The influence of skeletal size on age-related criteria from the pelvic joints in Portuguese and North American samples

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ABSTRACT

Estimating age of death for adult skeletons with accuracy is still one of the chief predicaments in bioanthropology. It has been recognized that methods' inaccurate results from the lack of a better understanding of the ageing process and associated confounding factors. In the present study was investigated if body size (measured by stature, body mass, robusticity and articulation size) affects age-related morphological criteria of the pubic symphysis, auricular surface of the iliac and acetabulum. Adult individuals of both sexes with age at death superior to 17 years old were analysed from the Identified Skeletal Collection from the University of Coimbra (Portugal), and the William Bass Donated Skeletal Collection (USA). Three levels of analysis were followed to evaluate joints degeneration: individual traits, components (weighted linear clustering of correlated traits) and a composite score (sum of all the scores across all characters). Furthermore, stature, body mass and robusticity were computed through femoral measurements, and the surface area of the pelvic joints were calculated from three-dimensional digital polygon objects created with a white light scanner. A logistic regression analysis was carried out, showing especially body mass, stature and joint surface area affect some of the morphological criteria at the pelvic joints. Robusticity has a minimum effect on the pelvic joints metamorphosis. Results suggest that smaller individuals tend to age slower, with the transition from a "younger" to an "older" stage occurring at an older age compared with bigger individuals. Different patterns were obtained between population samples, possibly due to body size and age distributions differences between collections, or due to the complex and variable effect body size has in bone degeneration. The present research shows that body size influences the pelvic joints age-related criteria, which is important to incorporate in future age at death estimation methods.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 4

Chapter 5

LIST OF TABLES

Chapter 2

Chapter 4

Chapter 5

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CHAPTER 1

INTRODUCTION

Accurate[1] estimation of chronological age at death for adult skeletons is still one of the main problems in bioanthropology. Such age estimation is performed by observing the biological changes that occur in the skeleton with advancing age, such as the pelvic joints metamorphosis (degenerative changes to the morphology of specific traits). Macroscopic analyses of the metamorphosis of pelvic joints are the most frequently employed age estimation methods due to their easy and direct application. Additionally, the pelvic joints tend to preserve better than the sternal end of the ribs in archaeological and forensic contexts. However, ageing estimation methods which analyse the pelvic joints metamorphosis tend to be associated with high inaccuracy and bias[2]. The testing of the ageing estimation methodologies has shown a bias in overageing the younger adults. Furthermore, underageing of older individuals has also been reported, which lead to the incorrect assumption that past populations died at a younger age and so providing an incorrect mortality profile (Bocquet-Appel and Masset 1982). A great emphasis has been placed on the methodological component to improve the accuracy and precision[3] in ageing estimation. Researchers have focused on the re-arrangement of traits scores, on the number of phases and even on the statistical tests employed. Nevertheless, the revised methodologies do not seem to improve substantially age estimation accuracy, even with the application of Bayesian inference. The application of

[1] Accuracy refers to the closeness of the observed value to the actual value (Jamison and Zegura 1974; Yezerinac *et al.* 1992; Ferrante and Cameriere 2009). For age estimation methods, accuracy is measured in terms of how close the estimated value is to the true chronological age. The further the estimated age is from the chronological age the higher is the estimation error (inaccuracy). The error magnitude of an ageing method is measured by: Inaccuracy = Σ|(estimated age-chronological age)|/number of individuals (Saunders *et al.* 1992).

[2] Bias also provides information about the age estimation accuracy of a method. While the inaccuracy formula provides information about the average magnitude of the age estimation error (reporting how far the estimated age is from the chronological age), the bias reports what the error direction is. That is, it tells if a systematic over- or underage estimation to the chronological age exists. Bias is measured by: Σ(estimated age-chronological age)/number of individuals (Saunders *et al.* 1992).

[3] The success of an ageing estimation method is not only measured through the accuracy but also according to precision. However, statistically accuracy and precision reports to two distinct concepts (Yezerinac *et al.* 1992; Ferrante and Cameriere 2009). Precision measures the similarity of the recorded data for the same criteria by two different observers (inter-observer error), or at various moments by the same researcher (intra-observer error) (Yezerinac *et al.* 1992; Walter and Moore 2005; Ferrante and Cameriere 2009). Thus, it does not measure if the observed data is close to its actual value as accuracy does. For a detailed definition of accuracy, see footnote 1 and 2 at Chapter 1.

Bayesian inference has contributed to an improvement in age estimation (*e.g.*, removing some of the bias), but there are still shortcomings (Miller and Boldsen 2012). Much emphasis has been placed on improving the statistical and methodological components in the field of age estimation without satisfactory results when the lack of a full understanding of skeletal ageing is possibly the leading cause of the methods inaccuracy and bias.

Testing of different ageing estimation methods on several identified skeletal collections, from different periods of time and geographic origins, has shown a lack of uniformity among different populations in patterns and rates of skeletal ageing. Suggesting that not every individual or population age at the same rate and this contributes to the methods' inaccuracy (Hoppa 2000). It has been suggested that genetic and environmental factors account for the intra- and interpopulation ageing rate variability, but such a vague statement indicates a lack of understanding about the ageing process. Currently, little is known about which, and to what extent, confounding factors affect skeletal ageing in adult individuals. This fact has not prevented researchers from speculating on which factors affect ageing at the joints, but without systematically supporting their assertions (*e.g.*, Ferembach *et al.* 1980; Angel 1984; Meindl *et al.* 1985; Katz and Suchey 1989; Santos 1995; Scheuer 2002; Falys *et al.* 2006; Anderson *et al.* 2010; Buk *et al.* 2012; Rissech *et al.* 2012). However, research has started to emerge that aims to understand which factors affect age-related metamorphosis at the post-cranial joints. Recent research has tested potential confounding factors that may influence the ageing process at joints, including parturition (Hoppa 2000), occupation and physical activity (Campanacho *et al.* 2012; Mays 2012; Miranker 2015), body size (Merritt 2014a, 2015; Wescott and Drew 2015), substance abuse (Taylor 2000; Hartnett 2007; Passalacqua 2014), and diseases (Mays 2012). These studies represent an important step towards increasing our knowledge and understanding about skeletal ageing. Some of these studies were performed using small sized samples, which may not be representative of the full range of population variability, thus implying the need to perform this type of research with larger samples. There is also a lack of comprehensive biographic information about each specimen from the skeletal reference collections.

A major critique of this kind of research is the employment of an indirect and non-extensive methodological approach. Too much weight is placed on testing if a determined factor affects the accuracy and precision of the age estimation methods, which does not measure the real effect the factor has on the joints metamorphosis.

Therefore, such an approach does not provide detailed information by trait. If the ageing traits of the iliac auricular surface show some level of degenerative independence (Buckberry and Chamberlain 2002), it is possibly caused by the effect of different confounding factors on each trait. Even though it is important to determine the overall impact that each factor has on joint degeneration, these factors may represent a skewed vision, especially if the effect by trait is unknown. Therefore, the extensive effect that confounding factors have on skeletal ageing, including for the pelvic joints, remains poorly understood.

It has been suggested that body size influences degeneration of the pelvic joints (Merritt 2014a, 2015; Westcott and Drew 2015). The main goal of these studies was to evaluate age estimation methods in association with body size (stature and body mass) in North American samples. Merritt (2014a) found that taller and heavier individuals tended to be overaged, while shorter and lighter individuals were underaged. Wescott and Drew (2015) obtained similar results, finding that obese specimens (BMI $\geq$ 30) were overaged and presented a higher inaccuracy compared with individuals of normal BMI (18.5 – 24.9). However, for Wescott and Drew (2015) the differences among groups were only significant when using the Buckberry and Chamberlain (2002) method, and not when using the Suchey and Brooks system. The analysis was performed using five features (*i.e.* transverse organization, surface texture, apical changes and micro- and macroporosity following the descriptions in Buckberry and Chamberlain (2002). Merritt (2015) found a significant difference in recorded scores among the different body size groups for the auricular surface features. Additionally, Wescott and Drew (2015) found a lower correlation between the auricular surface features and age at death for obese individuals. However, it is unknown what effect body size has separately for each of the surface texture traits (*i.e.* fine and coarse granularity and dense bone), since the analysis was performed by clustering the distinct traits together. Furthermore, it remains unclear which specific traits are involved, particularly in the pubic symphysis and the acetabulum. It is also unknown if other body size variables (*e.g.*, joint surface area) have an effect in different skeletal collections. Thus, the present research tested the influence that four body size variables (measured as stature, body mass, robusticity and joint surface area) have on the degeneration of age-related criteria of the pubic symphysis, iliac auricular surface and acetabulum. Additionally, the present study includes two more body size variables not investigated by Merritt (2014a, 2015), and Wescott and Drew (2015). Robusticity

has been shown to affect the ligamentous outgrowth of the ventral bevelling at the pubic symphysis in Portuguese males (Campanacho *et al.* 2012). However, it is unknown if robusticity has an effect in female individuals, or if it has a similar effect in non-Portuguese samples. Regarding joint surface area, Meindl *et al.* (1985: 40) have stated that larger and more robust pubis bone seems to age slower. However, a proper statistical analysis has not been performed to confirm such an assertion. Two distinct study samples have been used in the present study: the Identified Skeletal Collection from the University of Coimbra (Portugal), and the William Bass Donated Skeletal Collection, University of Tennessee (USA). These two large reference samples were selected because some of their biographical data are known, such as age at death and sex, which are of paramount importance for the present research. The individuals of both collections are derived from different periods, with different life histories, which may consequently affect their body size proportions. For example, it has been suggested that the socio-economic environment in which the individual grows up (Macho 1991) may affect stature. Therefore, it is expected for 20th and 21st century Americans to present different size proportions from the late 19th and earlier 20th century Portuguese. This allows testing whether possible significant size differences among different populations may have a different impact on pelvic joints age-related degenerative changes, which has not been tested previously.

1.1. THE RESEARCH AIM AND OBJECTIVES

The present study intends to achieve a better understanding of the influence that confounding factors may have on bone degeneration at the acetabulum, iliac auricular surface and pubic symphysis. It aims to determine if body size (measured as stature, body mass, robusticity and joint surface area) affects age-related criteria from the pubic symphysis, iliac auricular surface and acetabulum in two skeletal reference collections with individuals of both sexes. It is hypothesised that individuals of bigger body dimensions will age faster than smaller individuals do, with the exception of the joint surface area. The inverse is hypothesised for the joint surface areas analysis: with a faster ageing rate for individuals with smaller joint surface areas. A higher stress loading on the pelvic joints may occur in individuals with bigger body dimensions, which can consequently result in an accelerated

ageing. On the contrary, a faster ageing rate may occur in individuals with smaller joint surface areas possibly caused by the concentration of biomechanical loading in a reduced area. In summary, these are the main objectives of this thesis:

1) Determine if body size variables affect age-related criteria following a three-level analysis (each trait, clusters of correlated traits and composite score of all traits) in the pelvic joints;
2) Investigate if body size influence is uniform across traits within a pelvic joint and among the Portuguese and North American samples;
3) Examine the level of association between the degenerative bone criteria and age at death for both samples;
4) Determine possible dimorphic degenerative differences among sexes in each sample.

1.2. STRUCTURE OF THE DISSERTATION

The dissertation is organised into seven chapters. In the Introductory chapter, the research question is addressed as well as the reason for undertaking this research. Chapter 2 provides a background to the history of age estimation by describing the macroscopic alterations at the pelvic joints alongside the relevant anatomical information. Chapter 3 discusses the limitations and problems existing in the ageing estimation of adults in human osteology. It focuses especially on the current research performed about the confounding factors affecting skeletal ageing. Chapter 4 presents the materials and methods used in the study and comprises two sections. The first part of the chapter presents the description and comparison of the identified skeletal material observed, while the second part presents the empirical research design and methodology applied and describes the skeletal analysis performed on the pelvic joints and the femur. The empirical and statistical approach employed to determine the effect of body size is presented in detail, as well as the variables age at death and sex. Chapter 5 summarises the results obtained from the empirical and statistical analysis performed, while in Chapter 6 the results are discussed and how they contribute to a better understanding of the degenerative skeletal ageing at the pelvic joints and its importance in human osteology. Chapter 7 concludes the significant findings and its implications in the ageing estimation field, with some future research recommendations.

CHAPTER 2
PELVIC JOINTS METAMORPHOSIS AGE ESTIMATION METHODS: A HISTORY

2.1. SKELETON AGING

Harper and Crews (2000) and Crews (2003) distinguished *ageing* as becoming old and the display of ageing features while *senescence* is the physiological process/mechanism of becoming old. Age is common to all animate and inanimate entities, but senescence only occurs in living organisms (Harper and Crews 2000). Contradictory opinions whether aging is one basic process or various interdependent processes (Carrington 2005), have led to the formulation of different ageing theories. These theories can be divided into two types: cellular and physiological (Moody 1998; Harper and Crews 2000; Kart and Metress 2001; Crews 2003; Carrigton 2005).

Bone is a dynamic and living tissue, which undergoes renewal, repair and remodelling, and therefore reflects modifications with age - just like soft tissue - allowing age at death to be estimated. A wide range of methods exists and continues to be formulated in bioanthropology. To estimate age at death comprises one of the fundamental aspects to be determined through the analysis of skeletal remains in paleodemography and forensic sciences. The study of archaeological human osteological material, including age at death estimation, allows the construction of demographic profiles of past communities including a mortality profile. Demographic profiles provide an understanding of the living conditions and relationships of past populations without written records. In paleodemography, the major focus is at the population level, while in forensic anthropology the main focus is usually at the individual level, even at mass grave circumstances. In a legal context, it is fundamental to establish the identity of single individuals from their skeletal remains by estimating, for example, age, sex, ancestry and stature.

For sub-adults, age estimation is made by evaluating bone growth and maturation, and tooth calcification and eruption. For adult individuals the age estimation methodologies analyse mostly degenerative/reparative changes after bone and dental maturation. Age estimation methodologies applied in mature skeletons are based on the following categories:

- Epiphysis fusion in young adults (Scheuer and Black 2000)
- Metamorphosis in articulations with limited movement or without movement (Cox 2000)
- Bone microstructure (Stout 1989; Stout and Paine 1992)
- Long bones spongiosa structure (Bergot and Bocquet 1976; Sorg *et al.* 1989)
- Tooth modifications due to age (Lipsinic *et al*. 1986; Drusini *et al.* 1997; Gilmore and Grote 2012)
- Biochemical changes in organic and mineral components of teeth and bone (Zapico and Ubelaker 2013)
- Ossification of hyaline cartilage (Loth and Íşcan 1989)

For adults, the most commonly applied methods for age estimation employ macroscopic analysis, especially through the examination of the metamorphosis of joints, such as the pelvic articulations (pubic symphysis, iliac auricular surface and acetabulum). These methods were established by recording the degenerative modifications in the joints of skeletons of known-age from reference collections and autopsy cadavers. Since the first established method, by analysing the pubic symphysis metamorphosis (Todd 1920), new methods and more complex analyses have emerged.

The present chapter introduces a review of the established methods used to analyse the metamorphosis of the pubic symphysis, iliac auricular surface and acetabulum. A brief description of the anatomical and physiological features of the pelvic joints will be provided.

2.2. PUBIC SYMPHYSIS

2.2.1. Physiology

The pubis comprises one of the three components of the *os coxa* bone, occupying an anterior position compared with the ilium and the ischium (Gray 1973; Pina 1995). The pubis comprises the pubic body, the superior and inferior ramus, and a medial articular face, the pubic symphysis (Gray 1973). The pubic bone articulates with the ischium via the inferior pubic ramus, and superiorly connects with the ilium by the

superior pubic ramus (Scheuer and Black 2000). The pubic symphysis, between the opposing pubic bones has an elliptical form elongated along the sagittal plane, and is a secondary cartilaginous joint. The stability of the articulation between the two pubic bones is maintained mostly by the inferior pubic ligament (or arcuate ligament) (Gamble *et al.* 1986). However, other ligaments (superior, anterior and posterior pubic ligaments) also contribute to neutralize shear and tensile stresses (Gamble *et al.* 1986). To the pubis is also attached the muscles rectus abdominis, gracilis, pyramidalis, adductors brevis and longus, and internal and external obturactor (Gamble *et al.* 1986).

2.2.2. Cartilage and the pubic fibrocartilaginous disc

The pubic symphysis is covered by thin layers of hyaline cartilage of between 1 to 3mm in thickness (Spalteholz 1972). In between the pubic articular surfaces is located a fibrocartilaginous disc (*discus interpubicus*) (Gray 1973). This disc is longer supero-inferiorly and narrow anterio-posteriorly, and sometimes can extend beyond the pubic symphysis faces (Becker *et al.* 2010). The disc presents layers of interiorly thicker fibres disposed obliquely, and exhibits size differences between the sexes, being shorter and wider in women (Alicioglu *et al.* 2008; Becker *et al.* 2010). Its composition allows resistance to tensional and compressive forces on the pubic symphysis and structurally the pubic fibrocartilaginous disc is similar to the intervertebral discs (Becker *et al.* 2010). Like the intervertebral discs, it loses flexibility and suffers an anterior and posterior narrowing with advancing age (Alicioglu *et al.* 2008). The disc may display a cavity - the interpubic cleft - on the anterior and the posterior area. The interpubic cleft is narrow with an oval outline occupying one-third to a half of the disc area (Becker *et al.* 2010), and is deeper in women than in men (Spalteholz 1972). Multiparous women may exhibit more than one irregular cleft (Becker *et al.* 2010).

2.2.3. Pubic symphysis function and mobility

The pubic symphysis provides stability to the pelvis, by neutralizing the tension, torsion, compression and shear forces, presenting a limited degree of movement (Alicioglu *et al.* 2008). In females, the mobility of the pubic symphysis tends to increase during the later stages of pregnancy caused by the effect of a hormone

(relaxin), resulting in an increase of an average between 6.5 mm to 7.1 mm between the faces (Alicioglu *et al*. 2008; Becker *et al*. 2010). The primary physiological movements in this area are of two types: the anterior-posterior rotation of the pubic rami during locomotion, and superior-inferior shear while lifting one leg (Li *et al.* 2007).

2.2.4. Bone modifications with age in the pubic symphysis bone

In adults, the pubic symphysis undergoes morphological alterations with age, which can be clustered into epiphyseal changes and bone degeneration modifications. Todd (1920, 1921a) first reported a complete investigation of the pubic symphysis metamorphosis, which led to the creation of an age at death estimation method for both sexes. With advancing age, the surface morphology of the pubic symphysis undergoes changes and these age-related alterations can be summarized as follows: in young adults, the surface presents a pronounced billowing system with transverse ridges and furrows. Due to bone deposition, billowing starts to flatten out until it disappears. With age, the surface face can then become depressed, and afterward can even suffer deterioration with the presence of erosion in older individuals. Additionally, with bone deposition at the margin of the surface gradually develops, forming the symphyseal rim usually with an oval shape. The upper and inferior extremities are the first to form, followed by the dorsal plateau and lastly by the ventral rampart. Todd (1923) considered the ventral rampart to be a retrogressive epiphyseal formation since it can build up as a distinct element separated from the face before fusing with the surface face. With the development of the upper extremity, the pubic tubercle becomes separated from the surface face. Furthermore, a ventral bevelling emerges in younger adults, which with age can undergo bone ossification at the ligamentous insertions. In older individuals, the pubic symphysis tends to undergo deterioration over time, becoming more irregular, with erosion, and even lipping on the dorsal plateau can occur. Appendix 1 provides detailed descriptions of the pubic symphysis morphological traits accompanied by illustrations.

2.2.5. Age at death estimation methods

The morphological changes of the pubic symphysis were first recorded by Bonn in 1777, and by Aeby in 1858 (cited in Todd 1920; Santos 1995). However, neither of

them studied the association between the metamorphosis of traits and age. The first researcher to make a link between the pubic symphysis metamorphosis and age was Henle (1872; cited in Todd 1920). However, the first age at death estimation method was only established at the beginning of the 20th century by Todd (1920).

Todd (1920) systematically studied the alteration of the degenerative characteristics of the pubic symphysis with age in 306 white male individuals aged over 18 years from the Hamann-Todd collection. His analysis produced an age at death estimation system with ten successive phases comprising narrow age ranges. Todd (1920) considered that the pubic symphysis provided a reliable age indicator due to the constant rate of morphological changes in individuals between 20 to 40 years; however, he did not provide a numerical assessment of the accuracy of the method. In the following year, Todd (1921a) extended the analysis to include black male individuals and black and white female individuals from the Hamann-Todd collection. The accuracy of this method was assessed in subsequent studies (*e.g.*, Brooks 1955; Meindl *et al.* 1985). Brooks (1955) reported only 54% of the individuals were correctly aged, with age overestimation mainly for the third and fourth decades of life. In turn, Meindl *et al.* (1985) stated an age underestimation for older individuals for Hamann-Todd collection specimens. Thereafter, new methods of age at death estimation based on the changes of the pubic symphysis emerged, such as the Suchey-Brooks method (S-B system), which in turn have also been tested. The established macroscopic age at death estimation methods and respective assessments for the pubic symphysis are presented in Table 2.1. In spite of the unreliability of Todd's method, the degenerative characteristics of the pubic symphysis described by him are still being used but with different scoring systems. Even though new age estimations have emerged after the S-B system was created, this is currently the most widely used method for skeletal remains in paleodemography and forensic fields (Hens *et al.* 2008; Wärmländer and Sholts 2011; Garvin and Passalacqua 2012). Possible reasons why the S-B system is so widely used may be associated with:

1) Easier application than other methods with a Bayesian inference
2) Clear description of the traits
3) Existence of pubic symphysis casts aiding the analysis
4) Provision of wider age ranges, in contrast to Todd's method

5) Inclusion of age ranges past 50 years old, which is not provided by Todd's method

However, Wärmländer and Sholts (2011) reported a lack of rigorous and uniform application of the S-B method and, therefore, presented a detailed and structured guideline to use when applying this method.

2.3. ILIAC AURICULAR SURFACE

2.3.1. Physiology

The iliac auricular surface occupies a posterior position compared to the pubic symphysis, and each of the auricular surfaces articulates with the corresponding sacral surfaces at the sacroiliac joint (Pina 1995). The sacroiliac joints are kept in position due to the anterior and posterior sacroiliac, interosseous and iliolumbar ligaments, as well as the joint capsule (Spalteholz 1972; Pina 1995). The auricular surface exhibits an inverted "L" shape, although its shape shows inter-individual variability (Schunke 1938; Walker 1992) and sex differences (İşcan *et al.* 1983; Ali and McLaughlin 1991). The auricular surface is divided into two areas: the superior and inferior demifaces (Lovejoy *et al.* 1985b). The superior demiface is shorter, directed dorsocranially and occupies the superior area above the apex. The inferior demiface occupies the area inferior to the apex, and it is longer and directed dorsocaudal (Scheuer and Black 2000; Dufour 2003). The sacroiliac joint is sometimes referred as a diarthrodial joint (Schunke 1938; Kampen and Tillmann 1998), and others prefer to use the term amphiarthrosis to define it (Pina 1995; Kampen and Tillmann 1998), while others use a mixture of diarthrodial and amphiarthrosis joints (Walker 1992; Dufour 2003).

2.3.2. Joint capsule and cartilage

The sacroiliac joints are covered by cartilage and surrounded by a joint capsule (Kampen and Tillmann 1998). The joint capsule inserts onto the outer rim of the sacroiliac joint contour (Pina 1995). The sacroiliac joint is covered with two types of cartilage: a thicker layer of hyaline cartilage and a thinner layer of fibrocartilage (Pina 1995; Dufour 2003). Usually the sacral cartilage is thicker than the iliac cartilage in a ratio of 1.5:1 to 3:1 (Walker 1992). Due to the size differences between

Table 2.1. Macroscopic age estimation methods and assessments for the pubic symphysis metamorphosis.

