pit length. This association was found in the youngest age group and indicates that greater body weight increases the strain acting on the dorsal pubic surface and resulting in larger pubic pits.

The present study showed that pregnancy and childbirth were not the primary factors causing the pelvic scars. Still, both might have some little effects on the degree of scarring. Nevertheless, this result suggests that the name "scars of parturition" should not be used any longer to bypass misconceptions. Also, the pelvic dimensions and the body mass did not affect the development of scarring substantially. It is more likely that pelvic architecture and the weight-bearing function of the pelvis are primarily responsible for the formation and manifestation of the pelvic imprints. Prospective studies might be able to examine these factors with samples with known parity history to test their true relationship with the pelvic scars. An examination of skeletal collections with known body mass also might be interesting in order to explore if pelvic scarring and body weight are truly associated.

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Appendix A: Zusammenfassung

Die Theorie hinter der Entstehung und Manifestierung der sogenannten „Scars of Parturition“ und ihre Verwendbarkeit um die Anzahl der Geburten einer Frau zu bestimmen, ist immer noch ein viel diskutiertes Thema unter AnthropologInnen. Aufgrund inkonsistenter Ergebnisse bisheriger Studien konnte der wahre Zusammenhang zwischen den Beckenmerkmalen, die als Indikatoren für Schwangerschaft und Geburt gelten, und Gravidität und Partus noch nicht gezeigt werden. Skelettsammlungen mit bekannter Geburtsgeschichte der weiblichen Individuen sind rar. Deshalb ist eine Untersuchung anderer potentieller Faktoren, welche die Entstehung und Manifestierung der Beckenmerkmale beeinflussen könnten, die beste Herangehensweise um diese spezifischen Merkmale zu analysieren.

Das Ziel dieser Studie war es, die Morphologie und die Häufigkeit der Beckenmerkmale, nämlich die dorsalen Schamgruben, das Tuberculum pubicum und der Sulcus praeauricularis, an einer Skelettsammlung der Universität Vilnius von 300 Individuen (170 Männer und 130 Frauen) zu untersuchen. Zudem wurde nach standardisierten Methoden Beckendimensionen gemessen und das Körpergewicht ermittelt. Die Beckenmerkmale, die Beckendimensionen und das Körpergewicht wurden entsprechend dem Geschlecht und dem Alter der Individuen verglichen. Weiters wurde der Zusammenhang zwischen den Beckenmerkmalen und den Beckendimensionen, sowie dem Körpergewicht untersucht.

Die statistische Analyse zeigte, dass die Beckenmerkmale sowohl bei Frauen, als auch Männern vorkommen. Der Ausprägungsgrad und das Vorkommen waren jedoch stärker im weiblichen Geschlecht anzutreffen. Die Merkmale wurden in allen Altersgruppen gefunden, allerdings erhöhte sich bzw. blieb die Häufigkeit und die Manifestierung konstant bei steigendem Alter. Die Korrelation zwischen den Beckenmerkmalen und den Beckendimensionen zeigte einen signifikant positiven Zusammenhang, sowohl zwischen der Pubislänge und dem Durchmesser des Tuberculum pubicums, als auch zwischen der Distantia interspinosa und der Tuberculumhöhe bei den Frauen. Weiters wurde ein signifikant negativer Zusammenhang zwischen dem Abstand der Spinae ischiadicae und der Extension des Tuberculum pubicums, sowie zwischen der Pubislänge und der Breite des Sulcus praeauricularis im weiblichen Geschlecht gefunden. Das Körpergewicht korrelierte negativ mit der Höhe des Tuberculums und der Sulcuslänge und Sulcusbreite bei Frauen. In der jüngsten Altersgruppe zeigte sich ein positiver Zusammenhang zwischen dem Körpergewicht und der Länge der Schamgruben, während bei den mittleren Adulten das Körpergewicht negativ mit der Sulcuslänge und Sulcusbreite korrelierte.

Die Ergebnisse legen nahe, dass Schwangerschaft und Geburt nicht primär für die Entstehung der spezifischen Beckenmerkmale verantwortlich sind. Das Körpergewicht beeinflusste ihre Formation ebenfalls nicht wesentlich. Stattdessen könnte die Architektur und die gewichtstragende Funktion des knöchernen Beckens in erster Linie zur Entstehung und Manifestierung der Beckenmerkmale beigetragen haben. Der flexible Beckengürtel bei Frauen führt zu einer erhöhten Bewegungsfreiheit. Dadurch werden die Ligamente des Beckens stärker belastet und somit führt dies zur Entstehung dieser spezifischen Beckenmerkmale.

Appendix B: Data collection form

General information

Accession number: ______________ Sex: ______________

Collection: ______________ Grave number: _____________ Age at death: _____________

Femur

	Left	*Right*
Head diameter:	___________	___________

Dorsal pubic pitting

Left

O absent O faintly perceptible
O present O prominent

O single pits: number _____ O groove

Right

O absent O faintly perceptible
O present O prominent

O single pits: number _____ O groove

	Left	*Right*
Length:	___________	___________
Width:	___________	___________

Pubic tubercle

	Left	*Right*
Height:	___________	___________
Diameter:	___________	___________
Orientation:	O cranial O ventral	O cranial O ventral

Preauricular sulcus

	Left	*Right*
Length:	________	________
Width:	________	________

Left

O broad-shallow O narrow-shallow
O defined O complex

O Grade 1 O Grade 2
O Grade 3 O Grade 4

O pitted O smooth

Right

O broad-shallow O narrow-shallow
O defined O complex

O Grade 1 O Grade 2
O Grade 3 O Grade 4

O pitted O smooth

Articulated measurements

Intercristal distance:	____________
Transverse diameter of the pelvic inlet:	____________
Transverse diameter of the pelvic outlet:	____________
Distance between ischial spines:	____________
Right oblique diameter:	____________
Left oblique diameter:	____________
Right anteroposterior diameter of the inlet:	____________
Left anteroposterior diameter of the inlet:	____________
Right anatomic conjugate:	____________
Left anatomic conjugate:	____________
Anterior upper spinal breadth:	____________
Inter-obturatum breadth:	____________

	Left	*Right*
Pubic length:	________	________
Pubic symphysis length:	________	________