Method	Description	Assessment studies	Assessment results
McKern and Stewart (1957)	349 USA male soldiers (17 to 30 years old) Three component system, with the sum of the stages for each component. The result corresponds to a mean age with a confidence interval and a standard deviation	Katz and Suchey (1986) Meindl *et al.* (1985) Brown (2010)	Less accurate than Todd's method Underage individuals Complex and of difficult application Inadequate sample truncated at 30 years
Gilbert and McKern (1973)	Three component system as McKern and Stewart (1957) for females (17 - 55 years)	Suchey (1979) Meindl *et al.* (1985) Klepinger *et al.* (1992)	Unreliable: high inter-observer error Inaccurate method
Hanihara and Suzuki (1978)	70 Japanese cadavers (F/M) - 18 to 38 years Multiple regression and quantification theory model I formulas according to 7 traits	Meindl *et al.* (1985) Santos (1995) Sinha and Gupta (1995)	Less accurate than anterior methods Inadequate sample truncated at 38 years Overages individuals younger than 30 years and underage specimens older than 31 years
Snow (1983)	Revised McKern and Stewart (1957) and Gilbert and McKern (1973) with linear regression models	Katz and Suchey (1986)	The revision did not improved the accuracy of the methods
Meindl *et al.* (1985)	N= 109 Hamann-Todd collection (M/F) Revision of Todd's method into 5 phases	Meindl *et al.* (1985)	More accurate than Todd's method
Suchey-Brooks (S-B) system Katz and Suchey (1986) Brooks and Suchey (1990)	1012 USA cadavers (F/M) Revision of Todd's method into 6 phases Provides mean age for each age range according to standard deviation and a 95% confidence interval Analysis aid: pubic symphysis casts (France Casting 1986)	Klepinger *et al.* (1992) Saunders *et al.* (1992) Santos (1995) Baccino *et al.* (1999) Schmitt (2004) Sakaue (2006) Matrille *et al.* (2007) Djurić *et al.* (2007) Hartnett (2007) Hens *et al.* (2008) Brown (2010) Fleischman (2011, 2013) Godde and Hens (2012) Rissech *et al.* (2012) Miranker (2015)	Accurate results for younger adults. Tends to overestimate younger individuals and underage older individuals. The only exception was obtained for Brown (2010), which reported the inverse bias trend. High percentage of individuals allocated into the correct phase, due to broad age ranges

Method	Description	Assessment studies	Assessment results
Hartnett (2007, 2010)	503 USA cadavers (F/M) Revision of S-B system into 7 phases Includes four more traits: bone mass and changes at the ventral and dorsal body at the pubic bone, and medial aspect of the *obturator foramen*	Merritt (2014b)	Lower inaccuracy and bias than the S-B system. Lower percentage of individuals assigned into the correct phase. Clearer descriptions than S-B system
Berg (2008)	Females: 104 from William Bass collection and 85 cadavers from genocides at former Yugoslavia Revision of S-B system into 7 phases Analyses presence of osteopenia and osteoporosis	———	———
Kimmerle *et al.* (2008)	209 males and females from Balkan populations Revised calibration for the S-B system with Bayesian statistical inference with a Gompertz-Makeham model	———	———
Chen *et al.* (2008)	262 Chinese Han males Scoring system of 9 traits with the use of regression equations	Fleischman (2011, 2013)	More accurate in ageing middle adults than S-B system. Overestimates age in older individuals. Subjective and complex scoring system
Chen *et al.* (2011)	338 Chinese Han females Similar scoring system as Chen *et al*. (2008) with the use of regression analysis equations	———	———

the joint cartilages, degeneration may occur earlier in the iliac cartilage (Kampen and Tillmann 1998).

2.3.3. Auricular surface function and mobility

The sacroiliac joints diminish the extent of forces due to abrupt movements of the lower limbs (Brooke 1924). This is achieved by the stability of the sacroiliac joint, which is provided by the ligaments, joint capsule and the surrounding muscles (Walker 1992). The contribution of the muscles is indirect from their fibre extensions onto the anterior and posterior sacroiliac ligaments (Walker 1992). The posterior interosseous ligament is considered one of the strongest ligament in the body, further contributing to the sacroiliac joint stability (Walker 1992).

There is little motion possible at the sacroiliac joints (Walker 1992; Zheng *et al*. 1997; Kampen and Tillmann 1998; Scheuer and Black 2000). However, the movements possible at the joint are translation, rotation and median-plane motion by flexion/extension (Walker 1992). The extent of motion at the sacroiliac joint is different between the sexes, with greater movement possible in females (Brooke 1924; Walker 1992). The range of motion in females can increase in late pregnancy and during parturition due to hormonal effect (Brooke 1924; Walker 1992; Scheuer and Black 2000). A reduced motion in males may be due to a higher strength of the ligaments (Brooke 1924). It has been suggested that the range of motion can diminish with advancing age, however, age effects on sacroiliac joint mobility are presently not well understood (Walker, 1992).

2.3.4. Bone modifications with age in the iliac auricular surface

The iliac auricular surface undergoes morphological alterations due to bone degeneration in adults over time. Lovejoy *et al.* (1985b) describe a younger appearance of the iliac auricular surface, as the presence of transverse organization (horizontally oriented billows and striae), finely granular surface, without porosity and lipping. Additionally, the apical area is smooth and regular without lipping, and the retroauricular area displays less “activity”, a term that refers to bone remodelling expressed as general surface irregularity, and the presence of osteophytes and porosity. With advancing age, billowing and striae disappear, and the articular face loses its transverse organisation, becoming amorphous in older individuals. The

auricular surface also suffers alterations in their texture, with the fine granularity being progressively substituted by coarse granularity, and then by dense bone. Microporosity can arise followed by the appearance of macroporosity in older specimens. With age, osteophytes may form along the articular margins, the apical area becomes irregular with osteophytic growth, and the retroauricular area exhibits more activity (remodelling). Appendix 1 provides detailed descriptions of the iliac auricular surface morphological traits accompanied by illustrations.

2.3.5. Age at death estimation methods

Sashin (1930) noted an increase in the proportion of fibrocartilage with age on the sacroiliac joint of 257 cadavers aged from birth to 60 years of age. Sashin's (1930) study is the first to mention an association between morphological changes with age at the sacroiliac joint. However, the first age at death estimation method based on the metamorphosis of the iliac auricular surface emerged only in 1985 with the work of Lovejoy and collaborators.

The age at death estimation method established by Lovejoy *et al.* (1985b) comprised a macroscopic evaluation of morphological characteristics of the iliac auricular surface into eight phases. The auricular surfaces analysed were from 764 individuals of three skeletal collections[4]. After careful testing, Lovejoy *et al.* (1985b) considered the method to be a reliable age at death estimation method for adults, and they emphasized that the degenerative alterations on the auricular surface were well defined, however, possibly less easy to interpret than the pubic symphysis characteristics. Another advantage claimed was that auricular surface morphological changes progress at a steady rate. A third advantage was the continuous degenerative alterations that occurred after the individual reached the age of fifty years (Lovejoy *et al.* 1985b). A further advantage is that the auricular surface usually preserves better than the pubic symphysis.

The method of Lovejoy *et al.* (1985b) has been widely tested by other investigators on diverse skeletal populations from Europe (Santos 1995; Hens *et al.* 2008; Rissech *et al.* 2012), North America (Bedford *et al.* 1989; Murray and Murray 1991; Saunders e*t al.* 1992; Osborne *et al.* 2004; Martrille *et al.* 2007), and Asia (Schmitt 2004). Contrary to Bedford *et al*.'s (1989) affirmation of the reliability of

[4] Lovejoy and colleagues analysed the Hamman-Todd collection (n = 500), the Libben collection (n = 250), and the forensic specimens identified in Cuyahoga County Coroner's Office in Ohio, U.S. (n = 14).

the Lovejoy *et al.* (1985b) method, subsequent studies have highlighted inaccuracy (Murray and Murray 1991; Santos 1995; Osborne *et al.* 2004; Schmitt 2004; Martrille *et al.* 2007; Hens *et al.* 2008; Rissech *et al.* 2012). The method tends to classify younger individuals accurately (Saunders *et al.* 1992; Martrille *et al.* 2007), although with some overestimation of age (Santos 1995), while for older individuals the opposite has been reported, with age being underestimated (Saunders *et al.* 1992; Santos 1995; Hens *et al.* 2008). The lack of accurate results for the Lovejoy *et al.* (1985b) method has prompted the emergence of new methods by analysing the metamorphosis of the auricular surface, presented in Table 2.2. Revisions were performed in the scoring system and statistical tests employed. In turn, the revised methodologies have also been tested showing a lack of major improvements to estimating chronological age with accuracy.

2.4. ACETABULUM

2.4.1. Physiology

The acetabulum is a concave cup-shaped articulation positioned laterally, inferiorly and anteriorly in the o*s coxae* (Norkin and Levangie 1992; Nordin and Frankel 2001). It is formed by the union of the pubis, ischium and ilium (Gray 1973). The acetabulum comprises three areas: 1) the lunate surface, constituting the peripheral area with a crescent shape, that articulates with the femur; 2) the acetabular notch, a non-articular portion delimiting the inferior part of the acetabulum fossa between the two horns of the lunate surface, and is the place of attachment for the capitis ligament and 3) the acetabular fossa, another non-articular area, in the central and deepest portion of the acetabulum with apertures filled with adipose tissue (Gray 1973). The acetabular anterior and posterior horns are different in shape. The anterior horn is rigid, less mobile, and appears correlated with the transmission of higher intra-articular stress, while the posterior horn is less rigid and more mobile associated with lower stress transmission (Govsa *et al.* 2005). The hip joint comprises the head of the femur and the acetabulum (Spalteholz 1972; Pina 1995), with the acetabulum being the concave element of the hip joint ball-and-socket shape. The hip joint constitutes one of the largest articulations in the body, surrounded by strong and large muscles (Nordin and Frankel 2001).

Table 2.2. Macroscopic age estimation methods and assessments for the iliac auricular surface metamorphosis.

Method	Description	Assessment studies	Assessment results
Schmitt (2001, 2005)	European samples (F/M). Four scoring system using a Bayesian approach	———	———
Buckberry and Chamberlain (2002)	N= 180 from Christ Church collection (F/M) Revision of Lovejoy *et al.* (1985b)'s method. Seven phase system consisting in the sum (composite score) of the scores attributed for 5 features.	Mulhern and Jones (2005) Falys *et al.* (2006) Hens and Belcastro (2012) Rissech *et al.* (2012) Moraitis *et al.* (2014)	Practical and easy to apply. More accurately classifies older individuals than Lovejoy *et al.* (1985)'s method. Moraitis *et al.* (2014) obtained a low bias and a high inaccuracy. Suggestions have been made to increase the wideness of the age ranges (Falys *et al.* 2006; Hens and Belcastro 2012).
Osborne *et al.* (2004)	266 North Americans (F/M). Revision of Lovejoy *et al.* (1985b) method into 7 phases with wider phases.	Rissech *et al.* (2012) Miranker (2015)	Critique to the wider age ranges reflecting the poor age information that the adult skeleton presents. Miranker (2015) obtained a high inaccuracy and a low correlation with age (r= 0.04).
Igarashi *et al*. (2005)	700 Japanese skeletons (F/M) Record of 9 traits' absence or presence Application of multiple regression analysis	Igarashi *et al*. (2005) Magee (2006, 2008)	Tendency to overestimate chronological age of younger adults and underestimate older specimens. Easy to apply but does not improve age at death estimation.

2.4.2. Cartilage, capsule and synovial membrane of the hip joint

The hip joint is a synovial multiaxial ball-and-socket joint. The acetabular surface is covered by a hyaline cartilage (Scheuer and Black 2000), and there is a fibrocartilaginous rim at the margin (Faiz and Moffat 2002). The hip joint also has an articular capsule attached to the acetabular margin and to the femur (Faiz and Moffat 2002).

2.4.3. Acetabulum function and mobility

The main function of the hip joint is to support the body mass from the head, upper limbs and trunk, and to transmit the forces from the pelvis to the lower limb (Norkin and Levangie 1992). The hip joint is one of the most stable articulations in the human body (Nordin and Frankel 2001). The stability is provided by ligaments, muscles, and by its ball-and-socket shape (Nordin and Frankel 2001; Faiz and Moffat 2002). Even though the hip joint is a stable articulation, it is the most mobile joint of the lower limb, with the ability of displaying a wide range of movements (Faiz and Moffat 2002). This great mobility allows locomotion and other activities, such as squatting, walking and sitting (Nordin and Frankel 2001).

2.3.4. Bone degeneration with age in the acetabulum

The acetabulum undergoes morphological modifications (Rougé-Maillart *et al.* 2004; Rissech *et al.* 2006, and Calce 2012). Usually, younger adults display a blunt-edged acetabular rim without osteophytes and porosity formation. The apex is smooth without bone spurs. It also exhibits a dense fossa, and the outer edge of the fossa and the lunate surface are smooth. With increasing age, the rim starts to form a crest due to the progressive bone deposition, which can acquire substantial size and porosity. In the acetabular fossa, microporosity can form, followed by the appearance of macroporosity that may become substantial. In older individuals, the acetabular fossa can exhibit destruction and new bone formation. The outer edge of the acetabular fossa starts to develop osteophytes that can form a crest, which can become extensive and cover the acetabular fossa. With age the lunate surface below the rim may show an acetabular groove, firstly it is shallow but progressively becomes deeper. At the apex, the smoothness is lost with age due to the formation of bone spurs that undergo an increase in size with advancing age. Appendix 1

provides detailed descriptions of the acetabulum morphological traits accompanied by illustrations.

2.3.5. Age at death estimation methods

The first study to investigate the possible correlation between age and morphological characteristics of the acetabulum was by Rougé-Maillart *et al.* (2004). Their study was based on 30 Spanish male individuals aged 24 to 81 years old. The investigators scored four criteria in the acetabulum (including changes in rim, fossa, apex and porosity on the lunate surface), and combine these as a composite score. Later, Rougé-Maillart *et al*. (2007) revised and tested the criteria established previously for four acetabular and four auricular surfaces on 52 individuals of both sexes. By establishing an overall score of these eight features, Rougé-Maillart *et al*. (2007) obtained a correlation with age of ≥ 0.577, and a low inter- and intraobserver error. Subsequently, Rougé-Maillart *et al.* (2009) established an age estimation methodology with the analysis of both acetabulum and auricular surface criteria. Stull and James (2010) further revised the score descriptions of three acetabular traits – acetabular rim, acetabular fossa and apical region – and established age distributions $\pm$ 2 standard deviations for each of the scores based on each trait. Stull and James (2010) obtained a low correlation between the traits and age, with the exception of the acetabular rim (r= 0.516). They also found a substantial overlap in age distribution between stages for each trait, with better results gained for the white males' acetabular rim changes. Pooling the sexes lead to an improvement with better stage delineations, however, Stull and James (2010) concluded that for acetabular fossa and apical region to be useful to estimate chronological age their scores required further revision.

The satisfactory results of the preliminary study of Rougé-Maillart *et al.* (2004) led to the establishment of new age at death estimation methods by Rissech *et al.* (2006) and Calce (2012). In Table 2.3 is described the recent age estimation methods and corresponding assessments by other researchers. Assessment of these methods showed similar results as obtained for the auricular surface and the pubic symphysis ageing estimation methods, without a substantial age estimation improvement regarding inaccuracy and bias.

Table 2.3. Macroscopic age estimation methods and assessments for the acetabulum metamorphosis.

Method	Description	Assessment studies	Assessment results
Rissech *et al.* (2006)	242 Portuguese males Scoring of 7 acetabular traits. Application of Bayesian inference	Rissech *et al.* (2007) Calce and Rogers (2011) Miranker (2015)	56% to 100% of the individuals with less than 10 years difference between estimated and known age (Rissech *et al.* 2007). Overage the young adult and underestimate age in the old specimens
Calce (2012)	239 North Americans (F/M) Revision of Rissech *et al.* (2006), with the analysis of 3 traits for three stages. Application of Stepwise multiple regression	Mays (2014) Miranker (2015)	Lower percentage of individuals correctly aged. Difficulty to attribute one of the age groups for the middle and older adults. Higher inaccuracy and bias than for the Rissech *et al.* (2007) method

CHAPTER 3

LIMITATIONS AND CRITIQUES OF AGE AT DEATH ESTIMATION METHODS FOR ADULT INDIVIDUALS

Macroscopic methods tend to be commonly applied by researchers due to their direct application without the need for specialised equipment, and consequently, for being cheaper and quicker to use (Gocha *et al.* 2015). Chapter 2 presented the existing age at death methodologies for adults based on scores reflecting macroscopic changes in the pelvic joints. Several of these methods have been refined over the years, in particular for the degenerative alterations of the pubic symphysis. With an increasing number of established methods there has been increased pressure for them to be more repeatable, precise and accurate when applied to unknown skeletal remains from a broad range of populations. However, estimating age in adults with accuracy is still one of the major problems in bioanthropology, since none of the current methods provides accurate chronological age estimation, as the tests results have shown. It is therefore expected that some degree of error will be present in all age estimations. Some methods may hold more promise, but when applied to different populations the results are usually less accurate, especially for individuals older than 40 years (Maples 1989; Cunha *et al.* 2009; Garvin *et al.* 2012). Often the methods present a systematic error of overestimating age for the younger adults and underestimating for older individuals (Scheuer, 2002; Schmitt *et al*., 2002). This bias in age estimation consequently affects the biological and cultural interpretation of age data obtained from skeletal remains (Schmitt 2004). In the present chapter, different critiques and limitations to metamorphic age at death estimation methods will be presented.

3.1. METHODOLOGICAL CRITIQUES AND LIMITATIONS TO AGE AT DEATH ESTIMATION METHODS

One of the criticism made is related to the methodological problems associated with the age estimation methods in general. These can be clustered into three groups: 1) the materials used; 2) the lack of a detailed description of the age-related criteria; and 3) the statistical tests employed which consequently dictates how age at death is

estimated (age ranges, probabilities, or through multiple regression formulae). In turn, these methodological problems create further bias, such as mimicry, and the "the attraction to the mean".

One of the structural problems in age at death estimation methods pertains to the reference collections from which the investigators have drawn their observations. The use of small sample size has been criticised because it may rely on uneven age distributions, a disproportionate number of individuals in particular sex and ancestry categories, and the elimination of biological outliers (Cox 2000). Another problem is the fact that the majority of the methods have been established using Occidental reference samples, which may affect the accuracy of the methods when applied to a non-Occidental population (Schmitt 2004). Furthermore reference collections may be based on individuals whose age at death can be imprecise, *e.g.*, some specimens from the Hamman-Todd collection, where ages were provided by soft tissue analysis and lacks documentary proof of age at death, sex and other biographical information (Cox 2000). The use of inadequate samples can lead to random error when applying an ageing method based on unknown skeletons when the reference collection also has unknown chronological age specimens (Cox 2000). Therefore, age estimation methods created with the Hamann-Todd collection have been the target of much criticism (Katz and Suchey 1989).

Not only has the choice of inappropriate samples been criticised, but so has the representativeness of the skeletal reference collections themselves (Usher 2002; Albanese 2003a; Komar and Grivas 2008). Population representativeness is dependent on the sampling method followed when creating each collection, *e.g.*, derived from a modern cemetery or body donations, but also from social and religious factors. In addition, where subsamples are selected for particular investigations.

Another methodological feature that may reduce precision is the existence of large, inclusive age ranges (Cox 2000; Berg 2008). An example of a large age range can be found in Falys *et al.* (2006). For the second phase, Falys *et al.* (2006) established an age range between 18 to 90 years old (mean= 52.3 ± 14.5 years; median= 55 years). A large age range, as the second phase from Falys *et al.* (2006) has, is not very informative for age estimation, since it does not allows to distinguish young adults and older individuals. However, age range is not the best measure of dispersion, because it is based on just two extreme values, and ranges increases as sample size increases.

Lack of reliability may result from the elaboration of complex and ambiguous descriptions of the degenerative characteristics, without sufficient visual representations provided (Saunders *et al.* 1992; Santos 1995; Calce 2012). As a solution, plastic casts have been created of the different stages of pubic symphysis (McKern and Stewart 1957; France Casting 1986), and 16 iliac auricular surface slides (Bedford *et al.* 1991). While these provide an observation accessory for specific methodologies, it still does not record the existing vast morphological variability (Santos 1995).

In Chapter 2 the methods established for each pelvic joint were presented. However, so-called "multifactorial" methods have also been used that conjointly analyse age-related changes using more than one skeleton criterion (Acsády and Nemeskéri 1970 cited by Ferembach *et al.* 1980; Lovejoy *et al.* 1985a; Boldsen *et al.* 2002; Schmitt *et al.* 2002; Corsini *et al.* 2005; Ferrant *et al.* 2009; Rougé-Maillart *et al.* 2009; Anderson *et al.* 2010; Martins *et al.* 2012). Analysing more than one age criterion has been seen as a possible solution to obtain accurate chronological age estimation (Ferembach *et al.* 1980; Lovejoy *et al.* 1985a; Bedford *et al.* 1993; Baccino *et al.* 1999; Corsini *et al.* 2005; Franklin 2010). However, this optimism about higher accuracy is not shared by all researchers, since multi-criteria methods share similar structural, methodological and inaccuracy problems (Saunders *et al.* 1992; Kemkes-Grottenthaler 1996; Schmitt 2001; Schimtt *et al.* 2002; Martrille *et al.* 2007). Besides the use of "true" multifactorial methods, the practice of combining the results of different age at death methods to estimate the age of unknown remains can also be followed. However, there is a lack of consensus concerning which methods should be employed (Franklin 2010; Garvin *et al.* 2012), although, guidelines have been proposed (Ritz-Timme *et al.* 2000; Rösing *et al.* 2007; Cunha *et al.* 2009). Another lack of consensus is how to report age estimation results by combining various methods, evaluating different skeletal criteria, applied to unknown remains since no standard procedure exists (Jackes 2000). For example, age estimation can be presented as an overall age range of all methods, or by the interval in which the age ranges overlap, or the age ranges from the most reliable methods according to the judgement of the researcher. These approaches, even though commonly applied, bear no statistical validity and can be highly biased. The different methods applied in a multifactorial analysis were constructed under different assumptions, with different samples and statistical procedures (Garvin and Passalacqua 2012; Garvin *et al.* 2012).

The statistical calculations performed have also been the target of criticism, especially because they have led to systematic errors in age estimation for the vast majority of methods applying a classic statistical approach. The first age estimation methods were based on the directly established age range values per phase using the documented age of the skeletal specimens (*e.g.*, Todd 1920, 1921a; Lovejoy *et al.* 1985b). Subsequent methods commonly used linear regression models[5] with classical and inverted calibration (*e.g.*, Hanihara and Suzuki 1978; Snow 1983; Katz and Suchey 1986, 1989). The linear regression equation converts the morphological data into predicted ages (Aykroyd *et al.* 1999; Schmitt *et al.* 2002; Corsini *et al.* 2005), however, these are associated with the incorrect notion of the existence of a linear relationship between degenerative morphological traits and chronological age (Schmitt *et al*. 2002). In addition, methods with traditional linear regression models with an inverse calibration −when age is regressed against morphological indicator state −misclassifies older individuals as being younger, leading to the biased notion that past communities did not lived to older ages (Buikstra and Konigsberg 1985; Meindl and Russell 1998; Aykroyd *et al.* 1999; Corsini *et al.* 2005; Falys and Lewis 2011; Buk *et al.* 2012). Moreover, young individuals can be aged as being older than they were. This systematic error for younger and older adult's age estimation has been designated by the "attraction of the middle" (Aykroyd *et al*. 1997; Flays and Lewis 2011). This bias is caused by the fact that the slope of the regression of age against the morphological criterion is less than the slope of the major axis through the data, so for higher values of the morphological criterion the estimated values of age is too small. Bias is higher when the correlation between biological and chronological data tends to be low, which makes these age estimation methods unreliable (Bocquet-Appel and Masset 1982; Aykroyd *et al.* 1999; Schmitt *et al.* 2002; Corsini *et al.* 2005). The use of linear regression has also been criticised for the age mimicry it produces, where the age distribution of the target sample (*e.g.*, archaeological sample) closely resembles the age distribution of the skeletal reference collection from which the method is derived (Bocquet-Appel and Masset 1982; Bocquet-Appel and Masset 1996; Meindl and Russell 1998).

The testing of linear regression methods and the obtaining of inaccurate results led to a different perception and statistical framework to evolve in the study of age estimation. It is presently accepted that the degenerative skeletal modifications do not have a perfect linear relationship with age and the classic linear

[5] Snow (1983) has also applied a polynomial regression (a non-linear regression model).

regression approach is increasingly abandoned. Instead, application of a probabilistic Bayesian statistic is a more reliable procedure to estimate age at death (Konigsberg and Frankenberg 1992; Lucy *et al.* 1996; Aykroyd *et al.* 1999; Schmitt 2001; Schmitt *et al.* 2002; Boldsen *et al*. 2002; Hoppa and Vaupel 2002; Konigsberg and Frankenberg 2002; Rissech *et al.* 2007; Godde and Hens 2012; Martins *et al*. 2012; Konigsberg and Frankenberg 2013; Godde and Hens 2015). The theory of probability of Bayes' theorem has three components, the posterior probability, the prior probability and likelihood and is formulated as (Lucy *et al.* 1996; Chamberlain 2006):

$$p(A \mid I) = \frac{p(I \mid A) \times p(A)\text{prior}}{\int [p(I \mid A) \times p(A)\text{prior}]}$$

Where, A = age; I = morphological indicator; posterior probability of the parameter = p(A | I); standardised likelihood of the data = p(I | A); and the prior probability = p(A)prior. Bayesian inference enables researchers to calculate the probability that an individual died at age *x* given the age-related traits that its skeletal remains exhibit (Hoppa and Vaupel 2002). The turning point for advocating the application of the Bayesian inference in age estimation and consequently its adoption by other researchers can be pinpointed to the Rostock Manifesto[6] (Hoppa and Vaupel 2002), although its application had been advocated previously (Konigsberg and Frankenberg 1992; Lucy *et al.* 1996; Aykroyd *et al.* 1999). Bayesian statistical inference provides a conditional posterior probability distribution across all possible age classes, by taking into consideration a prior probability and the observable skeletal morphological criteria (Boldsen *et al*. 2002; Chamberlain 2006; Godde and Hens 2012). The prior, which can be chosen by the researcher, influences the posterior probability of age (Jackes 2011). A prior probability can be uniform; assuming an equal probability of all age classes, and is applied when no contextual information is available for the skeletal remains, but as such being an uninformative prior (Chamberlain 2006). Another option is choosing an informative prior, such as a model prior established through model life tables from historically documented age at death profiles from hazard functions, such as a

[6] The Rostock Manifesto was established during a three-day workshop entitled "*Mathematical Modelling for Paleodemography: Coming to Consensus*" in 1999 at the Laboratory of Survival and Longevity at the Max Planck Institute for Demographic Research in Rostock, Germany.

Gompertz hazard model (Chamberlain 2006; Kimmerle *et al.* 2008; Konigsberg and Frankenberg 2013). A model prior can be of three types, attritional (from a mortality life-table), catastrophic (from a living population life-table) (Chamberlain 2006), and a mix with attritional and catastrophic models. Another informative prior option is to apply a maximum likelihood estimation by establishing the prior probabilities of age in the target sample from the distributions of the target sample morphological criteria (Konigsberg and Frankenberg 1992; Boldsen *et al.* 2002; Konigsberg and Frankenberg 2002; Konigsberg and Frankenberg 2013).

Bayesian statistical inference is recommended for being free of the age mimicry due to the use of a probabilistic prior (Boldsen *et al.* 2002; Chamberlain 2006; Bullock *et al.* 2013). For example, one of the age estimation methods based on the Bayes theorem with a maximum likelihood approach is the Transition Analysis, a multifactorial age at death estimation method, where each indicator provides different information about age[7]. In Transition Analysis, the probability can be modelled through a logistic regression or with a probit regression. Since Boldsen and co-workers (2002) published this approach, it has resulted in a more widespread application with a Bayesian component rather than the classical age estimation methods. The software programme ADBOU[8] for an easy employment of the Transition Analysis method has assisted this approach. Boldsen *et al.* (2002) established a scoring system for age-related criteria[9] to produce a maximum likelihood age estimation. The Transition Analysis estimates the age of transition from a younger phase to the subsequent phase, accompanied by a standard deviation, through the calculation of the intercept and slope. The Transition Analysis method has been tested and compared with traditional age estimation methods such as the S-B system (Godde and Hens 2012, Milner and Boldsen 2012; Bullock *et al.* 2013; Godde and Hens 2015). The Transition Analysis is considered more advantageous by providing an increased accuracy, outperforming the traditional methods, although it is far from ideal. Even Miller and Boldsen (2012: 107) stated that, "*Turning to the*

[7] Holman *et al.* (2002) disagrees that multiple criteria provides different age information, and therefore, presented another age estimation approach with a Bayesian inference, but by treating the likelihood component not as a transitional, but as "latent-trait" component. It is assumed that each individual has their own latent ageing rate - which is not observable but whose effects can be modelled - affecting correlated skeletal criteria simultaneously. This approach can assume one of two types of models: 1) the probability of the transition between a younger to an older stage occurs in a systematic way; or 2) that the latent effects can be modelled by the age transition average between stages.

[8] Available at: http://math.mercyhurst.edu/~sousley/Software/

[9] A scoring system was developed by Boldsen *et al.* (2002) for age related criteria from the cranial sutures, the pubic symphysis and the iliac auricular surface.

overall age estimates, it is not surprising that Transition Analysis estimates for people into their 40s tend to be reasonable, although far from ideal; after all, that is also true of most conventional methods". Additionally, they stated, "*Overall, the present version of Transition Analysis does not work as well as one would like, especially if the intent is to get age estimates for individual skeletons. It does better at capturing a general sense of a population's age-at-death distribution, at least for those typical of samples archaeological osteologists are likely to encounter*" (Miller and Boldsen 2012: 109). As stated before, one of the advantages of the Bayesian approach is the use of a prior as a weighted function in the calculation of the posterior probability of age, however, if chosen incorrectly, can pose as a limitation. Different results can be obtained when using different priors for the same skeletal data, which consequently, affects the level of accuracy and precision in ageing estimation (Schmitt 2001; Miller and Boldsen 2012). For example, a maximum likelihood approach if not constrained by a mortality model can lead to an unrealistic age estimation distribution (Chamberlain 2006). The prior can also cause bias if selected according to existing preconceptions of past populations mortality distributions (Jackes 2011:124).

Other statistical approaches for age estimation have been suggested, such as artificial neural networks (Corsini *et al.* 2005), Sugeno Fuzzy integral (Anderson *et al.* 2010), decision trees, nearest neighbours, computational intelligence methods and group of adaptive models evolution method (Buk *et al.* 2012). Therefore, the debate about what constitutes an "appropriate" statistical test to estimate age continues, with a major focus on the technological and statistical issues to improve age estimation methods. Deciding between and testing different statistical approaches are important issues to discuss, but those should be allied with a greater knowledge and understanding of the skeletal ageing process. As indicated by Jackes (2000: 451): "*We have seen that proposed statistical techniques do not provide the magic answer, and we would hardly expect that this would be so. If the "age indicators" do not directly manifest age, then redistributing frequencies of age indicators by a variety of statistical approaches will not lead to true ages*". The lack of a better understanding about the skeletal ageing may be the main cause of methods inaccuracy and bias (Jackes 2000). The biological issues will be addressed in detail in the next subsection.

3.2. INFLUENCE OF CONFOUNDING FACTORS ON BONE DEGENERATION, AND CONSEQUENT INACCURACY IN AGE AT DEATH ESTIMATION METHODS

The existing methods use the observation of skeletal biological maturation and degeneration to estimate the chronological age (Western calendar number years since birth to death) (Íşcan 1989; Garvin *et al.* 2012). A correlation exists between physiological and chronological age, but it is not a strict linear relationship (as mentioned in Section 3.1.), since physiological ageing can be delayed or accelerated (Ferembach *et al.* 1980). In adults, the discrepancy between physiological and chronological age tend to be greater than for sub adults. Ageing proceeds on a more variable rate among mature individuals, and thus, age at death estimation is less accurate for adults than for sub adults[10] (Maples 1989; Cox 2000). As a result individuals with the same chronological age may show different biological age stages. The increased variability in age-related skeletal criteria metamorphosis among individuals, with advancing age, is designated as the "trajectory effect" (Nawrocki 2010).

Variability in ageing does not occur only between individuals, but also between populations (Ferembach *et al.* 1980; Bocquet-Appel and Masset 1982). It was presumed that a uniform biological relationship existed between chronological age and degenerative indicator between different populations, implying that an ageing method can be applied to any skeletal series (Howell 1976). However, by testing the same methodology – such as the S-B system – on different populations a lack of a uniform pattern of skeletal ageing among different populations was found, which is reflected in the low accuracy obtained (Hoppa 2000). It has been advocated that population-specific ageing methods be established (Schmitt *et al.* 2002; Chamberlain 2006; Gocha *et al.* 2015). This is not always easy to perform since the reference collections are mostly from Europe and North America (Buk *et al.* 2012; Gocha *et al.* 2015).

The majority of the research performed shows that ageing methods are not accurate due to the ageing variability between individuals and populations, even after applying Bayesian inference. It has been suggested that genetic, cultural and

[10] The absolute accuracy of age estimation is less for adults than for sub adults, since the age range is smaller for sub adults. However, it may not be correct to compare individuals of different age groups as sub adults and adults are. Both groups should be compared with a relative accuracy as a percentage ((standard deviation/true value) x 100). However, the relative accuracy may be worse for sub adults. For example, , the relative accuracy for an individual of 40 years aged within ± 10 years is 30%, but for an individual aged 20 months aged within ± 6 is 25%.

environmental factors are the "noise" responsible for the inter- and intra-population variability, affecting the relationship between bone degenerative criteria and age. Several genetic, cultural and environmental confounding parameters, such as, diet, endocrine and hormonal imbalances, occupation and physical activity, pregnancy and parturition, diseases, alcohol and drug abuse, socioeconomic and cultural status have been proposed as important (Todd 1920; Stewart 1957; Ferembach *et al.* 1980; Angel 1984; Meindl *et al.* 1985; Katz and Suchey 1989; Santos 1995; Buckberry and Chamberlain 2002; Scheuer 2002; Rissech *et al.* 2003/2004; Igarashi *et al.* 2005; Falys *et al.* 2006; Magee 2006, 2008; Hartnett 2007; Anderson *et al.* 2010; Buk *et al.* 2012; Rissech *et al.* 2012). It is assumed that these factors are the true causes of ageing dissimilarities, but each lack a proper analysis and discussion with skeletal data. However, the nature of the confounding factors affecting the pelvic joints' degenerative ageing process are poorly understood due to the lack of more detailed research. Great attention has been given to comparing the ageing patterns among populations, but until recently less attention has been paid to the causes of this variability. Recent studies have led to a research shift in the analysis of skeletal ageing. A few studies have investigated the effects that occupation and physical activity, pregnancy and parturition, use of drugs and alcohol, body size and diseases have on skeletal age. The results of those studies are going to be presented in the subsequent sessions showing the different approaches and the samples used.

3.2.1. Pregnancy and parturition effect

Due to hormonal influence during pregnancy relaxation of the ligaments around the auricular surface and pubic symphysis lead to an increase in joint mobility (Brooke 1924; Walker 1992; Scheuer and Black 2000; Alicioglu *et al.* 2008; Becker *et al.* 2010). Researchers have long hypothesised that dimorphic degenerative differences at the pelvic joints are due to pregnancy and parturition in women. However, Hoppa (2000) compared the mean variation of stage by age, by applying the S-B system in females with low and high birth numbers, and found no significant differences between the two groups. One of the problems with this study was the small sample size, which may not be representative of the potential effect that pregnancy and parturition may have into skeletal ageing.

3.2.2. Drugs and alcohol consumption

Drugs and alcohol affect the body's homoeostasis (Taylor 2000; Passalacqua 2014) and chronic alcohol abuse may decrease bone mineral density and disturb calcium homoeostasis (Taylor 2000; Hartnett 2007). The intra-venous use of drugs can lead to osteosclerosis, osteomyelitis and septic arthritis, which can affect the skeleton (Taylor 2000; Hartnett 2007). If alcohol and drug abuse can affect skeletal tissue there may also be an influence on the metamorphosis of the joints (Taylor 2000; Hartnett 2007; Passalacqua 2014).

Taylor (2000) found that drug and alcohol abuse affects the accuracy of the İşcan and Loth method of age estimation. Two groups of individuals (65 individuals with and 55 without substance abuse of both sexes) were compared from forensic autopsies. Chronic substance abuse information was detailed through medical records, family, friends and autopsy findings, substantiated by scene investigation. However, Taylor (2000) could not determine if the consumption of drugs and alcohol resulted in underageing or overageing, since one-half of her sample appeared younger than the true age and the other half seemed to be older.

Hartnett (2007) compared two groups of individuals (99 individuals of both sexes with known alcohol and/or drug addiction *versus* 99 individuals without known abuse). The study compared the mean difference between the estimated and actual phase between individuals with and without substance abuse by applying the S-B system, the İşcan and Loth method and her revised version of those methods. A non-significant difference was obtained between the two groups, showing the lack of a significant effect of drug and alcohol abuse on the metamorphosis of the pubic symphysis and the sternal rib ends. Similar results were obtained by Passalacqua (2014), also by applying the S-B system and the İşcan and Loth method on the same sample as Hartnett (2007).

Limitations common to the three studies are associated with the sample studied. Hartnett (2007) pointed out that the drug and alcohol consumption records from medical records and information provided by familiars and medical records may be incorrect. Moreover, the degree of abuse and the number of years this chronic abuse took place is unknown for Hartnett (2007) and Passalacqua (2014). This implies the need for further investigation with detailed information about the substance consumption (Passalacqua 2014).

3.2.3. Influence of occupation and physical activity on the pelvic joints metamorphosis

It has been suggested that physically demanding occupations and activities can lead to a faster and greater ageing metamorphosis at joints. Campanacho *et al.* (2012), Mays (2012) and Miranker (2015) have investigated this hypothesis in different skeletal samples.

Campanacho *et al.* (2012) examined whether occupation and physical activity influenced the pubic symphysis degeneration in 161 male individuals from two Portuguese identified skeletal collections. The absence or presence of individual morphological traits at this joint were recorded. In this study occupation and physical activity refer to two distinct concepts: occupation was the individual's employment stated in the collection's biographical records, and physical activity was measured by femur robusticity. This distinction led, firstly to the division of the sample into manual and non-manual groups; secondly, between robust and gracile individuals. The authors only obtained one significant result: the ligamentous outgrowths on the ventral bevelling showed a faster ageing process (the transition from a "younger" to an "older stage" occurs in a younger age) for the robust group, compared with the gracile individuals.

Mays (2012) studied the effect occupation may have on the acetabulum metamorphosis of 50 male specimens from the Spitalfields collection, whose professional occupation is known. The individuals were divided between manual (n= 33) and non-manual workers (n= 17) without significant differences in age distribution between the occupation categories. The scoring system applied was revised from Rissech *et al.* (2006) and involved of four traits, which show significant correlation with age. A composite score was computed from the acetabular traits. The analysis showed that non-manual individuals had significantly higher composite scores-for-age compared to manual workers, showing a higher acetabular degeneration for the individuals with less physically demanding occupations.

Miranker (2015) analysed 203 specimens of both sexes from the William Bass Donated Skeletal Collection. The individuals were divided into manual and non-manual workers according to occupation from the biographic records. Analysis of co-variance was performed for the total and each sex samples to determine the influence of occupation on age estimation for four methods: the S-B system,

Osborne *et al*. (2004), Rissech *et al.* (2006) and Calce (2012). Miranker (2015) arrived at a similar conclusion as Mays (2012), with non-manual workers tending to appear older than manual workers (overestimation of age), and, therefore, suggesting that individuals with a less physically demanding occupation seem to age faster.

3.2.4. The effect of diseases on skeletal ageing

Mays (2012) analysed the impact of the diffuse idiopathic skeletal hyperostosis (DISH) on the composite acetabular score (CAS) on individuals of both sexes from the Spitalfields collection. The standardized residuals from the regression of the CAS upon age were compared for those with DISH (3 females and 9 males), with subclinical DISH (21 females and 27 males) and without DISH (60 females and 35 males). No significant differences were obtained between the groups, showing a lack of influence of this disease in the metamorphosis of the acetabulum. Two limitations to Mays' (2012) study can be identified, which are associated with the reference collection itself. Firstly, the analysis was performed to a small number of individuals in both groups with DISH, probably reflecting the frequency of this pathology in this skeletal sample. Secondly, no health records are associated with the Spitalfields collection. Medical certificates, if existent, could possibly bring more information about the lack of influence of this bone-forming disease on the acetabulum morphological changes with age.

3.2.5. The influence of body size on bone ageing degeneration

Biomechanical stress at joints may be greater for obese individuals, suggesting there may be a higher rate of skeletal ageing degeneration at the joints. Studies by Merritt (2014a, 2015) and Wescott and Drew (2015) investigated the possible effects body size may have on age-related degeneration of the joints.

Merritt (2014a, 2015) analysed 764 individuals, of both sexes, from two North American collections (the Hamann-Todd and the William Bass Donated Skeletal collections). In 2014, Merritt determined possible age estimation differences for age estimation methods according to body size. Additionally, in 2015, Merritt applied a Transitional Analysis to compare the age-of-transition between phases for such age estimation methods between groups of different body size. The largest individuals showed an accelerated rate of ageing, which was

attributed to different rates of bone remodelling and mechanical loading in individuals of different body sizes (Merritt 2014a). Heavier and taller individuals were consistently overaged, while lighter and shorter individuals tended to be underaged (Merritt 2014a). However, Merritt (2015) showed that the age-of-transition between age estimation occurs at a later age. In addition, the possible effect of body size was determined for five auricular surface features (following Buckberry and Chamberlain 2002). Merritt (2015) found a significant difference in recorded scores among the different body size groups for the auricular surface features.

Wescott and Drew (2015) studied 226 individuals of both sexes from the William Bass Donated Skeletal Collection, with the aim of determining if obesity affects the metamorphosis of the pubic symphysis and the auricular surface. They also compared the accuracy of two methods (S-B system and Buckberry and Chamberlain 2002), in two groups of different body mass index (BMI) (normal BMI (18.5 – 24.9) *versus* obese individuals (BMI $\geq$ 30). Higher ageing estimation inaccuracy and bias were obtained for the obese individuals, whose age was overaged. Furthermore, the correlation between estimated and chronological age was lower for the obese specimens. Merritt (2014a, 2015) and Wescott and Drew (2015) studies will be further discussed in Chapter 7.

3.2.6. Critiques of the recent biological studies on the confounding factors effecting skeletal metamorphosis

Recent studies of the possible effect of different confounding factors on skeletal ageing are important because they provide information on the biological process of metamorphosis of the joints. However, some studies appear to lack data collection in a larger sample of both sexes. The results obtained in small samples only seem to suggest a particular trend, however, to obtain a more robust conclusion there is a need to perform the research with a larger number of specimens from different populations. Senescence tends to be uniform for the majority of age-related indicators in different populations, but not on the ageing rate that accounts for a high variability. Therefore, it is possible that the effect of the same confounding factor may not be equal in different populations. Still, little is known about the impact of the same environmental or genetic factor on skeletal ageing across populations. Thus, it is important to perform this type of research by comparing large samples

derived from populations with different life histories. Another critique to be made regarding the samples studied is closely associated with the composition and available biographical information of the skeletal reference collections. The lack of more detailed biographical information also influences the number of specimens that can be included in the analysis. Without more detailed biographical information, there is always a level of uncertainty associated with the results. Nevertheless, the reference collections are still a paramount anthropological resource to be employed to understand the effect of confounding factors in skeletal ageing. Biographical information limitations can include:

- *Occupation*: limitations to this variable can be of two kinds. Firstly, the reliability of the information itself, and secondly, how the occupation records are exploited by a researcher. Occupation records may be incorrect or vague since it tends to refer to the workplace and not the position the person occupied (Armstrong 1972). Additionally, what other physical activities the individual may have performed during life besides his occupation is unknown, and the terminology may no longer be used or understood (Vidal 2004). Moreover, it may refer to the last occupation performed and possibly does not account for occupational fluctuations experienced in a lifetime (Vidal 2004; Campanacho *et al.* 2012; Mays 2012). How researchers employ the occupation records may affect the results obtained. A different allocation of the same individuals into manual and non-manual workers or different professional groups can lead to distinct results (Alves-Cardoso and Charlotte 2013). Even though there is not a consensus how to allocate the individuals into occupations groups, at least it should be clarified which criteria were employed to classify occupations (see Campanacho *et al.* 2012; Mays 2012).

- *Diseases:* Most reference collections have the cause of death recorded, but seldom is further medical information available. The lack of a more informative health status for each individual will affect the analysis. Furthermore, the exact period when an individual suffered from a disease also remains unknown. It is possible that a different length of a disease may not equally affect age-related criteria on the joints.

- *Body size*: Cadaveric data for stature and weight does not account for body size fluctuations during adulthood. Such information is usually unknown, as is the body

mass index, which has to be computed (Merritt 2015).

- *Drug and alcohol abuse*: The skeletal material used by Taylor (2000), Hartnett (2007) and Passalacqua (2014) derive from forensic cadavers whose substance abuse records may be based on unreliable sources (see Section 3.2.2). The length of time the substance abuse took place also remains unknown. It is expected for the period of addiction to vary among individuals, and even that individuals had gone through cycles of intense substance abuse followed by free periods. A different length of susbstance abuse may have different effects on the age-related criteria of the joints. However, this information is unknown for the current reference collections.

Methodological problems also relate to how the degenerative data are recorded and analysed. The majority of the research performed has measured how the accuracy and precision of different age estimation methods are affected by a confounding factor. This approach is indirect because it is not determining the exact effect a confounding factor has in the degenerative process, just how an ageing method responds overall to that factor. Additionally, by analysing only the overall effect a confounding factor has in bone degeneration (*e.g.*, composite score) is a non-extensive approach since the effect on each of the individual age-related criteria is unknown. Buckberry and Chamberlain (2002) reported a moderate agreement between five auricular surface features in the Spitalfields collection suggesting traits carried independent ageing information, and maybe even respond differently to various confounding factors. It is possible that this is also true for other features of joints, but little is known of how each trait-unit behave on the articulations, including the pelvic joints. Only two studies base their analysis on the performance of features: Campanacho *et al.* (2012) and Merritt (2015). However, Campanacho *et al.* (2012) is confined to males, with a binary scoring system that may not be reflective of all the metamorphosis stages within a trait.

The current thesis research is an important step to understanding skeletal ageing, but still our knowledge is limited as explained in this section. Therefore, much more investigation is necessary to comprehend what factors affect the degenerative ageing process, including on the pelvic joints. Not only by an overall level (*e.g.*, composite score), but also by each trait (unit level) and among correlated traits, without the application of an age estimation method. For this, it is important to compare results between different populations and integrate both sexes in the analysis. Senescence seems to be uniform but the rate in which the metamorphosis

of age-related criteria appears to occur at a different timing among populations. Thus, the same confounding factor may have a different effect on individuals and consequently among populations.

Body size seems to have an effect on skeletal ageing. Individuals of bigger dimensions may have a higher biomechanical stress on the joints associated with a higher bone remodelling, which can consequently lead to a accelerated ageing on the joints (Merritt 2014a; Wescott and Drew 2015). However, it is not known by extension how it affect each trait in different populations, and if other size variables, such as robusticity and joint surface area, are also influencing pelvic joints ageing metamorphosis. Robusticity seems to have a non-significant effect on the pubic symphysis of Portuguese males, affecting only one trait (Campanacho *et al.* 2012). However, it is unknown if robusticity influences the auricular surface and the acetabulum in both sexes. Possibly the size of the joints also influences bone degeneration. For example, Todd (1920, 1921b) points out accelerated degeneration in a few specimens with small pubic symphysis. Meindl *et al.* (1985) commented that in individuals with larger and more robust pubic symphyses the degeneration rate seemed to be delayed. However, this was never the focus of an empirical investigation, although it can be an important factor to understand bone degeneration. It may be possible that larger articulations have different bone degeneration rates, compared to smaller joints, possibly due to the levels of mechanical stress. Therefore, possibly for smaller joints the mechanical loading will be concentrated in a reduced area and thus, it may contribute to bone degeneration rate acceleration. The present study aims to determine if body size (measured as robusticity, body mass, stature, and joint surface area) affects age-related criteria from the pubic symphysis, iliac auricular surface and acetabulum in individuals of both sexes from the Identified Skeletal Collection of the University of Coimbra and the William Bass Donated Skeletal Collection. The aim and objectives are presented in more detail in Chapter 1.

CHAPTER 4
MATERIAL AND METHODS

4.1. SAMPLE

4.1.1. Sample selection

In the present study male and female individuals from two identified skeletal collections[11] were studied, the Identified Skeletal Collection from the University of Coimbra, Portugal (hereafter designated the Coimbra collection), and the William M. Bass Donated Skeletal Collection from the University of Tennessee, USA (hereafter designated the Bass collection). These two reference collections were selected because their specimens are derived from different periods, implicating

[11] The main importance of an identified human skeletal collection is the known biographical information each individual, alongside with a better preservation and completeness than most non-identified human remains, making it a valuable resource for the development of bioanthropology (Usher, 2002; Eliopoulos *et al.* 2007). Identified skeletal collections can be amassed from cemeteries, body donations and autopsies, whose biographical data derive from the obituary records, or from the coffins' plaque inscription (Cunha and Wasterlain 2007). Usually the biographical data documents age at death, sex, cause of death, occupation, ancestry and sometimes even cadaveric anthropometric data (Rissech and Steadman 2011). Therefore, an identified skeletal collection constitutes a direct osteological profile from a subset of the population from a specific time period. Besides knowing the biographical data, historical, socioeconomic, geographic and cultural context are also known, allowing the investigators to research behaviour patterns according to social categories (Alves-Cardoso 2008). Identified collections having an important role in research allowing the creation and testing of methodologies, besides being used in teaching (Eliopoulos *et al.* 2007; Rissech and Steadman 2011). The methods created with identified skeletal collections can then be applied to non-identified individuals from forensic and archaeological contexts, *i.e.* to establish their identity and health profile. Nevertheless, investigators have to be careful in the employment of those methods in populations different from those from which the methods derive. Not all methods apply to distinct populations, due to the existing biological variation between individuals. It is more appropriate to apply methods created using populations from the same geographic area even if a time lapse exists between populations. The biological variation among populations that constrains the methods' application, has led to the creation of many identified skeletal collections around the world (Eliopoulos *et al.* 2007). Identified skeletal collections may not represent the population they are derived from, due to the sampling method followed, and due to social factors, since there is an unequal chance of an individual being selected (Usher 2002; Albanese 2003a; Komar and Grivas 2008). Albanese (2003a, 2003b) acknowledges this problem but argues that a careful sampling can decrease bias and increase representativeness by uniting demographic data with historical information about the collection. In spite of the associated bias, identified skeletal collections are still a valuable research resource for bioanthropology. For the present study, the documented ages are important key data to understand how bone degeneration occurs with time, information that is not present for archaeological specimens, making identified skeletal collections a vital material for the current research.

different life histories. The socio-economic environment conditions under which an individual lives may have an effect on body size proportions. For example, it has been suggested the socio-economic environment in which the individuals grows up may affect stature (Macho 1991). Consequently, it is expected for the Portuguese to have different size proportions from the North Americans. By studying these two reference collections, it will allow us to determine if a different impact on age-related criteria from the pelvic joints between samples exists due to body size differences. As the aim of the present research is to investigate if body size variables have an effect on bone aging in adult individuals, only individuals with age at death equal to or greater than 18 years old were included in the study. Limited by the collections' composition and the selection criteria (explained below), there was a careful selection of individuals in order to have a wider age range, with a similar number of individuals in each age category. Another criterion followed was to have a wider year of birth range.[12] Even though the year of birth is not a predictor variable in the present study, it will account for the possible effect that secular variation may have on bone degeneration, contributing to a smaller representativeness bias, as suggested by Albanese (2003a, 2003b).

Individuals were excluded from the sample if:

- The pelvic bone were absent
- Age at death information is non-existent or appears as a probable age in the records
- Presence of prosthesis in the lower limb and acetabulum and/or with evidence of gross pathological changes at the pelvic bone and femur
- Individuals stated as disabled in their occupation records. The nature of the disability is not reported, nevertheless, it was assumed the possibility of physical disability, which may influence body mass and consequently create bias
- Possible cases of diffuse idiopathic skeletal hyperostosis (DISH) and spondyloarthropathies, since these pathologies may affect the pelvic

[12] Except for one female individual from the Coimbra collection whose year of birth is not possible to determine from the death records, but was not excluded from analysis. The inclusion of this single individual was not considered to bring bias to the present study. The Conchada cemetery, where the Coimbra collection derives, officially opened at the year of 1860 (Barata 2000), and the collection started to be amassed probably between 1915 (Rocha 1995) and 1942 (Fernandes 1985). Therefore, this female individual is most possibly from the same period as the other individuals that compose the Coimbra collection.

articulations (Rissech *et al.* 2003/2004; Martin-Dupont 2005; Martin-Dupont *et al.* 2006), and consequently might influence bone degeneration (Rissech *et al.* 2003/2004). Exclusion was undertaken according to information from two sources: 1) the reference to some of the spondyloarthropathy cases in the Coimbra collection by Martin-Dupont (2005) and Francisca Alves-Cardoso (personal communication); 2) individuals with sacroiliac joint fusion, and/or with three or more vertebrae fused

For the Coimbra collection only Caucasian individuals of Portuguese nationality were included, even though the number of individuals from other nationalities is small (n=9: Rocha 1995), and corresponds mainly to individuals from Spain and former Portuguese colonies. For the Bass collection, only Caucasians were selected, to avoid increasing the sample's possible biological heterogeneity.

4.1.2 Identified Skeletal Collection of the University of Coimbra

The Coimbra collection is composed of 505 complete skeletons and is housed at the Science Museum (*Museu da Ciência*) of the University of Coimbra, Portugal. The individuals from the Coimbra collection were born between 1822 and 1921 and died between 1904 and 1936 (Santos 2000). The collection comprises 239 female individuals (47.3%) and 266 males (52.7%), whose age at death ranges from 7 to 96 years, except for two individuals whose age at death is not given in their records (Santos 2000; Cunha and Wasterlain 2007; Alves-Cardoso 2008). Only 8.9% (n=45) of the collection has an age at death of less than 20 years (Female n=27; Male n= 18) (Cunha and Wasterlain 2007).

The Coimbra individuals are from the Conchada Cemetery (*Cemitério Municipal da Conchada*) (n=498, 98.6%), and seven individuals (1.4%) from the Anatomy Museum of the University of Coimbra (Rocha 1985). Professor Eusébio Tamagnini (1880-1972), the director of the former Anthropology Museum, started the collection. It is unknown the exact date when the collection was amassed, possibly between 1915 (Rocha 1995) and 1942 (Fernandes 1985). In Portugal, human remains were exhumed from their grave after the legally stipulated period of 5 years; presently the period of burial has been reduced to 3 years. The body is exhumed if completely skeletonized allowing for the re-use of the grave. The

exhumation is publicly advertised and with the payment of an annual fee, the skeletal remains of one individual can be maintained in an identified urn kept in an ossuary (*ossários*) at the cemetery. However, if relatives do not reclaim the skeletal remains, they are considered "abandoned", and placed into secondary communal graves or cremated, losing their identity. The former Anthropology Museum, with the permission of the Coimbra Council, retrieved these unclaimed skeletons. The selection criteria used for this collection is unknown (Santos 2000), but it is an important resource for the development of anthropology at the University of Coimbra (Alves-Cardoso 2008). The biographical data for each individual are derived from the cemetery records, and comprise the individual's name, as well as the parent's names, sex, age at death, birthplace, occupation, marital status, year, place and cause of death, and place of inhumation (Santos, 2000). Additional biographical data have been collected by Santos (2000) from 236 patient files from the Coimbra University Hospital.

The occupations of males are more diverse compared with females. Of the 239 females, 224 have their professions listed, the great majority of which (n=197, 84.9%) were housekeepers and/or housemaids (*domésticas;* Santos 2000). The rest were recorded as domestic servants, dressmakers, and farmers (Santos 2000). In the 19th and beginning of the 20th century, Coimbra was a more rural district compared with the capital, Lisbon. Therefore, even though males' occupations are more diversified compared to females, the majority of males) were unskilled workers (*trabalhadores*), farmers and waiters (*serviçais*), followed by more skilled professions, such as tailors and carpenters (Alves-Cardoso 2008). There were also a few males that worked in commerce, transport, liberal professions (civil service and academia), armed forces, industry, and landlords (*proprietários*) (Alves-Cardoso 2008). The causes of death are varied, with infections and parasitic diseases, especially tuberculosis, being the most frequent causes, followed by circulatory, respiratory, digestive diseases and neoplasms (Santos 2000; Alves-Cardoso 2008).

The Coimbra collection individuals have been associated with a low socioeconomic status (Cunha 1995; Santos 2000; Cunha and Wasterlain 2007).[13] From the 236 patient files obtained by Santos (2000), beginning in 1926 the forms

[13] The socioeconomic status is inferred from the occupation records, together with the main cause of death (tuberculosis) and the type of grave provenience – from the common burial ground, possibly because the relatives could not afford to pay a higher sum for the burial (Cunha 1995; Santos 2000; Cunha and Wasterlain 2007).

include the socioeconomic status, divided into 1st, 2nd, 3rd class pensioners and the "poor". For the individuals that died after 1926, one had a 1st class, and three had a 2nd, meaning they would have to pay each time they used the hospital services. In contrast, 31 were considered to be "poor", three to be from the 3rd class, and one came from the prison, but for those the hospital services were free of charge.

4.1.2.1 Coimbra skeletal sample demographic profile

Three hundred and seventeen individuals from the Coimbra collection were analysed with age at death ranging from 18 to 88 years old. Table 4.1 shows the age distribution for the total sample and for each sex. There is a higher concentration of individuals with an age at death ≤49 years old (*e.g.*, Pooled sexes: n=215; 67.8%) than for individuals with >49 years old (Pooled sexes: n=102; 32.1%). The deficit of a higher number of older individuals is due to the Coimbra collection composition, with fewer older individuals (≤49 years: n= 268; >49 years: n= 203; Rocha 1995) allied to restricted sample selection criteria. For example, DISH and spondyloarthropathies affect mainly older individuals, and therefore the exclusion of those cases consequently led to a lower number of individuals in the older age categories. This exclusion was made in order to avoid the effect these pathologies may have on bone degeneration.

Table 4.1. Number of individuals from the Coimbra collection, for each age at death range, for the total sample and both sexes.

Age range (Years)	Female		Male		Pooled sexes	
	N	%	N	%	N	%
18-19	7	4.9	7	4.0	14	4.4
20-29	33	23.1	45	25.9	78	24.6
30-39	28	19.6	44	25.3	72	22.7
40-49	21	14.7	30	17.2	51	16.1
50-59	26	18.2	25	14.4	51	16.1
60-69	11	7.7	16	9.2	27	8.5
70-79	15	10.5	6	3.4	21	6.6
80-89	2	1.4	1	0.6	3	0.9
Total	143	100	174	100	317	100

The statistics calculated for the age distribution (mean, median, standard deviation, minimum and maximum age) are presented in Table 4.2. Since age distribution is not normally distributed (Pooled sexes: KS= 0.091, p<0.001; Females: KS=0.098, p=0.002; Males: KS=0.092, p= 0.001) a Mann-Whitney test was performed in order to compare age distributions between both sexes. The test indicated that male and female individuals have a similar age distribution (U=11168.500; p=0.117).[14]

Table 4.2. Mean, median and standard deviation age at death (in years) for both sexes and pooled sexes for the Coimbra collection.

Statistic	Female	Male	Pooled sexes
Mean	44	40	42
Median	40	38	39
Standard deviation	17.5	15.0	16.3

Individuals from the Coimbra collection sample were born between 1834 and 1918[15], and died between 1910 and 1938. Year of birth is not part of Coimbra collection's records. Thus, it was calculated by the formula: (year of death – age at death) + 1 (Santos 2000). Total sample representativeness according to age at death by year of birth is represented in Figure 4.1, with individuals spread across the 4 quadrants for the scatter plot graphic, showing that the Coimbra sample is constituted by individuals with less and more than 50 years old, born before and after 1870.

[14] Even though age distribution is not normally distributed, the transformation of the raw data to increase its normality was not followed because: it makes the analysis and interpretation more complex (Tabachnick and Fidell 1989) since it is an abstract transformed value instead of the concrete age at death value; the raw data histogram is close to a normally distributed curve; a larger robustness may be obtained with larger samples (Dancey and Reidy 2007) as is the case of Coimbra sample with 317 individuals; the data conversion by squares root and logarithm transformation did not improved the age at death distribution normality, except for the male sample with a logarithm transformation (KS= 0.065, p=0.071).

[15] Female individuals were born between 1834 and 1913, and male individuals between 1844 and 1918. Due to the non-normal distribution of the year of birth, a Mann-Whitney test was calculated, showing that both sexes have a similar year of birth distribution (U= 11308.500; p= 0.196).

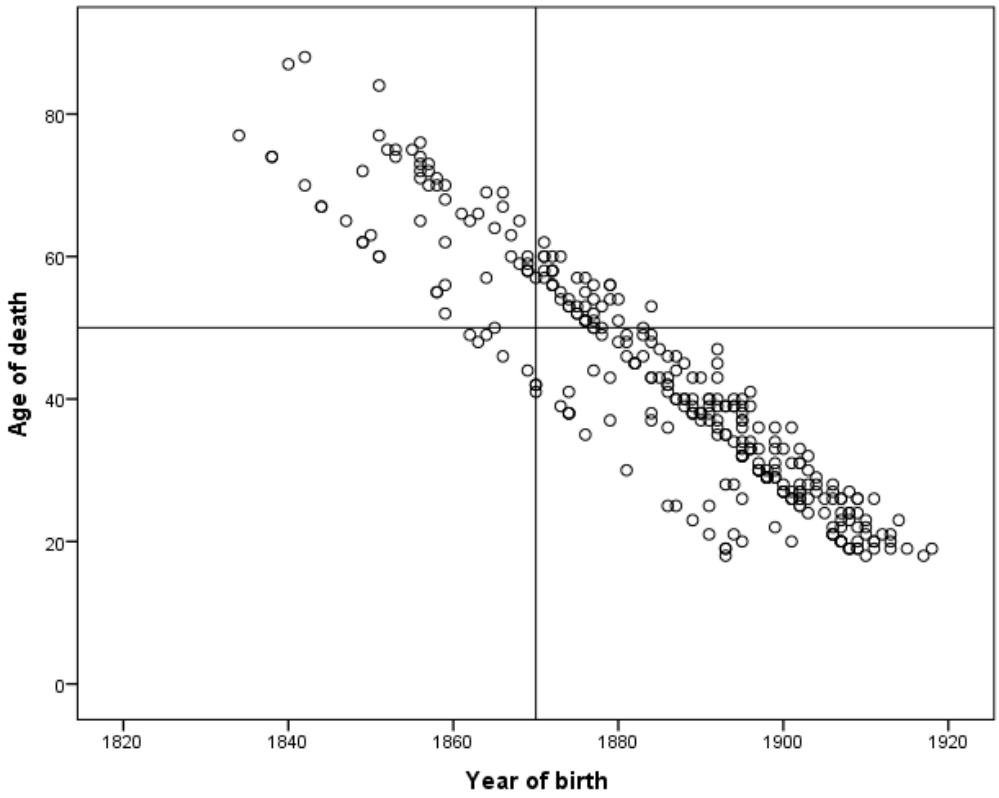

Figure 4.1. Scatter plot of Coimbra sample individuals' distribution according to age at death and year of birth.

The causes of death for the 317 individuals analysed is shown in Table 4.3, adapted from the World Health Organization's ICD-10 International statistical classification of diseases and related health problems 10th revision (W.H.O. 2010). In order to compare with the Bass collection (20th and 21st century) the most recent version of the W.H.O. international classification of diseases, from 2010, was applied. Even though an older version (*i.e.* from 1975) would be more appropriate for the Coimbra collection, since the individuals are from the 19th and 20th century, and, therefore, the medical knowledge of the time is different from nowadays, it would not be adequate for the Bass collection. The main causes of death for the Coimbra collection are the infectious and parasitic diseases, especially pulmonary tuberculosis, affecting a higher percentage of males compared with females (Table 4.3. males 35.1%; females 28.7%; total 32.2%). The values obtained for the study sample are in agreement with the values for the overall collection. Females present a higher percentage of neoplasms and of diseases of the digestive system compared with males. However, males have a higher percentage of individuals in the category "symptoms, signs and abnormal clinical and laboratory finding not elsewhere classified", referring to less defined diagnoses not categorized before. This category

included cases of natural death; individuals whose cause of death was not informative enough to put in a more precise category (*e.g.*, collapse, acute failure); and reports with two or more possible diagnoses.

Table 4.3. Causes of death distribution for females and males from the Identified Skeletal Collection from the University of Coimbra.

International classification of disease W.H.O.	Female		Male		Total	
	N	%	N	%	N	%
Certain infectious and parasitic diseases	41	28.7	61	35.1	102	32.2
Neoplasms	16	11.2	10	5.7	26	8.2
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	2	1.4	2	1.1	4	1.3
Diseases of the nervous system	0	0.0	2	1.1	2	0.6
Diseases of the ear and mastoid process	0	0.0	1	0.6	1	0.3
Diseases of the circulatory system	23	16.1	29	16.7	52	16.4
Diseases of the respiratory system	14	9.8	20	11.5	34	10.7
Diseases of the digestive system	20	14.0	11	6.3	31	9.8
Diseases of the genitourinary system	3	2.1	0	0.0	3	0.9
Pregnancy, childbirth and puerperium	5	3.5	0	0.0	5	1.6
Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	12	8.4	25	14.4	37	11.7
Injury, poisoning and certain other consequences of external causes	1	0.7	4	2.3	5	1.6
External causes of morbidity and mortality	1	0.7	8	4.6	9	2.8
Unknown	5	3.5	1	0.6	6	1.9

Twelve larger occupational categories were created to allow comparisons between the two geographically and temporally distinct populations represented by the Coimbra and Bass collections. The classification was adapted from Armstrong (1972), Roque (1988), and Alves-Cardoso (2008) for 19th and 20th century occupations in England and Portugal – more appropriate for the Coimbra collection. Additionally, the Standard Occupational Classification version 2010 from the United States Department of Labor (S.O.C. 2010) was used, for a more recent/modern occupational designation in the US. Table 4.4 exhibits the Coimbra collection sample distribution by occupational groups, except for the category more than one occupation, since none of the individuals had more than one profession documented,

and it also does not contain unemployed stated in the records. There is a large difference between the sexes, with a vast majority of females (96.5%) classified into the cleaning and maintenance/domestic category. Males present a more diverse distribution between occupations, with a higher concentration into two categories, qualified workers/services/commerce" (43.1%, *i.e.* tailor, barber) and unskilled labourer (28.2%, *i.e. Trabalhador* that can be translated into unskilled worker).

Table 4.4. Occupational groups distribution for the Coimbra collection sample.

Occupation groups	Females		Males		Pooled sexes	
	N	%	N	%	N	%
Academia/intellectual occupations	0	0.0	6	3.4	6	1.9
Administrative occupations	0	0.0	10	5.7	10	3.2
Army/Navy	0	0.0	14	8.0	14	4.4
Cleaning and maintenance/Domestic	138	96.5	4	2.3	142	44.8
Farmers	1	0.7	3	1.7	4	1.3
Landlords	0	0.0	6	3.4	6	1.9
Qualified worker/Services/Commerce	3	2.1	75	43.1	78	24.6
Transport	0	0.0	5	2.9	5	1.6
Unknown/unemployed	0	0.0	2	1.1	2	0.6
Unskilled worker	1	0.7	49	28.2	50	15.8

4.1.3. William M. Bass Donated Skeletal Collection

The William M. Bass Donated Skeletal Collection is housed at the Forensic Anthropology Center at the Department of Anthropology, University of Tennessee, USA. This collection was initiated because of the establishment of a body donation programme started in 1981, under the direction of William M. Bass (Bass and Jefferson 2003; Bassett *et al.* 2003; Jantz and Jantz 2008; University of Tennessee 2014). Bass, a forensic anthropologist, sought to establish better knowledge about human decomposition leading to the creation of a body donation program, but it also had the purpose of creating the largest modern human skeleton collection (20th and 21st century) in the USA (Bass and Jefferson 2003; Wilson *et al.* 2008; Shirley *et al.* 2011).[16]

[16] Body donations of cadavers are derived from three sources, pre-registered by the individuals themselves in life, from the relatives of the deceased and from medical examiner and state donations of unclaimed individuals (Jantz and Jantz 2008; Wilson *et al.* 2008; Shirley *et al.* 2011; Maijanen 2014; University of Tennessee 2014). When a cadaver arrives it is deposited in the Anthropology Research Facility (ARF), the outdoor laboratory (also called informally "the body farm") where it is left to decompose naturally (University of Tennessee 2014). The University of Tennessee receives on

At present, the Bass collection has over 1234 skeletons and 40 cremations, making it the largest collection of modern skeletons in the USA, with age at death ranging from foetus up to 101 years old from both sexes (Shirley *et al.* 2011; University of Tennessee 2014). The collection comprises a higher number of male than female individuals, and there are more European Americans, followed by African Americans, and a few Hispanic and American Indian individuals reflecting Tennessee demographics (Marks 1995; Basset *et al.* 2003; Jantz and Jantz 2008; Shirley *et al.* 2011). There is a higher mean age at death for the self-donors (n= 119; mean age= 66 years), with a high incidence of natural causes of death. There is a lower age at death for the Medical Examiner and State donations (n=256; mean age= 55 years), whose causes of death are mostly associated with accidental and non-natural causes. Therefore, reflecting a close link between age at death distribution and the donation source (Wilson *et al.* 2008). From a sample of 88 self-donation individuals, the majority worked in the service and construction industry, with a high-school diploma and college education. However, educational levels were only recorded after 2004 (Wilson *et al.* 2007). Maijanen (2014) states that 39% of the 180 individuals analysed - whose donations occurred between the years 2000 and 2008 – have their childhood socio-economic status recorded. The majority (50%) were reported to be middle class; followed by 24% from a lower class; 17% lower middle class and only 9% from the upper class. According to Maijanen (2014), these data are in accordance with all the donations made between 2000 and 2008.

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average 100 new donations per year from 50 states and from 6 countries, especially from Tennessee and neighbouring states in USA (Bassett *et al.* 2003; Wilson *et al.* 2007; University of Tennessee 2014). Payment for the cadavers is not provided, and only donations are accepted, however the university tries to meet requests made regarding the cadaver's use, if it is within reason, and if it is in accordance with the research that is being carried out during the time the body is donated (University of Tennessee 2014). At first, the main donations source was of unclaimed individuals from the medical examiners, but a shift has been reported with 65% of current donations being made by relatives and from self-donors (Wilson *et al.* 2008). Donations from relatives are usually performed when the deceased succumbed to a long-standing disease, or when the death occurred suddenly (Wilson *et al.* 2008), or to avoid funeral expenses (Marks 1995). Forms must be filled for consent, with the biographic information, and with the annexation of medical records of known conditions, accompanied by a frontal view picture to be used in facial reconstruction research projects, and since 2008 hair and blood samples started to be collected as well (Wilson *et al.* 2008; Shirley *et al.* 2011; University of Tennessee 2014). However, body donations before the year 2000 have less biographic information than recent ones due to the implementation of the biological questionnaires (Maijanen 2014). After the cadaver decomposes, which takes on average two years, the skeletonised remains are then cleaned of remaining soft tissues, inventoried, labelled with their collection number and measured forming the William M. Bass Donated Skeletal Collection (Jantz and Jantz 2008; Shirley *et al.* 2011; University of Tennessee 2014). Even though the skeletal remains donated can be viewed by visiting relatives, those remains are not returned and are used for research and teaching (University of Tennessee 2014).

4.1.3.1. Bass collection demographic profile

From the Bass collection, 236 individuals of both sexes were analysed and their age distribution is presented in Table 4.5. The sample's age at death ranges between 19 and 92 years. The Bass sample has a higher percentage of individuals older than 49 years (Total sample: ≤49 years: n=74, 31.4%; >49 years: n=162; 68.6%). This reflects the collection's demographic profile due to the sampling method by body donations, creating a bias towards a more restricted group of individuals, in this case mainly European-American white males (Marks 1995; Basset *et al.* 2003; Jantz and Jantz 2008; Shirley *et al.* 2011; Maijanen 2014).

Table 4.5. Number (N) and percentage (%) of individuals by age at death range for both sexes and for the total sample of the Bass collection.

Age range (years)	Females		Males		Pooled sexes	
	N	%	N	%	N	%
18-19	0	0.0	1	0.8	1	0.4
20-29	2	1.8	4	3.3	6	2.5
30-39	6	5.3	19	15.4	25	10.6
40-49	19	16.8	23	18.7	42	17.8
50-59	27	23.9	27	22.0	54	22.9
60-69	24	21.2	19	15.4	43	18.2
70-79	23	20.4	15	12.2	38	16.1
80-89	11	9.7	12	9.8	23	9.7
90-99	1	0.9	3	2.4	4	1.7
Total	113	100	123	100	236	100

The Bass collection presents a higher mean age compared to the Coimbra collection, and the age distributions of the two collections are significant different (Mann-Whitney test: Total sample: U= 18067.000, $p<0.001$; Female U= 3846.500, $p<0.001$; Male U= 5308.500, $p<0.001$). Figure 4.2 compares the age distributions of the samples from the Coimbra and Bass collections. The major differences encountered between the two samples is at ≤ 39 years and ≥50 years, with the Coimbra collection sample presenting a higher percentage of younger individuals and lower percentage of older individuals when compared to the Bass collection sample. Those differences seem to be more accentuated for the females than for the males. The elevated percentage of individuals aged ≤ 39 years in the Coimbra collection allows analysis of age-related changes that occur in younger adults (*e.g.*, the different stages associated with the rim at the pubic symphysis), alterations that

possibly will not be represented in the Bass collection. The higher number of individuals in the Coimbra collection sample also allows for the exclusion of some individuals for some of the degenerative criteria analysis due to *post-mortem* damage that the collection has suffered from the constant handling by researchers. In contrast, the Bass collection may have a better representation of the age-related changes characteristic of older individuals than the Coimbra collection. This difference may not allow a straightforward comparison between both collections, as would be desired, but it may enable some understanding of bone degeneration processes at younger and older stages, that would not be possible if the same number of individuals by age range were established for both collections.

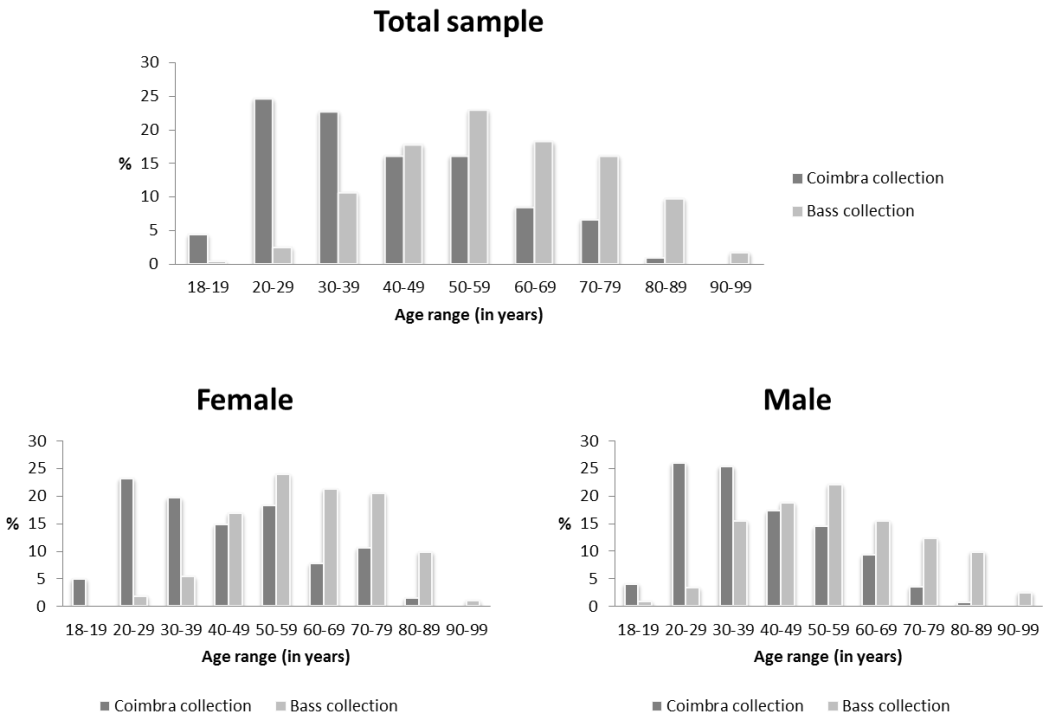

Figure 4.2. Comparison of the age distribution between Coimbra and Bass collections.

The parameters of the age at death distribution for the Bass collection sample are presented in Table 4.6. The sample is normally distributed (KS= 0.054, p= 0.093), therefore the age at death distributions for the separate sexes were compared with an independent samples T-test, showing a significant difference between them (t=2.120, p= 0.035). This difference seems to result from the lower proportion of female individuals between 30 and 39 years in comparison with males (Table 4.3).

Table 4.6. Mean, median and standard deviation age (in years) for the Bass collection.

Statistic	Females	Males	Pooled sexes
Mean	60	56	58
Median	60	54	58
Standard deviation	14.4	16.9	15.9

Bass collection individuals were born between 1904 and 1991 and died between 1981 and 2010.[17] Not all of the individuals have their year of birth recorded, and therefore when absent the age of birth was calculated with the same formula applied for the Coimbra collection (Section 4.1.2.1 of the present chapter). The representativeness of the Bass collection is displayed in Figure 4.3, showing that the 236 individuals are spread in all four quadrants, with ages at death superior or inferior than 50 years, and born before and after the year of 1950.

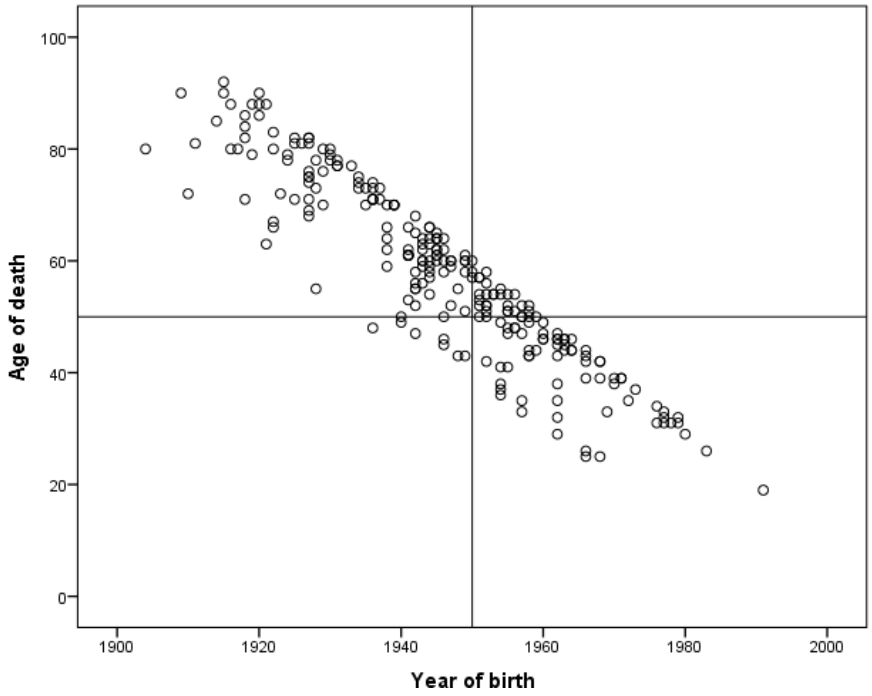

Figure 4.3. Bass individuals' representativeness according to age at death by year of birth.

[17] Female individuals were born between1904 and 1980, and males between 1909 and 1991. The year of birth for the Bass collection is normally distribution, therefore the assessment of possible differences between the two sexes was determined by an independent samples T-test, whose results show that females and males have a similar year of birth distribution (t= -0.635, p= 0.526).

The cause of death for the individuals from the Bass collection sample shows a different picture from the Coimbra collection (Table 4.7). There is a higher concentration of causes of death into the category "Symptoms, signs and abnormal clinical and laboratory finding not elsewhere classified" (22.5%), instead of the predominance of infectious and parasitic diseases as seen in the Coimbra collection. The lower percentage of infectious and parasitic diseases in the Bass collection is due to the exclusion criteria applied to selection into the body donation programme. Body donations for the University of Tennessee are declined if an individual had HIV, tuberculosis, hepatitis and/or an antibiotic resistant infection, such as Methicillin-resistant *Staphylococcus aureus*, unless cremated (Jantz and Jantz 2008; University of Tennessee 2014). For the present sample, the five cases of infectious disease refer mainly to septicaemia, with only one male individual reported with jaundice/hepatitis. The second most frequently reported cause of death was external causes of morbidity and mortality, with a higher incidence in males, comprising for example, suicides, gunshots wounds and motor vehicle accidents. Followed by unknown causes of death, neoplasms, and by diseases of the circulatory system. Female individuals present a higher percentage of neoplasms and diseases of the circulatory system, compared to male individuals.

Table 4.7. Causes of death for the William M. Bass Donated Skeletal Collection adapted from the international classification of disease W.H.O. (2010).

International classification of disease W.H.O.	**Female**		**Male**		**Total**	
	N	**%**	**N**	**%**	**N**	**%**
Certain infectious and parasitic diseases	1	0.9	4	3.3	5	2.1
Neoplasms	21	18.6	16	13.0	37	15.7
Endocrine, nutritional and metabolic diseases	1	0.9	0	0.0	1	0.4
Mental and behavioural disorders	0	0.0	1	0.8	1	0.4
Diseases of the nervous system	2	1.8	2	1.6	4	1.7
Diseases of the circulatory system	17	15.0	10	8.1	27	11.4
Diseases of the respiratory system	7	6.2	7	5.7	14	5.9
Diseases of the digestive system	1	0.9	0	0.0	1	0.4
Diseases of the musculoskeletal system and connective tissue	2	1.8	0	0.0	2	0.8
Diseases of the genitourinary system	2	1.8	0	0.0	2	0.8
Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	27	23.9	26	21.1	53	22.5
Injury, poisoning and certain other consequences of external causes	4	3.5	2	1.6	6	2.5
External causes of morbidity and mortality	7	6.2	31	25.2	38	16.1
Unknown	21	18.6	24	19.5	45	19.1

As for the cause of death, the occupation groups' distribution for the Bass collection sample also differs from the Coimbra collection sample (compare Tables 4.4 and 4.8). The Bass collection has a high percentage of cases in which the occupation was not recorded, with only two recorded as unemployed. A few individuals also have recorded some of the activities they performed in life, including ballroom dancing, fishing and football in high school. Females show a more diverse range of occupations performed in life compared to the 19th and beginning of the 20th century Portuguese females. American females present a higher frequency of qualified worker/services/commerce occupations, followed by professions in the administrative sector, academic/intellectual occupations but also at cleaning and maintenance/domestic occupation. For the three females whose occupation was recorded both as a profession and as housewives, these were not considered to have more than one occupation, but were classified according to the first profession (secretary, cook and caregiver). The American males, similarly to the Coimbra collection males, have a high percentage of individuals classified as qualified worker/services/commerce, followed by academic/intellectual occupations, although they have a lower percentage compared with females (males: 12.2%; females: 16.8%).

Table 4.8. Bass collection sample distribution by occupational groups.

Occupation groups	Females		Males		Pooled sexes	
	N	%	N	%	N	%
Academic/intellectual occupations	19	16.8	15	12.2	34	14.4
Administrative occupations	20	17.7	6	4.9	26	11.0
Army/Navy	0	0.0	2	1.6	2	0.8
Cleaning and maintenance/Domestic	19	16.8	0	0.0	19	8.1
Farmers	0	0.0	1	0.8	1	0.4
Landlords	0	0.0	1	0.8	1	0.4
More than one occupation	1	0.9	2	1.6	3	1.3
Qualified worker/Services/Commerce	27	23.9	42	34.1	69	29.2
Transport	0	0.0	6	4.9	6	2.5
Unskilled worker	2	1.8	4	3.3	6	2.5
Unknown/unemployed	25	22.1	44	35.8	69	29.2

4.2. METHODOLOGY

This section describes the methodology followed to analyse whether skeletal size

influences age-related bone degeneration at the pubic symphysis, auricular surface and acetabulum. The statistical analysis was performed with the software IBM SPSS Statistics version 22, Windows Excel version 2013 and Excel software version 2013.

4.2.1. Analysis of the degenerative characteristics of the pelvic articulations

The present research aims to determine if skeletal body size influences bone degeneration in adults. Therefore, age-related degenerative characteristics were analysed macroscopically in three pelvic articulations: acetabulum, iliac auricular surface and pubic symphysis. For a better understanding of the bone degeneration process at the pelvic articulations, the analysis was undertaken at three different levels of study, ranging from the particular to the general. It was analysed each trait, secondly components (correlated traits established with a principal components analysis and a partial correlation controlling for age), and finally composite score (sum of all the scores obtained for each trait).

4.2.1.1. First level of analysis: degenerative traits analysis

Age-related bone traits were recorded independently according to a quantitative scoring system adapted from literature sources (Todd 1920, 1921a, 1921b; Lovejoy *et al.* 1985b; Brooks and Suchey 1990; Buckberry and Chamberlain 2002; Rissech *et al.* 2006; Harnett 2007, 2010; Campanacho 2010; Calce and Rogers 2011). The traits analysed for the three joints are listed in Table 4.9 (a detailed description of each studied trait can be found in Appendix 1).

A desk lamp was used during inspection of articular surfaces and, when necessary, a magnifying glass to aid the observation of smaller characteristics, such as microporosity on the auricular surface. The acetabulum, auricular surface and pubic symphysis were studied at separate times for each specimen, as were the left and the right sides to avoid observation bias. For example, firstly all the left pubic bones were analysed, followed by all the right pubic bones. The same procedure was performed for the acetabulum and the auricular surface separately. A distinct observation of each joint ensures that the observation of the left side does not influence the trait recording of the right side of the same individual, and similarly between the three joints. Only acetabular degenerative characteristics were observed twice at the Identified Skeletal Collection from the University of Coimbra, but

solely the data from the second observation was used in the statistical analysis. A second analysis was necessary due to the author's initial inexperience in analysing acetabular degenerative traits. The analysis was made without knowing the age at death of the individuals.

Table 4.9. List of the traits analysed for the acetabulum, the auricular surface and the pubic symphysis.

Acetabulum	**Pubic symphysis**
Rim shape	Billowing
Rim porosity	Inferior extremity
Groove	Superior extremity
Apex activity	Dorsal plateau
Activity on the outer edge of the fossa	Ventral rampart
Acetabular fossa	Symphyseal rim
	Symphyseal face shape
Auricular surface	Erosion of the symphyseal face
Transverse organization	Erosion of the symphyseal rim
Fine granularity	Dorsal body of the pubic bone
Coarse granularity	Ventral body of the pubic bone
Dense bone	Ventral beveling
Microporosity	Ligamentous outgrowths on the ventral bevelling
Macroporosity	Pubic tubercle
Apical area	Medial aspect of the *Obturator foramen*
Lipping	

For each trait score the number of individuals was calculated (due to *post-mortem* destruction not all traits were recorded in every individual), as well as age descriptive statistics, such as mean, median, standard deviation, and minimum and maximum ages. This calculation was made separately for the Bass and Coimbra collections. For some traits, original scores stages were fused due to the low number of individuals in some of the scores, in order to increase the number of subjects. Even though not always the same number of individuals by score was similar in both collections, the new score system was applied equally to Coimbra and Bass collections. The new scores are presented in Appendix 2. The combining of scores was not possible to apply as a solution to increase the number of individuals due to the scores stages incompatibility. For example, only one individual was recorded for

score 1 (absence) of the pubic symphysis' superior extremity from the Coimbra collection. However, it was not possible to fuse score 1 with score 2, since the second score measures the level of superior extremity presence.

4.2.1.2. Second level of analysis: traits components

The second level of the analysis consists of correlated age-traits that can form components. To determine the features that share most degenerative variance with each other and can therefore be clustered into components two statistical tests, a principal components analysis (PCA) and a partial correlation between traits controlling for age at death, were undertaken. The analyses were carried out for each articulation for the pooled sexes sample for each skeletal collection separately.

PCA is an exploratory multivariate statistical technique that indicates patterns of correlation between variables that share the most variance with each other (Field 2005; Dancey and Reidy 2007). PCA analyses all variables' common and unique variance (specific + error/random), assuming no error in the data exists (Dancey and Reidy 2007). The more shared variance variables have between them, the lower is the unique variance, but if the inverse is true, the higher unique variance the variables have, the less is the value of common variance (Dancey and Reidy 2007). Not all variables are correlated, but those that share a high variance constitute a linear component (Dancey and Reidy 2007).

PCA first calculates a pairwise matrix of correlation coefficients between variables, also designated by an R-matrix, that corresponds to Pearson's r coefficient[18], whose values range from 0 (unrelated variables) to 1 (perfect correlation between variables), with significant r values at $p \leq 0.05$ (Field 2005; Dancey and Reidy 2007). In the present study, a Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) was calculated. KMO is the ratio between the sum of the partial correlation between variables and the sum of the correlation, ranging from 0 to 1 values (Tabachnick and Fidell 1989; Field 2005). A value of 0 reports that the analysis is inadequate, since indicates a diffuse correlation pattern, because the sum of the partial correlations is higher compared to the sum of correlations, and in opposition, a KMO of 1 indicated a reliable components formation by the PCA (Tabachnick and Fidell 1989; Field 2005). Kaiser indicates that a KMO value of 0.5

[18] A Pearson's r coefficient requires normally distributed metric variables, however principal components analysis still produces valid results with ordinal and binary variables (Drennan 2009).

is the cut-point between what is acceptable or not, *i.e.* considering values between 0.5 and 0.7 as acceptable; between 0.7 and 0.8 as good; between 0.8 and 0.9 as great; and values greater than 0.9 as excellent (Field 2005). Furthermore a Bartlett's test of sphericity was performed. Bartlett's test the null hypotheses that the correlation is zero at the coefficient matrix, but if $p \leq 0.05$ the null hypothesis is rejected, indicated that the correlation between variables is significant (Tabachnick and Fidell 1989; Maroco 2007).

Posteriorly, after the components are extracted, the factorial axes from the coefficient matrix are rotated, in order to find a better discrimination between components (Field 2005; Dancey and Reidy 2007; Maroco 2007; Abdi and Williams 2010). In the present study, a varimax orthogonal rotation was used, which makes sure that every component of the coefficient matrix continues to be independent of each other, even after rotation, by maximizing the higher correlation and minimizing the low correlations (Field 2005; Dancey and Reidy 2007; Abdi and Williams 2010). For the varimax rotation, it was selected as a cut-off point loading values >0.40, in order to obtain a better interpretation of which components to be retained, as suggested by Field (2005). Loading values refers to the correlation coefficients between variables and a component (Abdi and Williams 2010). Only loading values higher than 0.40 – which contribute significantly to a component – will be presented for the varimax orthogonal rotated component matrix results, Varimax rotation can be represented as (Maroco 2007):

$$L^* = LT$$

and,

$$V = \frac{1}{p} \sum_{j=1}^{n} \left[p \sum_{i=}^{p} \frac{l_{ij}^{*4}}{b_i^{*4}} - \left(\sum_{i=}^{p} \frac{l_{ij}^{*2}}{b_i^{*2}} \right)^2 \right]$$

In the first formula, L represents the correlation coefficient matrix, and T the orthogonal matrix. The second formula reports to the variance of the squared factorial/component weight for each variable. Therefore, varimax rotation aims to determine the orthogonal matrix T, with the maximum variance if the communalities do not change (Maroco 2007).

The Kaiser's criterion was also followed at the PCA calculation in which only components with eigenvalues ≥ 1 were maintained (Field 2005; Maroco 2007),

meaning that not all components are retained. Eigenvalues represent the amount of variance the component has (Dancey and Reidy 2007; Maroco 2007), in which a component with an eigenvalue of 1 is considered to have a substantial proportion of variance (Field 2005). However, some authors consider being a very strict condition. Nevertheless, the Kaiser's criterion implies that only components with a high variance from the original variables are maintained (Field 2005). However, the Kaiser's criterion is more reliable when the sample is larger than 250 with an average communality higher than 0.6, or the number of variables does not exceed 30 with communalities higher than 0.7 (Field 2005).

In the present study, the PCA was performed to understand bone degenerative structure of the traits for each articulation in the Bass and Coimbra collections. PCA results and conclusions are limited to the samples under study, and population generalizations can only be made if the same components are obtained when studying different samples (Field 2005). Therefore, PCA results obtained in the present investigation are restricted only to the Bass and Coimbra samples and are not generalised to the population levels, since several samples from the same population were not studied.

Additionally partial correlation between traits, but controlling for age at death, was performed. Partial correlation results will assist in the components formation along with the PCA results, especially when in the PCA the same trait is included at different components. The partial correlation measures only the correlation (shared variance at bone degeneration) that exists between traits without age at death affecting the results. At the partial correlation is formed a correlation matrix with patterns of correlation, whose coefficient correlation (r) values also ranges from 0 (low correlation) to 1 (high correlation) (Dancey and Reidy 2007). Partial correlation aims to determine the percentage of common variance between features. However the lower the r value is, higher is the independence between traits, meaning that the proportion of unique variance is high. The proportion (%) of shared variance between bone degeneration features was also determined by the formula (Field 2005; Dancey and Reidy 2007):

$$r^2 \times 100$$

Where, r^2 corresponds to the correlation coefficient squared. After carrying out a PCA and a partial correlation analysis and determining which traits are most correlated, components were formed by summing up the scores of the correlated

traits for the same individual. For each component was calculated the number of individuals, and age descriptive statistics, such as age mean, median, standard deviation, and minimum and maximum age for each Bass and Coimbra collections.

4.2.1.3. Third level of analysis: composite score analysis

A composite score is the sum of the scores for all traits at the same individual (Buckberrry and Chamberlain 2002), representing a broad bone degeneration phase at a joint.

The composite score could only be calculated for those individuals whose scores were recorded for all traits. In some traits, it was not possible to record the trait due to *post-mortem* destruction. Therefore, those cases were not included in the composite score analysis. A statistical imputation of the missing trait value, *i.e.* by regression mean imputation, was not performed. The missing score imputation would derive from an artificial value and not from the direct observation of the trait. Besides the missing scores imputation is calculated by taking in consideration the recorded traits scores values at a joint. However, not all traits are correlated. Therefore, the imputation of missing values may not reflect the true metamorphosis stage, creating bias and error at the composite score level.

A Kendall's W coefficient of concordance between ranks was also calculated to measure the agreement between variables (Field 2005; Legendre 2005), in order to quantify the exact level of concordance or independence between the traits' metamorphosis at the same joint, and if at least a moderate agreement was obtained, the composite score was calculated. As the concordance coefficient, the Kendall's W coefficient of concordance varies between 0 and 1, with the value 0 indicating a *no agreement*, and the value 1 a *complete agreement between variables* (Field 2005; Legendre 2005). Even though Kendall's W coefficient of concordance can be calculated from two formulas, exemplified below, the same value of W is obtained (Legendre 2005):

$$W = \frac{12S}{m^2\,(n^3 - n) - mT}$$

or,

$$W = \frac{12S' - 3m^2 n\,(n+1)^2}{m^2\,(n^3 - n) - mT}$$

Where, $S = \sum_{i=1}^{n} \quad (R_i - \bar{R})^2$ and, $S' = \sum_{i=1}^{n} R_i^2 = SSR$, with R_i is the row-marginal sums of the ranks and $\bar{R}$ is the mean of the R_i values. The *m* represents the number of variables, *n* the number of objects and T is the correction factor for tied ranks ($T = \sum_{k=1}^{m} \quad (T_K^3 - T_K)$; where T_K is the number of tied rank in each (K) of m groups of ties). The Kendall's W coefficient of concordance was calculated with a significance of 0.05. For the composite score, the number of individuals and age descriptive statistics, such as mean, median, standard deviation, and minimum and maximum age were calculated. The analysis was made for each articulation for the Bass and Coimbra collections separately.

4.2.2. Estimation of femur robusticity, body mass, stature and pelvic joint area

This section contains a description of the skeletal anthropometric measurements that were performed to determine stature, body mass, robusticity and pelvic joints' surface area.

4.2.2.1. Femur measurements as an osteological proxy of stature, body mass and robusticity

Femur measurements were used as an osteological proxy for stature, body mass and robusticity. Even though the biographic records of some of the individuals from the Bass collection include stature and weight, to make the data comparable with the individuals in the Coimbra collection – whose stature and weight is unknown – and to make the procedure applicable to unidentified skeletal remains, only anthropometric measurements of the femur were used.

The maximum length of the femur was used as a proxy for stature, since it has been reported as the measurement with the best positive correlation with stature (Trotter and Gleser 1951b, 1958; Jantz and Jantz 1999; Mendonça 2000; Kemkes-Grottenthales 2005). It was decided not to use a regression formula to estimate stature due to the population specificity associated with these formulae, and because the present study analyses two samples from very distinct populations, therefore it was more appropriate to use the maximum femoral length. Maximum femoral length was measured according to Bass (1995): the distal condyles were directed to the osteometric board fixed structure, and to the femoral head is put the mobile structure. The femur is then slightly moved until the maximum height is obtained. The femoral maximum height was recorded to the nearest 1 mm.

The vertical diameter of the femoral head was used as proxy for body mass, since vertical (superior-inferior) diameter of the femur head has an association with body mass (Ruff *et al.* 1997). The vertical diameter of the femur head was measured with a digital sliding calliper to the nearest 0.1 mm. When it was not possible to measure directly the vertical diameter, this was calculated by transforming the horizontal (anteroposterior) diameter with the following formula (Ruff *et al.* 2006)[19]:

Vertical head diameter = 1.004 x horizontal head diameter

In contrast to stature and body mass, which have a higher association with specific measurements, the same is not applicable to robusticity. Due to difficulty of using just one measurement in association with robusticity, the midshaft robusticity formula by Wescott (2001, 2008) was calculated:

$$100 \times (\sqrt{APS} \times MLS)/FHD$$

The femoral vertical diameter (FHD) was measured with a sliding digital calliper (Wescott personal communication). The diaphysis midpoint was determined by measuring the femoral length with an osteometric board and using a pencil to indicate the midpoint. This allowed the measurement of the maximum anterior-posterior midshaft diameter (APS) with a digital sliding calliper (Bass 1995). Midshaft mediolateral diameter (MLS) was measured at right angles to the midshaft anterior-posterior diameter with a digital sliding calliper (Bass 1995). It should be recorded with the *linea aspera* midway between the two branches of the sliding calliper. All measurements were measured to the nearest 0.1 mm.

4.2.2.2. Area calculation of the acetabulum, auricular surface and pubic symphysis

The pubic symphysis, iliac auricular surface and acetabulum may present an irregular topography and border, irregularity that possibly will increase with age, and therefore it is difficult to measure the joint area surface with traditional anthropometric measurement techniques. Hence, the surface areas of the

[19] The vertical diameter and horizontal diameter of the femoral head are similar, and all body mass estimation equations use the vertical diameter of the femoral head (Ruff et al. 2006). Therefore, a ratio for converting between the two diameters was calculated to have the vertical diameter of the femoral head analysed for all individuals.

articulations were computed from three dimensional (3D) polygonal images (virtual copies of the pelvic surface).

Each pelvic bone from both sides[20] was digitized with a structured white light 3D scanner from the Department of Archaeology, University of Sheffield. The structured white light scanner consists of a projector with two cameras. The projector is an Optoma Ex330e DLP, with, a brightness of 2200 lumens, a native XG resolution 1024x768, and a contrast of 2000:1. Both cameras are a U Eye UI 1545LE-M-HQ model, with a resolution of 1280 (H) x 1024 (V) pixel, SXGA with 1.3 megapixel, and with an exposure time in freerun mode of 35µs - 980 ms. The cameras are equipped with Fujinon 1:1.4/12.5mm HF12.5SA-1 lenses. With a structured white scanner a pattern of bright and dark stripes is projected over the bone, allowing the light reflection to be detected by the cameras (sensors), which constitutes an optical triangulation system, represented in Figure 4.4 (Rocchini *et al.* 2001; Sadlo *et al*. 2005; Li *et al.* 2006; Lane and Harrel Jr. 2008; Georgopoulos *et al.* 2010; Rodríguez-Quiñonez *et al.* 2011; Friess 2012; Weber 2014).

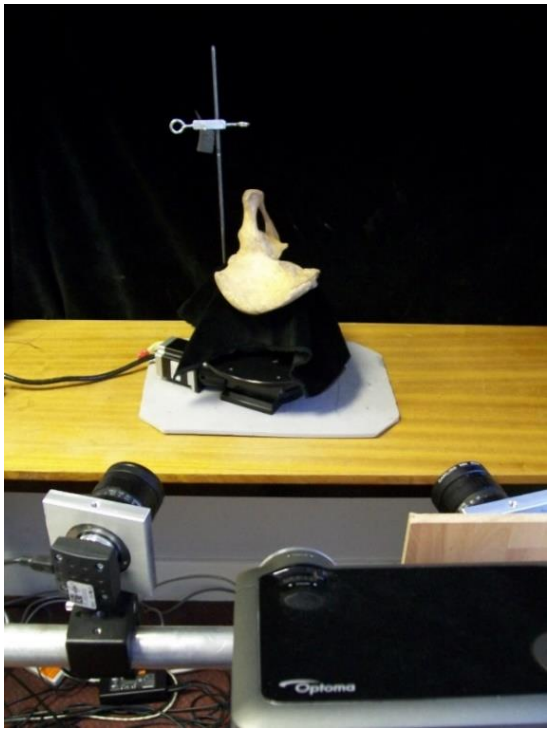

Figure 4.4. A left pelvic bone and the scanner components (two cameras and a projector) in position to perform the scanning.

[20] Due to technical problems associated with the rotation plate it was only possible to manually digitize the left pelvic bone from the Bass collection since a manual digitalization increases the time per bone (Friess 2012).

The position of the cameras is associated with the position of the rotation table, where the bone was digitized. The distance between the cameras is approximately half the distance between the cameras and the rotation table, and the cameras should be positioned equally to either side of the projector. Not all areas of the bone are reflected from the light source, since the cameras do not capture narrow and deep structures outside the triangulation viewpoints (Friess 2012). In addition, the system does not recognize the colour black, which consequently leaves holes in the 3D polygon model. To create less noise from the surrounding environment during digitalization a black background was positioned behind the bone. The lighting in the laboratory facilities of the Bass and Coimbra collections were controlled in order to create the minimum noise possible. The cameras and projector were focused carefully to ensure the digitalization quality. Firstly, the pelvic bone were digitalized with a rotation motion (covering 360º), subsequently it was digitalized manually for the bone zones that were not initially captured during rotation. Special attention was made regarding the pubic symphysis, auricular surface and acetabulum for them to have the smallest holes possible. It was not always possible to cover all of the surface area of the articulations due to the triangulation system, especially for the acetabulum, since it is a deeper articulation.

The scanner equipment was connected to the programme FlexScan 3D 3.1©, from 3D3 Solutions, LMI Technologies. Similarly, to a photograph, each image is captured of the bone in different perspectives. In this programme, each image is transformed into dense 3D polygonal meshes (triangulated point cloud, Remondino and El-Hakim 2006; Friess 2012) of only the bone surface. The meshes are automatically and temporarily aligned reconstructing a 3D model of the pelvic bone (Figure 4.5), due to the application of a merging algorithm. However, in order to be able to do the mesh align, each picture taken in different views has to have some overlapping areas (Sadlo *et al*. 2005; Remondino and El-Hakim 2006; Lane and Harrel Jr. 2008; Weber 2014). FlexScan 3D 3.1© was used to clean up any residual artefacts from the metallic structure used to position the pelvic bone during rotation during scanning.

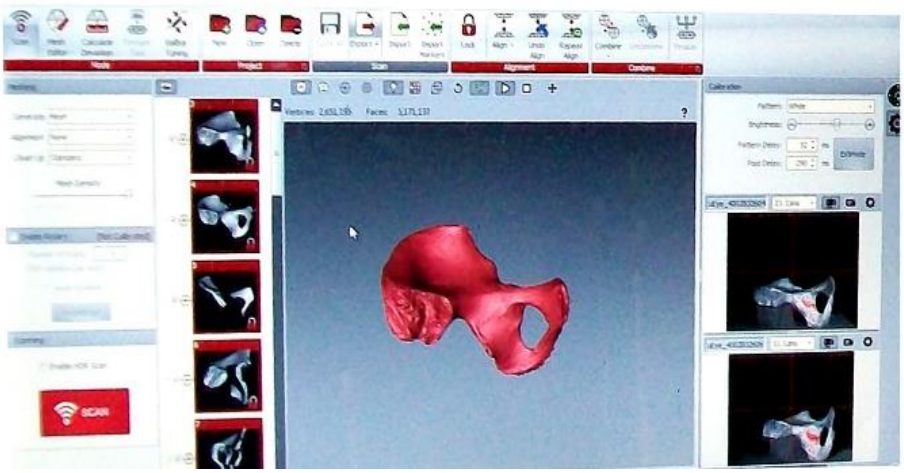

Figure 4.5. Pictures collected by both cameras whose mesh is temporary aligned to form a three-dimensional polygon object at the FlexScan 3D 3.1© software while scanning a left pelvic bone from the Bass collection.

A calibration table, with a chessboard pattern with 17 mm squares (Figure 4.6), was used to determine the sensors axis position in relation to the projector and cameras, before bone scanning. The calibration table was digitised at different positions on the rotation table in order to have calibration space coverage more than 75%. The chessboard pattern was processed with an algorithm in FlexScan 3D 3.1©. During and after calibration the scanner apparatus was not moved to avoid disrupting the scanning and to prevent the acquisition of inaccurate 3D models. As a precaution, to detect possible deviations of the scanner equipment, the colour tape was used to identify the position and place of different components.

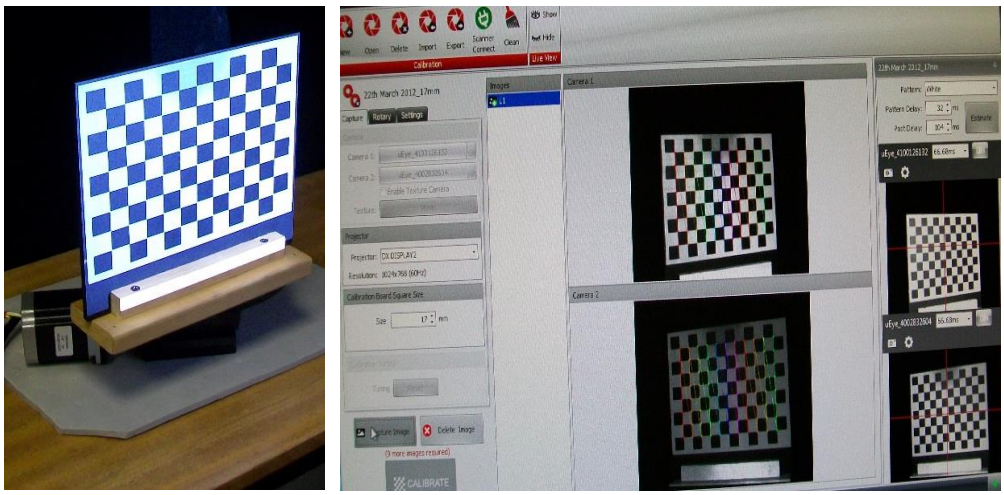

Figure 4.6. Calibration board at the rotation table (left image) and its capture by both cameras and imaged by the FlexScan software (right image).

In a second phase, the meshes were exported to the Geomagic Wrap© programme, version 12 - a post-processing tool - to calculate each articulation area. Geomagic Wrap© software merges each digitalized mesh, and allows gap filling of the holes representing areas not captured during the scanning. It also allows smoothing of the 3D polygon model, if necessary, with the removal of scanner noise, making the surface cleaner (Friess 2012). Figure 4.7 shows different view of a pelvic bone 3D polygon image by the FlexScan 3D3, and by the Geomagic Wrap© with the corresponding two dimensional (2D) pictures.

Only the surface area of the joint, limited by the border, was recorded to the nearest 1 mm^2, and is represented in Figure 4.8. When the rim is incomplete at the pubic symphysis the selection of the articulation area was made artificially according to the medial plane, and where there was an angle change at the superior and inferior limits. For the acetabulum and auricular surface meshes it is not possible to completely distinguish the lipping from the original border (Figure 4.9), therefore, when osteophytes were present, those were included in the establishment of the articulation border and not the original limit. The surface area was still computed and even if the scanner captured the porosity and bone erosion. Lipping and porosity can increase the value of the surface area, but correspond to the area the individual had at the time of the death, and small changes in the area in the same individual may affect bone degeneration. However, it is not just traits associated with older bone degeneration phases that increase the area surface, since in younger phases there exists peripheral macroporosity at the acetabular fossa and billowing in the pubic symphysis and auricular surface, which was also computed in the area calculation.

Two dimensional pictures of each articulation were taken to assist in the 3D area selection. In the 3D polygon model the surface area of the articulations was not computed if artefacts were present or if *post-mortem* damage was present across 5% or more of the joint area and if the 3D polygon had a large gap in the articulation that even after being filled in by Geomagic Wrap© it is noticeable that it is an artificial filling.

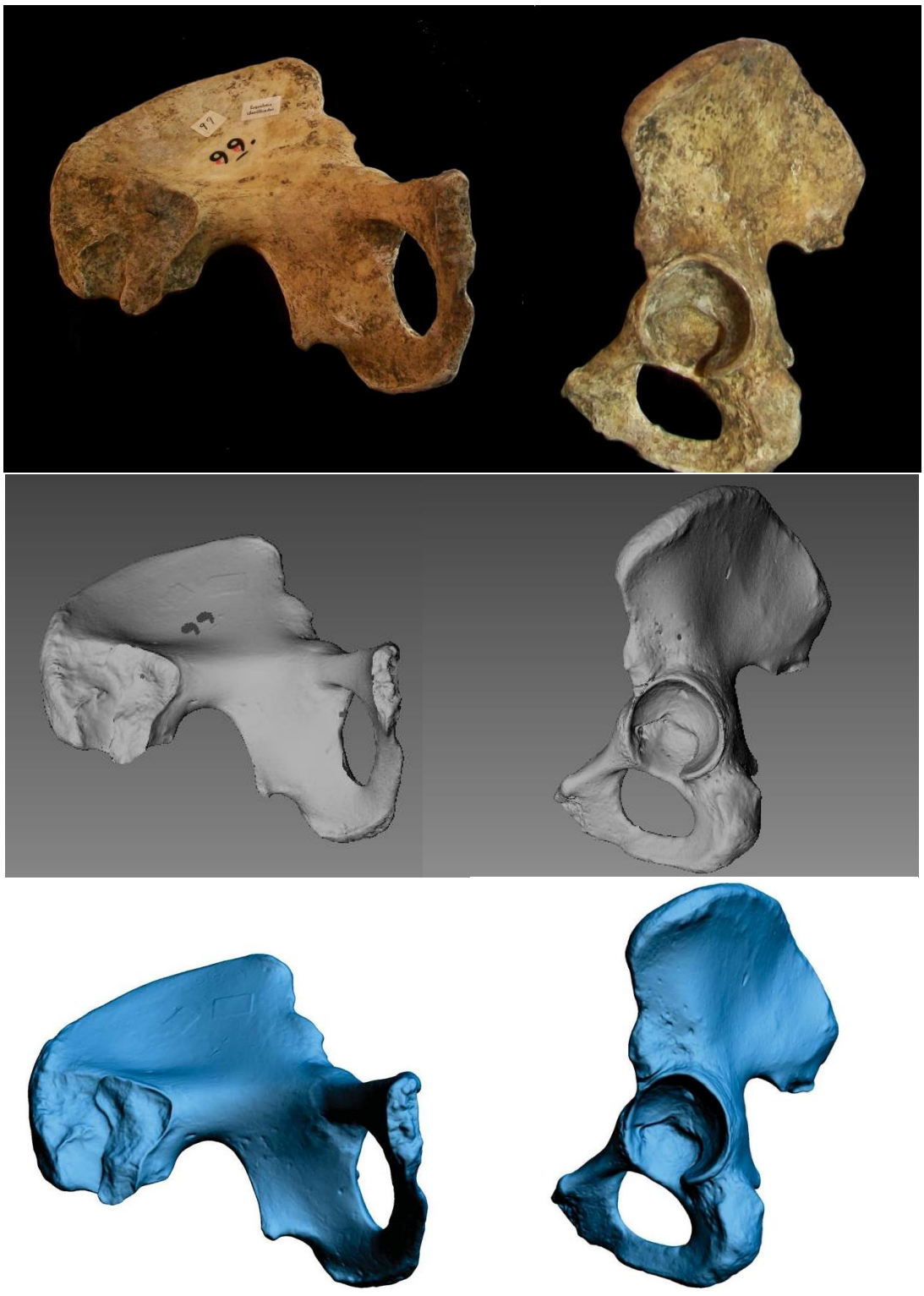

Figure 4.7. Two different views of the specimen 99's left pelvic bone from the Coimbra collection in two dimensional pictures, FlexScan 3D3, and Geomagic wrap© final three dimensional polygon object, respectively from top to bottom.

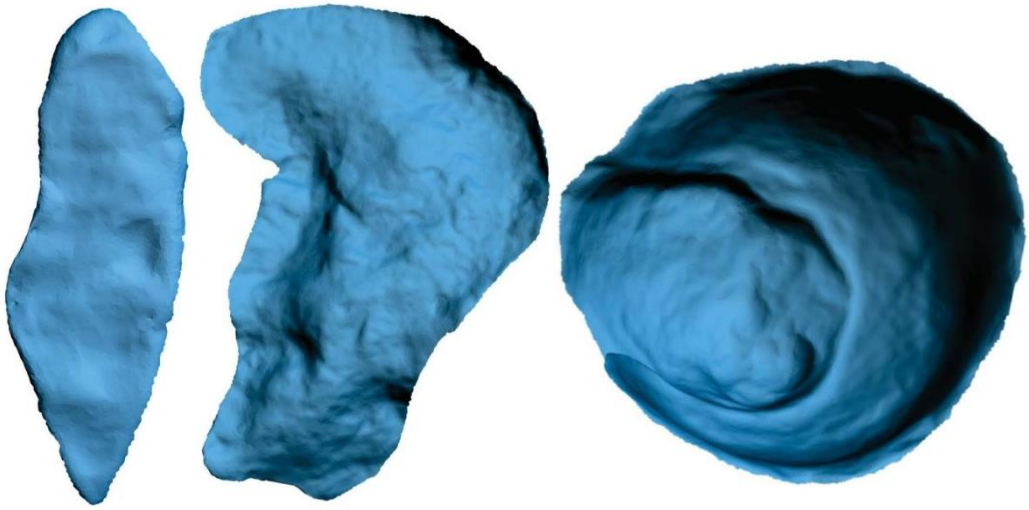

Figure 4.8. Surface area delimitation of three dimensional polygon, respectively from a pubic symphysis, auricular surface and acetabulum at Geomagic wrap©.

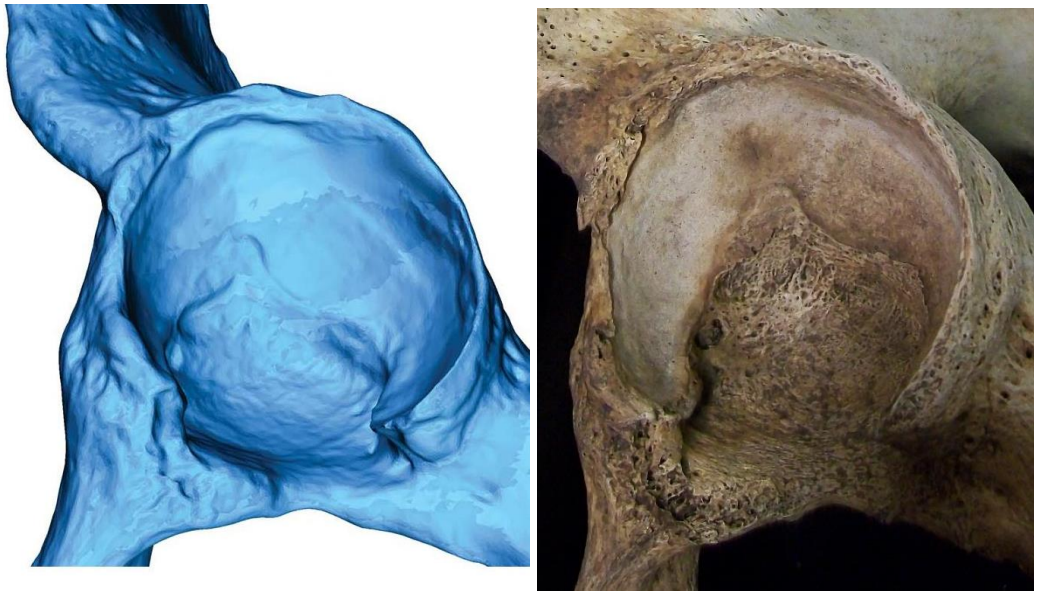

Figure 4.9. Left acetabulum joint UT3-09from the Bass collection with exuberant lipping non-discernible from the original border.

Fourteen pelvic bones were scanned a second time, from the Coimbra sample, to evaluate the deviation between two 3D polygon models of the same bone to evaluate the quality of the polygon models used to measure the joints surface area. The deviation analysis, computed by the Geomagic Wrap© software, measures the difference in position between the test 3D polygon model (the second polygon

object) and the reference polygon model (first model created and measured). The default criteria – maximum deviation: 10.4mm and critical angle: 45.0 - of the deviation analysis of the Geomagic Wrap© was followed, and it was recorded the maximum deviation, the average and the standard deviation of the deviation between test and reference models. The deviation analysis also creates a deviation spectrum with projects a color-coded mapping the differences between the test and reference models, as represented in Figure 4.10.

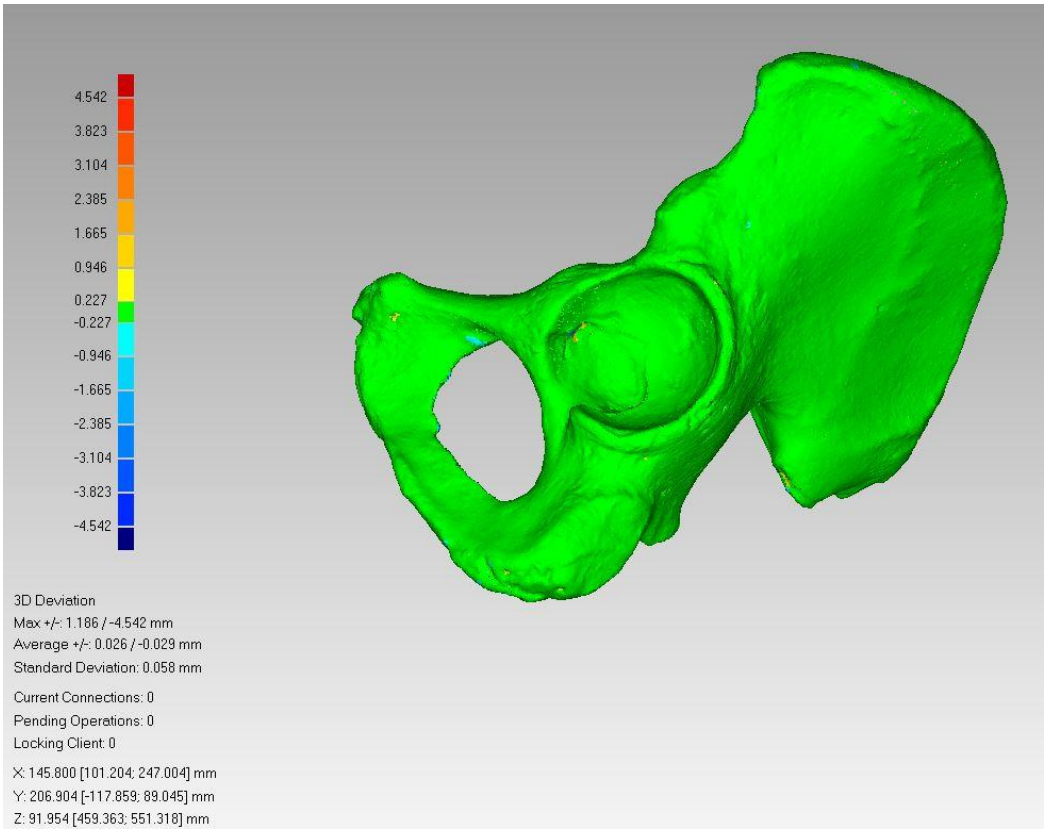

Figure 4.10. Color-coded mapping the deviation spectrum between the test and reference 3D polygon models from the left pelvic bone of the specimen 200 from the Coimbra collection.

4.2.3. Intraobserver error

The quality of the recorded data must be evaluated to determine the level of observation precision by the investigator and the error included in the observed variance, and how it may affect the results of the research. For example, an elevated observation error in anthropometric measurements can reduce the correlation magnitude, increase the mean variance, and may increase the probability of

incurring a type II error, acceptance of a false null hypothesis, when it should be rejected (Yezerinac *et al.* 1992; Cardoso 2005). Multivariate statistical tests are also more sensitive to a high measurement observation error (Jamison and Zegura 1974). Analysis precision should not be confused with accuracy since statistically they refer to different concepts (Yezerinac *et al.* 1992; Ferrante and Cameriere 2009). Accuracy measures the closeness the observed data has to the "true" (actual) value (Jamison and Zegura 1974; Yezerinac *et al.* 1992; Ferrante and Cameriere 2009). In contrast, precision quantifies the similarity between two observations of the same measurement at different moments (Yezerinac *et al.* 1992; Walther and Moore 2005; Ferrante and Cameriere 2009). Thus, precision is not related to the "true" value of the data as accuracy is but related only to the recorded values of the observed variables (Walther and Moore 2005). Precision can measure the repeatability (comparison of the variables analysis from two different moments by the same investigator – intraobserver error) and the reproducibility (evaluation of the data study made by two different raters – interobserver error) (Ferrante and Cameriere 2009). A high precision implies a lower observation random error (Walther and Moore 2005). In the present study, only data repeatability (intraobserver error) was determined for the age-related traits from the pelvic joints, the skeletal measurements and the quality of the three dimensional polygon models produced.

Two weeks after the first analysis was completed, 54 individuals were re-analysed from the Coimbra collection. From the 54 individuals, 20 pubic symphyses, 20 iliac auricular surfaces, 20 acetabulae were analysed at different moments as done for the traits observation (explained at section 2.2.1.1.). It was also re-measured 20 femurs and 20 3D polygons models. The selection of the 36 individuals was performed according to three criteria: 1) cases in which it was not possible to observe one or more variable due to *post-mortem* destruction were eliminated from the error sample; 2) without knowing the scores and measurements values obtained for the pelvic articulations' variables and the femur, individuals for which the three articulations and femurs were all present were selected; 3) as the cases with all four areas present do not add up to 20 individuals, therefore, more individuals were randomly selected to make 20 individuals per articulation and femurs.

4.2.3.1. Bone degeneration features repeatability

Ferrante and Cameriere (2009) criticised the lack of a systematic study of inter- and intraobserver error in most age at death estimation studies, asserting that it may have a negative consequence on age estimation. For age at death estimation methods by analysing the pelvic articulations metamorphosis when the observer error is reported it usually refers to the differences in age estimation stages, and not between the scores attributed to each age-related feature. Nevertheless, some recent studies present a more detailed scrutiny of observation error by traits (*i.e.* Rougé-Maillart *et al.* 2009; Campanacho 2010; Calce and Rogers 2011; Calce 2012).

The number and frequency of concordant cases between both observations were recorded. Cohen's kappa and Cohen's quadratic weighted kappa (Kw) was calculated to evaluate the intraobserver error, since both methods can be applied to evaluate the agreement between categorical (nominal and ordinal) variables (Fleiss and Cohen 1973). Cohen's kappa was used for binary scores and quadratic weighted kappa for variables with more than two scores.

Cohen's kappa allows the determination of the agreement between both observations correcting for chance (Fleiss and Cohen 1973; Kundel and Polansky 2003; Sim and Wright 2005; Vieira and Garret 2005; von Eye and von Eye 2005; Warrens 2010, 2013). Cohen's Kappa is formulated as:

$$K = \frac{(\pi_0 - \pi_e)}{(1 - \pi_e)}$$

Where, Π_0 represents the concordance proportion between first and second observations, and Π_e the expected proportion of agreement caused by chance alone (Kundel and Polansky 2003; Sim and Wright 2005; von Eye and von Eye 2005).

Cohen's kappa (K) considers all disagreements between both observations as having an equal weight, since the k value will be the same independently if the disagreement is between closer or distant scores, and consequently the k value diminishes as the number of categories in a variable increases (Fleiss and Cohen 1973; Kundel and Polasky 2003). It has been suggested that Cohen's quadratic weighted kappa (K_w) should be used for ordinal variables instead of the Cohen's kappa, since it will weigh differently the agreement between closer scores versus distant scores correcting for chance (Fleiss and Cohen 1973; Kundel and Polasky 2003; Sim and Wright 2005; Vieira and Garret 2005; von Eye and von Eye 2005; Warrens 2013). Cohen's quadratic weighted kappa formula is:

$$Kw_{ij} = 1 - \frac{(i-j)^2}{(k-1)^2}$$

The numerator is the number of disagreement categories, where, *i* refers to the row category on the scale, *j* is the number of the column. On the denominator, *k* is the total number of categories (Kundel and Polasky 2003; Sim and Wright 2005).

K and K_w values range between -1 and 1, where K = 0 specifies non-agreement between observations and K = 1 indicates an almost perfect agreement (Fleiss and Cohen 1973; Kundel and Polansky 2003; Sim and Wright 2005; Vieira and Garret 2005; von Eye and von Eye 2005; Ferrante and Cameriere 2009; Warrens 2013). In the present investigation, K and K_w values were evaluated according to the kappa evaluation system suggested by Landis and Koch (1977), represented in table 4.10.

Table 4.10. Landis and Koch (1977) evaluation system for kappa values.

Kappa value	Interpretation
< 0.00	Poor
0.00 - 0.20	Slight
0.21 - 0.40	Fair
0.41 - 0.60	Moderate
0.61 - 0.80	Substantial
0.81 - 1.00	Almost perfect

A paradox can occur where a high percentage of agreement and a low K and K_w appear together (Kundel and Polamsky 2003; Vieira and Garrett 2005). Therefore, priority was given to K or K_w value for the analysis of the observation error, since it allows determining the concordance between both observations correcting for chance. Feature that is not achieved by the percentage of concordant observations. However, K and K_w are also not free of problems, such as the fact it can be affected by the relative probability of each score at a trait and the number of categories/scores (Byrt *et al.* 1993; Kundel and Polasky 2003; Vieira and Garret 2005), and it was not always possible to compute when the trait is a constant. Therefore, it was also calculated the percentage of concordant observations to allow additional information regarding the observation error. In traits with k_w values below

0.60, indicate a moderate to lower level of agreement between the initial and second observations, the Cohen's quadratic weighted kappa test was repeated a second time, but with less categories for the variable by fusing some categories. In cases where K_w values would improve the fusion of the categories were maintained, if the K_w value did not increase the original scores were retained. The fusion of scores can increase the Kappa, but it can also lead to the decrease, dependent of which scores are fused, and therefore to obtain the maximum value the combination of scores should be performed by trial and error (Warrens 2010). In the present study, a trial and error analysis was not performed. Instead, the scores were fused taking into consideration the biological information, since the stage for the absence of the trait could not be fused with a score indicating the presence of the trait.

4.2.3.2. Femoral and **pelvic** *articulations' measurements error*

The intraobserver errors for the measurement analysis of the femur and the pelvic articulations area, from the same 3D polygon model, were evaluated with the technical error of measurement (TEM), the coefficient of reliability (R) and the mean average difference (MAD), which are appropriate statistical tests for continuous metric variables.

The technical error of measurement formula is:

$$TEM = \sqrt{\frac{\sum D^2}{2N}}$$

D is the difference between first and second measurements and *N* is the number of individuals analysed for the observation error (Jamison and Ward 1993; Cardoso 2005). TEM allows the determination of a measurements' precision when it is repeated, expressed with the same unit type as the variable studied (Cardoso 2005; Perini *et al.* 2005). The coefficient of reliability can be calculated as:

$$R = 1 - [\frac{(TEM)^2}{(SD)^2}]$$

Where, SD refers to the standard deviation of the first and second observation data (Cardoso 2005). The coefficient of reliability quantifies the proportion of the variance non-associated with measurement error, and whose values

range from 0 to 1 (Cardoso 2005). The coefficient of reliability allows calculating the percentage of observation error variance by the formula (1 – R) x 100. The mean average difference formula is:

$$MAD = \frac{\sum |D|}{N}$$

Mean average difference quantifies the absolute differences between both observations (Cardoso 2005). To understand the data distribution of the second observation and to help the intra-observer tests performed the mean, median, minimum and maximum values were also calculated.

4.2.4. Skeletal asymmetry

Asymmetry is the variation that exists between left and right sides of a dividing line at the medial plane or paired bones. It is a common phenomenon and implies that each half of the body may differ in skeletal anthropometric dimensions and features (Gawlikowska *et al.* 2007; Kujanová *et al.* 2008; Krishan 2011; Zaidi 2011; Franks and Cabo 2014). Even though body asymmetry aetiology is not fully understood it has been suggested that it may be due to environmental factors (various types of stress, for example, caused by inadequate nutrition and excessive noise), biomechanical loading, genetic and hormonal causes, or pathological factors (Auerbach and Ruff 2006; Kujanová *et al.* 2008; Özener 2010). Additionally, is associated with poor adaptation by the individual to those perturbations (van Dongen and Gangestad 2011). In the present study, it was determined if significant asymmetry existed between left and right sides, at two levels: morphologically, for each age-related trait from the pelvic articulations, and metrically, for the measurements taken at the femur and for the surface area of the joints. The asymmetry analysis shaped the subsequent investigation, since the data analysis would be adjusted depending on whether or not there was a significant asymmetry, *e.g.*, for the morphological traits if there were a significant asymmetry only data from the left side was studied; if no significant asymmetry the left side was studied. If the left side was not available, due to *post-mortem* destruction, the right side was used. The statistical procedures to determine if the asymmetry was significant for the studied variables are explained in detail below. The analysis was made only when data were recorded for left and right sides for the same individual.

4.2.4.1. Morphological asymmetry in the bone degenerative features from the **pelvic** *articulations*

The analysis to test if the asymmetry was significant in bone degeneration between left and right sides was only made for each morphological trait from the pubic symphysis, iliac auricular surface and the acetabulum. This step was only made for each trait, and not by components and composite score because the asymmetry analysis was carried out predominantly to determine which data to use to form the components and composite score. The analysis was run for the total samples, and by each sex, separately for Bass and Coimbra collection.

A Wilcoxon signed rank test was used to determine if the asymmetry is significant between left and right sides. The Wilcoxon signed rank test ranks the differences between left and right side scores, followed by the signed ranks' sum computation. Lastly, tests the signed ranks' sum for deviation from the value expected from a normal distribution. (Dancey and Reidy 2005; Field 2005). The significance p-value was determined with a Bonferroni correction. In multiple comparisons, there can occur the increase of the probability of error type I (accepting as true when no effect exists), however, by using a Bonferroni correction (dividing the p-value of 0.05 by the number of comparisons) it may resolve this issue by adjusting the significance of the p-value (Wright 1992; Field 2005; Abdi 2007). Conjointly it was calculated the number and percentage of asymmetrical cases, and the determination of which side, the right or the left, presents a higher score value when asymmetrical. If there were traits with significant asymmetry, only the left side data was subsequently analysed, even for traits that did not have a statistically significant asymmetry. This will allow to control any effect asymmetry may have in age markers at the pelvic articulations. The average of left and right sides values was not followed, because it would result in scores without a biological meaning. For example, if for acetabular apex activity a score of 1 (osteophyte is absent) was recorded for the left side, and a score of 2 (presence of a osteophyte with $\leq$ 2mm) for the right side, therefore an average of 1.5 would be obtained, which does not correspond to a concrete biological stage, suggesting an unclear trait expression between absence or presence. Furthermore, selecting the highest or lowest score value between left and right side by individual was not considered, because it would not control the significant asymmetry some traits have. Additionally, averaging or selecting the highest or lowest value would lead to a

smaller sample, because only individuals whose left and right side data were recorded would be included, which consequently would affect the present research negatively.

4.2.4.2. Metrical asymmetry at the skeletal size measurements and surface area at the pelvic joints

The metrical asymmetry analysis was performed for femur robusticity, body mass (superior-inferior diameter at femoral head), stature (femur maximum length) and surface area of the joints for the pooled sexes sample and by sex for each skeletal collection.

For left and right sides, it was calculated the number of individuals, medium, median, standard deviation, minimum and maximum measurement values. It was also calculated descriptive statistics for the difference between the measurement values obtained from the left and right femurs from the same individual. The statistical test to determine if the asymmetry is significant was decided based on the distribution normality of the measurements for each side with a Kolmogorov-Smirnov test. Data were normally distributed ($p > 0.05$ – data not shown) for most cases, except for, the right side at: 1) males for femur maximum length from the Bass collection; 2) vertical diameter of the femoral head for the right side for the pooled sexes from the Coimbra collection and left and right sides of the pooled sexes sample from the Bass collection; 3) femur robusticity for pooled sexes and males from the Coimbra collection; and 4) for females for pubic symphysis and acetabulum surface area from the Coimbra sample. Therefore, a paired samples t-test was calculated to determine if side asymmetry is significant.

A paired samples t-test determines if the differences between left and right sides average are statistically significant or if have arisen by chance, since it compares the t value - calculated from the average and standard deviation of differences between pairs of observations - with the theoretical t-distribution. This test can be formulated as:

$$t = \frac{\overline{D} - \mu D}{SD/\sqrt{N}}$$

$\overline{D}$ corresponds to the mean differences between left and right sides at the analysed sample, μD is the difference that it would be expected at a population level

and $SD/\sqrt{N}$ is the standard error difference, where SD is the standard deviation of differences at the sample and N the sample size (Field 2005).

When the asymmetry was significant, the paired samples t-test was repeated a second time without outliers (determined with a boxplot). The first and the second analysis were compared to determine if the elimination of the outliers were influencing the results or not. If the asymmetry continued to be statistically significant, the outliers were maintained in the analysis. It was also calculated the medium, median, minimum and maximum value for the difference between left and right sides. If significant symmetrical cases were present, it was decided to average the data between left and right sides to use in the subsequent statistical analysis. The exception was for the joint surface area. For the Bass sample, it was not possible to digitalize the right pelvic bone due to a malfunction of the rotary table. Without the rotary table, the bone were digitalized manually, whose process is slower, making only possible to scan the left pelvic bones in the time-frame it was given permission to study the Bass collection. For the Coimbra collection, even though a paired-samples t test was performed to determine if the asymmetry is significant, due to the lack of enough number of individuals to calculate the mean between the left and right sides, and also to make it more comparable to the Bass sample it was also analysed only the left side. The small number of individuals which the joint area surface was computed in both left and right sides was due mostly to *post-mortem* destruction at the articulation, and in some cases due to the presence of artefacts that influence the reliability of the 3D polygon object.

4.2.5. Establishment of the body size groups and anthropometric measurements' correlation with age

To understand if skeletal size influences bone degeneration rate with age at the pelvic articulations, the sample was divided according to joint surface area, femur robusticity, stature (maximum femur length) and body mass (vertical diameter of the femoral head). The number of individuals according to measurements is different due to the limitation imposed by *post-mortem* destruction, or even due to the existence of artefacts in the 3D images that prevented that accurate measurement of the object. Hence, for each anthropometric measurement the number of individuals and descriptive statistics (mean, median, standard deviation, minimum and maximum value) were recorded. Nevertheless, before dividing the samples into

groups, it was explored anthropometric relations. An independent samples t-test was performed to compare the mean between: 1) each sex in the same collection; and 2) between collections for total samples and by each sex.

A Kolmogorov-Smirnov test showed that the majority of data were normally distributed ($p > 0.05$ – data not shown), with the exception of the surface area of: 1) the auricular surface for the pooled sexes from the Coimbra sample; 2) the acetabulum for the pooled sexes from the Coimbra and Bass collections; and 3) for the auricular surface for the female individuals from the Bass collection. Therefore, since the majority of the cases present a normal distribution, the mean value was used as the cut-point value to establish the different groups described at tables 4.11. For example, for stature, an individual whose measurement is below to the mean constitutes the shorter individuals group, and if it is equal or above the mean value it forms the taller individuals group. Individuals with values closer to the mean were not eliminated from analysis, although their removal would increase the anthropometric differences between both groups, it would overly decrease the number of individuals and affect the subsequent analysis negatively. The groups' formation was made by total sample and by sex, according to the mean value, for Bass and Coimbra collections separately.

Table 4.11. Groups' designation by different anthropometric variables according, if the measurement value is inferior to the mean ($i < \bar{x}$), or if the measurement value is equal or superior to the mean ($i \geq \bar{x}$).

Anthropometric variable	Group ($i < \bar{x}$)	Group ($i \geq \bar{x}$)
Stature	Shorter individuals	Taller individuals
Body mass	Lighter individuals	Heavier individuals
Robusticity	Gracile individuals	Robust individuals
Joint surface area	Smaller articulations	Larger articulations

Descriptive statistics were calculated for each of the groups by total samples and by sex. Possible differences between age distributions of the groups were tested with independent t-tests. It is important to have similar age distributions between the different groups not to create a bias in the analysis. Descriptive statistics according to age distribution were also calculated for each morphological trait, components

and composite score from the pelvic articulations by each anthropometric measurement.

An association between femur measurements and age has been reported by some studies (*e.g.*, Borkan *et al.* 1982; Stinson 1985; Ruff *et al.* 1994; Kemkes-Grottenthaler 2005; Raxter *et al.* 2006; Niskanen *et al.* 2013; Fernihough and McGovern 2015). Thus, if age affects the measurements performed in the present study, it will inevitably cause bias in the results. The aim is using the different skeletal anthropometric measurements to compare the rate of bone aging metamorphosis in individuals with different sizes, but the results can be confusing and unreliable if the variables distinguishing between individuals are also affected by age. Pearson's correlation was used to determine the level of association between the anthropometric variables and age at death. Pearson's r measures the strength and direction of the correlation between quantitative variables (Moore and McCabe 1999; Pallant 2004). R values range between -1 and 1, where 0 indicates the lack of correlation and 1 a perfect association (Pallant 2004; Maroco 2007). The sign indicates the nature of the correlation, where a negative value indicates both variables have an inverse relation, and when it is positive, it means that both variables covary in the same direction (Pallant 2004). As with the Pearson's r correlation, the scatterplot represents visually the strength of the relationship bone between the two continuous variables (Moore and McCabe 1999; Pallant 2004; Dancey and Reidy 2007).

4.2.6. Bone degeneration associated with age and sexual dimorphism

Possible sexually dimorphic differences in bone metamorphosis at the pubic symphysis, auricular surface and acetabulum were investigated with twofold objectives, first to determine if there exists a statistically significant degenerative difference in bone metamorphosis at the articulations, a subject not explored extensively before, and second to determine if the female and male data sets should be analysed separately. The cases with a significant sexual difference in bone degeneration were subsequently analysed separately by each sex in addition to being studied as pooled sex samples. The effect of age on the metamorphosis of features, components and composite scores were quantified in order to determine if age is the most important factor in bone degeneration or if in some cases there is a small effect of age, suggesting other factors are involved.

A 2 x 3 Factorial Analysis of Variance (ANOVA) was performed to quantify the effects that sex and age at death (independent variables, IV) have on bone degeneration (dependent variable, DV): traits, components sums and composite score sums for each pelvic joint) for the Bass and Coimbra collections. A 2 x 3 Factorial ANOVA was also used to determine the interaction effect that both independent variables have on the dependent variable (Pallant 2004). The present study shows that the effect of age on bone degeneration is different in males and females. 2 x 3 Factorial ANOVA requires categorical variables to be selected as independent variables (Pallant 2004), so age at death, a metrical variable, was grouped into 3 categories: 18-29 years; 30-49 years; and +50 years. For the Factorial ANOVA, the F-statistic is calculated associated with a significance p-value, for each IV and the interaction between both IV (Field 2005). The F-statistic quantifies the ratio between the model variation (systematic variance) and the unsystematic variance (Field 2005), and is expressed by the formula (Tabachnick and Fidell 1989; Field 2005):

$$F = \frac{MS_M}{MS_R}$$

MS_M is the model mean squares and represents the average amount of variation by the model, in opposition MS_R is the residual mean squares and denotes the average variation by extraneous variables (Field 2005). F values significance is dependent upon the sample size, since the value of F is tested against the F distribution, taking into consideration the degrees of freedom and the p-value. For smaller samples, it is necessary to have a higher value of F, so that it is statistically significant than for larger samples. . Therefore, the Factorial ANOVA accounts for the possible sources of variance from each IV, and the interaction between them, have in the DV, but also from the error variance (Pallant 2004; Dancey and Reidy 2007).

It is argued that ANOVA results are more reliable if the assumptions of data normality and the homogeneity of variance are met (Field 2005). However, it is also argued that those assumptions are not strict since the ANOVA analysis can be robust when no normality or homogeneity of variance exists (Field 2005; Ehiwario *et al.* 2013). In the present study, bone degeneration data is not normally distributed, and not all criteria follow the homogeneity of variance (tested with a Levene's test of equality of error variances). If the sample number is similar between both sexes the

F- statistic tends to be robust even when the variance is heterogeneous (Field 2005; Ehiwario *et al.* 2013). Nevertheless in cases where the variance is heterogeneous (equal variances between samples for the DV were tested with a Levene's test $p \leq 0.05$) it can lead to the increase the probability of error type I occurring (Field 2005). Thus in the present investigation to decrease the probability of error type I a Bonferroni correction was employed to adjust the p-value significance.

Age association with bone degeneration was also quantified with a Spearman's rho correlation. Spearman's rho correlation is similar to Pearson's r correlation, except it applies to ordinal variables (Field 2005). Correlation with age was performed separately for the pooled sexes of Bass and Coimbra collections, and for the degenerative criteria that showed a significant sexual dimorphism according to the 2 x 3 Factorial ANOVA. A partial correlation between bone degeneration criteria and age at death was calculated, controlling separately for each body size variable – stature, body mass, robusticity and joint area surface - and by controlling all the body size variables. The results obtained for the Spearman's rho correlation and the partial correlation were compared to see if the r value changes by controlling for body size variables.

4.2.7. Bone degeneration rate comparison

To determine possible differences of bone degeneration between groups established for stature, body mass, robusticity and surface area of the pelvic joints a logistic regression with the method ENTER was used (Maroco 2007). Logistic regression determines the probability for one of the dependent variable categories to occur using binary variables as independent predictors (Maroco 2007). In the present study, the dependent variable refers to bone degeneration criteria (traits, components and composite score) in relation to the skeletal size variables and chronological age (continuous variables) as independent variables. Logistic regression is less affected by the uneven age at death distribution and by the non-normality or heteroscedasticity of the independent variables (Cardoso *et al.* 2010), and can be computed as (Kleinbaum 1992; Maroco 2007):

$$\text{Logit}\ (\Pi/1-\Pi) = a + b \times a$$

Logistic regression can be used to obtain the transition age (median age or 50^{th} percentile) from a younger stage to the subsequent older stage, giving the age when half of the individuals have attained the older stage. The 25^{th} and 75^{th} percentiles were also calculated to measure the variability around the median age. The transitional age and the percentiles were not obtained from the sample distribution, but calculated from the logistic regression formula model. When a criterion had more than two scores, the analysis was made from one score to the following and so on, *i.e.* pubic symphysis' dorsal plateau had 3 scores, therefore the logistic regression analysis was performed firstly between scores 1 and 2, and secondly between scores 2 and 3. Only for the Logistic regression analysis were the total sum values for the components and composite score assembled into smaller groups. This allows a more feasible comparison between stages, since it diminishes the number of times the logistic regression model is computed and can be used to analyse all the data due to the fact some of the sum values have very few individuals (the assembled stages for the composite score and components are represented in Appendix 3). Not in all cases were the sum grouped into stages, if there were less than 5 sum values and the number of individuals was more or less equivalent between sum values. The transition analysis was calculated by computing a logistic regression analysis with age at death as the predictor, separately for each group of individuals according to skeletal size variables, with the significance of the logistic regression coefficients being determined by the Wald statistic. A Homer and Lemeshow test was performed to determine the fitness of the logistic regression model. However, if the logistic regression model could not be fitted to the data, it was eliminated from the analysis.

If a significant and valid model was obtained for a criterion between opposite skeletal size groups, *i.e.* shorter individuals versus taller individuals, the logistic regression analysis was computed a second time, but with the inclusion of skeletal size variables as predictors alongside age at death. The analysis was done separately for stature, body mass, robusticity and surface area of the joints and those variables were treated as categories. This determines if the transition age is significantly different between groups and indicates if bone ageing occurs faster or slower for one of the groups. The significance was evaluated with the Wald statistic. The logistic regression analysis was carried out a third time by computing a combined model with age at death and skeletal size variables, but with age and size treated as a continuous variable. It is possible that treating the skeletal size as a continuous

variable can lead to a more sensitive model, compared to having the skeletal size variables as categories due to the interference that individuals close to the mean cut point value that distinguishes between categorical groups may have in the analysis.[21]

Some logistic regression models presented outliers (cases with two times values superior to the standard deviation (Maroco 2007). However, in the present analysis those were not eliminated because it was considered to reflect the nature of bone aging in adult individuals and that the elimination of the outliers would just bias the analysis. However, it was analysed if the outliers could be associated with an error made during observation by looking at the raw data.

The analysis was carried out for Bass and Coimbra collections separately.

[21] A Bonferroni correction was not employed to adjust the p-value significance - although multiple Wald values were calculated - due to the unequal number of valid models for pubic symphysis, auricular surface and acetabular traits between Coimbra and Bass collections.

CHAPTER 5
RESULTS

The present chapter summarises the results obtained from the empirical and statistical analysis performed with the data collected for the Coimbra and Bass collections. It will cover the results obtained for the following analyses: intra-observer error, asymmetry, and the creation of body size groups, establishment of pelvic joint components and composite score, and age at death, sex and body size effects pelvic bone ageing.

5.1. INTRA-OBSERVER ERROR

In the present section, intra-observer error results for the morphological analysis at the pubic symphysis, iliac auricular surface and acetabulum and for the anthropometric measurements calculated for the Coimbra collection are presented.

5.1.1. Precision of degenerative traits' analysis

Overall, Cohen's kappa (K), quadratic weighted kappa (K_w), number and percentage of agreement indicated a low intra-observer error for the majority of pubic symphysis, auricular surface and acetabulum traits. Intra-observer error results for pelvic joint traits are presented in Tables 5.1 to 5.3. In Table 5.3, only pubic symphysis features' K_w values are exhibited, excluding two binary traits, whose error analysis was performed with a K. For ventral bevelling, a significant K value of 1 was obtained, with 20 concordant observations (100%). For ligamentous outgrowths of the ventral bevelling (LOVBe), sixteen concordant observations (80%) were recorded, with a K value of 0.385 ($p= 0.071$). K and K_w values ranged between slight and almost perfect agreement, with better results for acetabular and pubic symphysis traits. However, most features presented an almost perfect or substantial agreement between analyses. For traits with a significant K and K_w values, a $\geq$ 65% of concordance between observations was obtained. For traits with non-significant kappa values, or if the kappa test was not possible to be computed (observations were a constant), intra-observer error was evaluated only through the number and percentage of concordance between analysis, whose analysis showed a

low error with observation concordance equal or higher than 80%.

Table 5.1. Intra-observer error for acetabular traits: number (N) and percentage (%) of concordant observations and weighted kappa (K_w) values, and corresponding categories interpretation according to Landis and Koch (1977). Strength of agreement are defined in Section 4.2.3.1.

Trait	No. categories	N	%	K_w	Strength of Agreement
Outer edge	4	13	65	1.000	Almost perfect
Acetabular rim shape	4	17	85	0.892	Almost perfect
Apex activity	3	17	85	0.815	Almost perfect
Acetabular groove	3	16	80	0.742	Substantial
Acetabular fossa	5	15	75	0.715	Substantial
Acetabular rim porosity	4	16	80	0.682	Substantial

Table 5.2. Number (N) and percentage (%) of concordant observations and kappa (K) and weighted kappa (K_w) values, for intra-observer error for auricular surface traits, and corresponding interpretation according to Landis and Koch (1977).

Trait	No. categories	N	%	K	K_w	Strength of Agreement
Dense bone	2	20	100	1.000	—	Almost perfect
Transverse organization	3	19	95	—	0.857	Almost perfect
Macroporosity	3	19	95	—	0.844	Almost perfect
Apical area	2	19	95	0.773	—	Substantial
Microporosity	3	18	90	—	0.404	Fair
Coarse granularity	3	17	85	—	0.063	Slight
Fine granularity	2	18	90	*	—	—
Lipping	2	17	85	0.318**	—	—

*It was not computed because fine granularity is a constant.
**Non-significant (p= 0.298).

Table 5.3. Intra-observer error for pubic symphysis trait analysis: number (N) and percentage (%) of concordant observations and weighted kappa (K_w) values and corresponding interpretation according to Landis and Koch (1977).

Trait	No. categories	N	%	K_w	Strength of Agreement
Superior extremity	3	20	100	1.000	Almost perfect
Inferior extremity	3	20	100	1.000	Almost perfect
Ventral rampart	3	20	100	1.000	Almost perfect
Medial aspect of the *obturator foramen*	3	20	100	1.000	Almost perfect
Symphyseal rim	4	19	95	0.898	Almost perfect
Billowing	3	18	90	0.856	Almost perfect
Dorsal body of the pubic bone	4	17	85	0.808	Almost perfect
Symphyseal face shape	5	13	65	0.801	Almost perfect
Ventral body of the pubic bone	5	13	65	0.489	Moderate
Pubic tubercle	3	18	90	0.459	Moderate
Erosion of the symphyseal face	3	18	90	0.444	Moderate
Dorsal plateau	3	19	95	*	—
Erosion of the symphyseal rim	3	17	85	*	—

*It was not computed because the trait is a constant.

Cohen's kappa and quadratic weighted kappa tests were performed a second time, with fused scores, for traits with kappa values below 0.60. The K value improved only for auricular surface microporosity, with K= 0.643, and 19 cases of agreement (95%) between both observations. Therefore, only for microporosity was score reduction maintained (from three to two scores).

5.1.2. Anthropometric measurements intra-observer error

In Tables 5.4 and 5.5 intra-observer error is displayed, respectively for femoral and joints surface area measurements, showing overall a low error. Values obtained for the coefficient of reliability (R) are high. For femoral measurements, intra-observer error variance ranged between 0.2% and 0.5%, and for joint surface area between 1.6% and 5.6%. Technical error of measurement and mean average difference were higher for joint surface areas, especially the acetabulum.

Table 5.4. Technical error of measurement (TEM), coefficient of reliability (R), mean average difference (MAD), minimum, maximum, mean, median and standard deviation (SD) values for second femoral measurements.

Statistics	Femoral head diameter	Anterior-posterior shaft diameter	Medial-lateral shaft diameter	Maximum length
TEM (mm)	0.172	0.155	0.120	0.806
R	0.997	0.995	0.997	0.998
MAD (mm)	0.065	0.010	0.060	0.200
Minimum (mm)	38.600	23.500	21.200	400.000
Maximum (mm)	51.100	31.600	30.000	465.000
Mean (mm)	43.640	27.570	26.250	426.750
Median (mm)	43.950	27.350	26.300	426.000
SD (mm)	3.238	2.192	2.200	18.918

Table 5.5. Technical error of measurement (TEM), coefficient of reliability (R), mean average difference (MAD), minimum, maximum, mean, median and standard deviation (SD) values for pelvic joint surface area measurements.

Statistics	Pubic symphysis area	Auricular surface area	Acetabulum area
TEM (mm^2)	20.156	37.143	56.983
R	0.944	0.955	0.984
MAD (mm^2)	11.750	23.150	69.850
Minimum (mm^2)	230.000	902.000	3117.000
Maximum (mm^2)	598.000	1552.000	4678.000
Mean (mm^2)	378.500	1245.200	3664.600
Median (mm^2)	368.500	1237.500	3712.500
SD (mm^2)	84.810	175.194	447.838

5.2. DEVIATION BETWEEN THREE DIMENSIONAL POLYGON MODELS

Deviation values between three dimensional (3D) polygon models - created at different moments - of the same pelvic bone were measured to evaluate model quality. In Table 5.6, maximum and average distance values between reference and test polygon models of fourteen pelvic bones are presented, indicating a low deviation. The only deviation value of concern was for positive maximum distance in Coimbra specimen number 217's left pelvic bone, although its average distance value was low. All fourteen pelvic bones were depicted in a green colour, with a few cases presented small areas of yellow (2.178mm to 0.523mm), light blue (-0.523mm to -2.178mm) and in one case darker blue (< -10.456mm). For specimen number 217 the deviation spectrum also showed a low deviation, presenting mainly a green colour (lower deviation between 0.523 mm to -0.523mm, Figure 5.1).

Table 5.6. Maximum, average and standard deviation distance values between test and reference polygon models (in mm).

Specimen	Side	Maximum distance		Average distance	Average distance		Standard deviation
		Positive	Negative		Positive	Negative	
179	L	1.375	-1.155	-0.012	0.029	-0.037	0.046
179	R	0.769	-1.121	0.007	0.029	-0.026	0.045
199	L	0.747	-1.627	-0.002	0.021	-0.018	0.034
199	R	1.105	-1.056	-0.009	0.020	-0.023	0.038
200	L	0.756	-1.306	0.005	0.028	-0.022	0.041
208	L	1.186	-4.542	-0.003	0.026	-0.029	0.058
217	L	10.455	-1.614	-0.016	0.022	-0.029	0.058
217	R	0.986	-1.139	-0.002	0.027	-0.027	0.046
237	L	2.610	-0.990	0.006	0.022	-0.017	0.036
237	R	0.920	-2.535	-0.009	0.029	-0.033	0.050
252	L	0.955	-0.833	-0.011	0.020	-0.022	0.029
252	R	0.733	-0.788	-0.019	0.021	-0.033	0.034
255	R	1.446	-1.324	-0.009	0.022	-0.029	0.047
264	L	0.977	-5.278	-0.042	0.028	-0.059	0.055

Legend: L- left, R- right

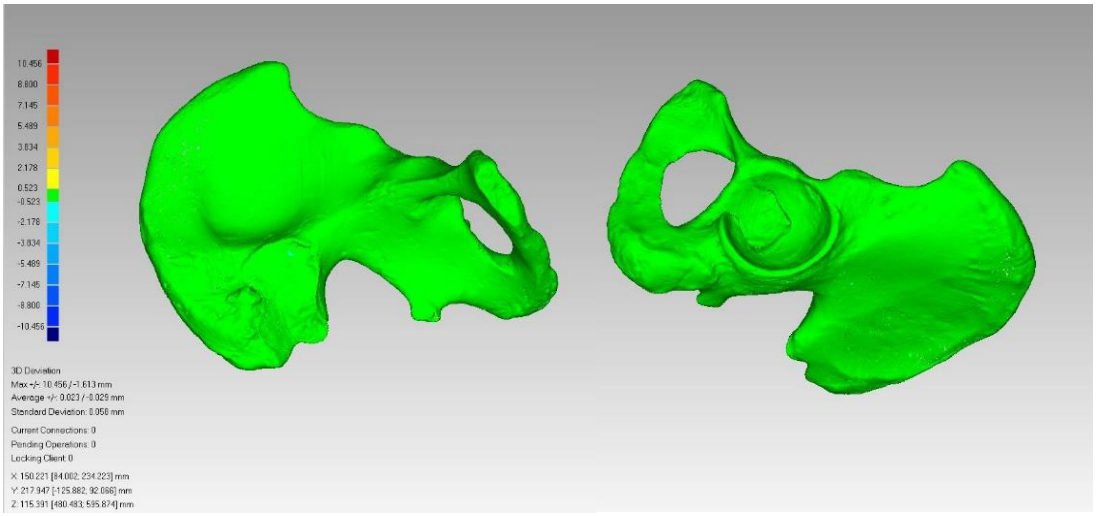

Figure 5.1. Deviation spectrum for the left pelvic bone of specimen number 217 from the Coimbra collection.

5.3. ASYMMETRY

Data from left and right side of pelvic joints and femurs for the same individual were compared. This analysis was important to decide how to shape the subsequent statistical investigation since the data analyses would be adjusted depending on if asymmetry was significant or not.

5.3.1. Traits degeneration asymmetry between left and right pelvic joints

5.3.1.1. Acetabular morphological trait asymmetry

For the Coimbra pooled sex and male samples, only activity and porosity of the acetabular fossa presented a significant asymmetry, with higher scores attributed to right side compared with left side data (Table 5.7). Even for nonsignificant asymmetrical traits a right side higher score was attributed.

Wilcoxon results that indicate significant asymmetrical acetabular traits for the Bass collection are presented in Table 5.8. For the pooled sex sample, four traits presented a significant asymmetry, with a majority of traits exhibited right side dominance (a higher score). For each sex, only male acetabular grooves showed a significant asymmetry with left side dominance. Right side dominance was recorded for a majority of traits but without a significant asymmetry. By comparing both collections, a higher number of significant asymmetrical acetabular traits were recorded for the Bass pooled sex sample than for the Coimbra collection.

Table 5.7. Number (n) and percentage (%) of asymmetrical acetabular traits from analysed cases (N), and Wilcoxon test results for the Coimbra collection (Bonferroni correction: p<0.008).

Sample	Trait	N	n	%	Wilcoxon test				
					Z	p	n left	n right	Ties
Pooled sex sample	Acetabular groove	282	86	30.5	-0.742	0.458	39	47	196
	Acetabular rim shape	163	59	36.2	-1.105	0.269	26	33	104
	Acetabular rim porosity	119	24	20.2	-0.439	0.661	12	12	95
	Apex activity	135	53	39.3	-0.962	0.336	23	30	82
	Outer edge	236	120	50.8	-2.050	0.040	50	70	116
	Acetabular fossa	216	125	57.9	-4.336	**<0.001**	38	87	216
Females	Acetabular groove	130	40	30.8	-0.632	0.527	22	18	90
	Acetabular rim shape	85	26	30.6	-0.672	0.501	12	14	59
	Acetabular rim porosity	63	15	23.8	-0.814	0.416	7	8	48
	Apex activity	66	24	36.4	-2.041	0.041	7	17	42
	Outer edge	113	50	44.2	-1.054	0.292	21	29	63
	Acetabular fossa	99	60	60.6	-2.375	0.018	20	40	39
Males	Acetabular groove	106	46	43.4	-1.571	0.116	17	29	106
	Acetabular rim shape	78	33	42.3	-0.880	0.379	14	19	45
	Acetabular rim porosity	56	9	16.1	-0.303	0.762	5	4	47
	Apex activity	69	29	42.0	-0.557	0.577	16	13	40
	Outer edge	123	70	56.9	-1.791	0.073	29	41	53
	Acetabular fossa	117	65	55.6	-3.769	**<0.001**	18	47	52

Table 5.8. Number (n) and percentage (%) of asymmetrical acetabular traits from analysed cases (N), and Wilcoxon test results, with significant results in bold (p<0.008), for the Bass collection.

Sample	Trait	N	n	%	Wilcoxon test				
					Z	p	n left	n right	Ties
Pooled sex sample	Acetabular groove	227	185	81.5	-13.073	**<0.001**	185	0	42
	Acetabular rim shape	210	75	35.7	-1.446	0.148	32	43	135
	Acetabular rim porosity	179	74	41.3	-3.430	**0.001**	23	51	105
	Apex activity	203	66	32.5	-1.083	0.279	29	37	137
	Outer edge	180	86	47.8	-3.858	**<0.001**	32	54	94
	Acetabular fossa	187	93	49.7	-4.983	**<0.001**	22	71	94
Female	Acetabular groove	109	98	89.9	-9.297	**<0.001**	98	0	11
	Acetabular rim shape	104	37	35.6	-0.493	0.622	17	20	67
	Acetabular rim porosity	91	39	42.9	-2.795	**0.005**	11	28	52
	Apex activity	97	34	35.1	-1.480	0.139	13	21	63
	Outer edge	89	44	49.4	-2.840	**0.005**	15	29	45
	Acetabular fossa	87	41	47.1	-4.439	**<0.001**	5	36	46
Male	Acetabular groove	118	87	73.7	-9.276	**<0.001**	87	0	31
	Acetabular rim shape	106	38	35.8	-1.512	0.131	15	23	68
	Acetabular rim porosity	88	35	39.8	-1.996	0.046	12	23	53
	Apex activity	106	32	30.2	0.000	1.000	16	16	74
	Outer edge	91	42	46.2	-2.840	0.010	17	25	49
	Acetabular fossa	100	52	52.0	-2.388	0.017	17	35	48

To control for the effect significant asymmetry has in some acetabular traits it was decided to use only data from the left side in subsequent statistical analyses, as explained in Section 4.2.4.1.

5.3.1.2. Iliac auricular surface morphological trait asymmetry

For the Coimbra collection, auricular surface traits do not showed a significant degenerative laterality (Table 5.9). Even though asymmetry was not significant, a left dominance for the pooled sex and female samples was obtained for a majority of traits. Males showed no side dominance.

Table 5.9. Number (n) and percentage (%) of asymmetrical traits and Wilcoxon test results for auricular surface traits from Coimbra analysed cases (N), with a Bonferroni correction ($p<0.006$).

Sample	Trait	N	n	%	Wilcoxon test				
					Z	p	n left	n right	Ties
Pooled sex sample	Transverse organization	219	49	22.4	-2.143	0.032	17	32	170
	Fine granularity	250	15	6.0	-1.291	0.197	5	10	235
	Coarse granularity	206	27	13.1	0.000	1.000	14	13	179
	Dense bone	101	6	5.9	-0.816	0.414	4	2	95
	Microporosity	87	2	2.3	0.000	1.000	11	11	65
	Macroporosity	83	21	25.3	-0.955	0.340	13	8	62
	Apical area	206	41	19.9	-1.406	0.160	25	16	165
	Lipping	46	8	17.4	-1.414	0.157	6	2	38
Female	Transverse organization	97	25	25.8	-2.200	0.028	7	18	72
	Fine granularity	108	6	5.6	-0.816	0.414	2	4	102
	Coarse granularity	90	14	15.6	-0.243	0.808	8	6	76
	Dense bone	52	2	3.8	-1.414	0.157	2	0	50
	Microporosity	46	12	26.1	-0.577	0.564	5	7	34
	Macroporosity	45	9	20.0	-1.667	0.096	7	2	36
	Apical area	110	12	10.9	0.000	1.000	6	6	98
	Lipping	28	6	21.4	-0.816	0.414	4	2	22
Male	Transverse organization	122	24	19.7	-0.816	0.414	10	14	98
	Fine granularity	133	9	6.8	-1.000	0.317	3	6	133
	Coarse granularity	116	13	11.2	-0.277	0.782	6	7	103
	Dense bone	49	4	8.2	0.000	1.000	2	2	45
	Microporosity	41	10	24.4	-0.632	0.527	6	4	31
	Macroporosity	38	12	31.6	0.000	1.000	6	6	26
	Apical area	96	29	30.2	-1.671	0.095	19	10	67
	Lipping	18	2	11.1	-1.414	0.157	2	0	16

For the Bass pooled sex sample, only lipping presented a significant asymmetry, with left side dominance (Table 5.10). No significant results were obtained when the analysis was performed by sex. Regarding nonsignificant results, left side dominance was observable for a majority of traits, similar to the Coimbra collection.

Table 5.10. Number (n) and percentage (%) of asymmetrical auricular surface traits from analysed cases (N), and Wilcoxon test results from the Bass collection (significant results in bold: p<0.006).

Sample	Trait	N	n	%	Wilcoxon test				
					Z	p	n left	n right	Ties
Pooled sex sample	Transverse organization	207	43	20.8	-0.762	0.446	24	19	164
	Fine granularity	210	56	26.7	-0.535	0.593	26	30	154
	Coarse granularity	204	63	30.9	-1.082	0.279	27	36	141
	Dense bone	158	10	6.3	-0.632	0.527	6	4	148
	Microporosity	150	36	24.0	-2.333	0.020	25	11	114
	Macroporosity	152	52	34.2	-1.727	0.084	33	19	100
	Apical area	208	70	33.7	-0.717	0.473	38	32	138
	Lipping	123	36	29.3	-3.667	**<0.001**	29	7	87
Female	Transverse organization	99	16	16.2	-1.500	0.134	11	5	83
	Fine granularity	101	24	23.8	-1.633	0.102	8	16	77
	Coarse granularity	97	26	26.8	-1.569	0.117	9	17	71
	Dense bone	73	4	5.5	0.000	1.000	2	2	69
	Microporosity	69	17	24.6	-0.728	0.467	10	7	52
	Macroporosity	70	21	30.0	-1.895	0.058	15	6	49
	Apical area	101	32	31.7	-0.707	0.480	14	18	69
	Lipping	63	23	36.5	-2.711	0.007	18	5	40
Male	Transverse organization	108	27	25.0	-0.192	0.847	13	14	81
	Fine granularity	109	32	29.4	-0.707	0.480	18	14	77
	Coarse granularity	107	37	34.6	-0.152	0.879	18	19	70
	Dense bone	85	6	7.1	-0.816	0.414	4	2	79
	Microporosity	81	19	23.5	-2.524	0.012	15	4	62
	Macroporosity	82	31	37.8	-0.615	0.538	18	13	51
	Apical area	107	38	35.5	-1.622	0.105	24	14	69
	Lipping	60	13	21.7	-2.496	0.013	11	2	47

As for acetabular data, it was decided to use only left side in subsequent statistical analyses, although the Bass collection showed a significant asymmetry only for lipping.

5.3.1.3. Pubic symphysis morphological traits asymmetry

For the Coimbra pooled sex and male samples, only the medial aspect of *obturator foramen* showed a significant asymmetry, with left side dominance (Tables 5.11 and 5.12 respectively). For females, no significant results were obtained (Table 5.13). However, a majority of non-significant asymmetry traits suggested right side dominance, with the exception of males, without side dominance.

For the Bass collection, a majority of pubic symphysis traits did not show a significant asymmetry (Tables 5.14 to 5.16). For the pooled sex sample, significant bilateral differences were found only for the dorsal body of the pubic bone, symphyseal face shape alterations and LOVBe. The dorsal body of the pubic bone and the LOVBe had right side dominance, and inversely the symphyseal face shape presented left side dominance. For each sex, dorsal body of the pubic bone (right side dominance) and symphyseal face shape alterations (left side dominance) also exhibited a significant asymmetry.

Table 5.11. Number (n) and percentage (%) of asymmetrical pubic symphysis traits from analysed cases (N), and Wilcoxon test results for the Coimbra pooled sex sample, with a Bonferroni correction ($p<0.003$).

Trait	N	n	%	Wilcoxon test				
				Z	p	n left	n right	Ties
Billowing	199	62	31.2	-0.682	0.495	27	35	137
Superior extremity	117	6	5.1	-0.333	0.739	2	4	111
Inferior extremity	172	5	2.9	-0.966	0.334	2	3	167
Dorsal plateau	172	15	8.7	-1.930	0.054	3	12	157
Ventral rampart	144	18	12.5	-1.091	0.275	6	12	126
Dorsal body	231	71	30.7	-0.853	0.393	32	39	160
Ventral body	317	162	51.1	-0.880	0.379	82	80	155
Medial aspect of the obturator foramen	242	37	15.3	-3.124	**0.002**	28	9	205
Symphyseal rim	88	30	34.1	-2.191	0.028	9	21	58
Pubic tubercle	109	14	12.8	-0.243	0.808	6	8	95
Ventral bevelling	225	8	3.6	-2.121	0.034	1	7	217
Symphyseal face erosion	64	20	31.3	-0.894	0.371	12	8	44
Symphyseal rim erosion	37	4	10.8	-2.000	0.046	4	0	33
Symphyseal face shape	203	69	34.0	-0.620	0.535	31	38	134
Ligamentous outgrowth of the ventral bevelling	71	21	29.6	-1.528	0.127	7	14	50

Table 5.12. Number (n) and percentage (%) of asymmetrical pubic symphysis traits from analysed cases (N), and Wilcoxon test results for the Coimbra male sample, with a Bonferroni correction (p<0.003).

Trait	N	n	%	Wilcoxon test				
				Z	p	n left	n right	Ties
Billowing	113	35	31.0	-0.745	0.457	19	16	78
Superior extremity	72	0	0.0	0.000	1.000	0	0	72
Inferior extremity	109	2	1.8	-0.447	0.655	1	1	107
Dorsal plateau	95	7	7.4	-2.428	0.015	0	7	88
Ventral rampart	94	8	8.5	-1.414	0.157	2	6	86
Dorsal body	119	38	31.9	-0.973	0.330	16	22	81
Ventral body	174	87	50.0	-1.886	0.059	49	38	87
Medial aspect of the obturator foramen	133	23	17.3	-3.128	**0.002**	19	4	11
Symphyseal rim	59	18	30.5	-1.414	0.157	6	12	41
Pubic tubercle	68	9	13.2	-0.333	0.759	5	4	59
Ventral bevelling	125	5	4.0	-1.342	0.180	1	4	120
Symphyseal face erosion	43	12	27.9	-1.155	0.248	8	4	31
Symphyseal rim erosion	13	4	30.8	-1.414	0.157	2	0	11
Symphyseal face shape	112	38	33.9	-1.019	0.308	16	22	74
Ligamentous outgrowth of the ventral bevelling	56	17	30.4	-1.698	0.090	5	12	39

Table 5.13. Number (n) and percentage (%) of asymmetrical pubic symphysis traits from analysed cases (N), and Wilcoxon test results for the Coimbra female sample, with a Bonferroni correction (p<0.003).

Trait	N	n	%	Wilcoxon test				
				Z	p	n left	n right	Ties
Billowing	86	27	31.4	-2.117	0.034	8	19	59
Superior extremity	45	6	13.3	-0.333	0.739	2	4	39
Inferior extremity	63	3	4.8	-0.816	0.414	1	2	60
Dorsal plateau	77	8	10.4	-0.577	0.564	3	5	69
Ventral rampart	50	10	20.0	-0.277	0.782	4	6	40
Dorsal body	112	33	29.5	-0.271	0.787	16	17	79
Ventral body	143	75	52.4	-0.901	0.368	33	42	68
Medial aspect of the obturator foramen	109	14	12.8	-1.069	0.285	9	5	95
Symphyseal rim	29	12	41.4	-1.732	0.083	3	9	17
Pubic tubercle	41	5	12.2	-0.707	0.480	1	4	36
Ventral bevelling	100	3	3.0	-1.732	0.083	0	3	97
Symphyseal face erosion	21	8	38.1	0.000	1.000	4	4	13
Symphyseal rim erosion	24	2	8.3	-1.414	0.157	2	0	22
Symphyseal face shape	91	31	34.1	-0.142	0.887	15	16	60
Ligamentous outgrowth of the ventral bevelling	15	4	26.7	0.000	1.000	2	2	11

Table 5.14. Number (n) and percentage (%) of asymmetrical pubic symphysis traits from analysed cases (N), and Wilcoxon test results for the Bass pooled sex sample, with a Bonferroni correction (p<0.003).

Trait	N	n	%	Wilcoxon test				
				Z	p	n left	n right	Ties
Billowing	207	71	34.3	-1.329	0.184	43	28	136
Superior extremity	188	5	2.7	0.000	1.000	3	2	183
Inferior extremity	211	2	0.9	-1.414	0.157	0	2	209
Dorsal plateau	215	0	0.0	0.000	1.000	0	0	215
Ventral rampart	209	6	2.9	-1.633	0.102	1	5	203
Dorsal body	217	102	47.0	-5.908	**<0.001**	20	82	115
Ventral body	213	85	39.9	-1.757	0.079	34	51	128
Medial aspect of the obturator foramen	224	18	8.0	-0.471	0.637	8	10	206
Symphyseal rim	118	20	16.9	-0.894	0.371	12	8	98
Pubic tubercle	179	9	5.0	-0.577	0.564	6	3	170
Ventral bevelling	229	0	0.0	0.000	1.000	0	0	229
Symphyseal face erosion	125	26	20.8	-2.746	0.006	20	6	99
Symphyseal rim erosion	105	10	9.5	-1.265	0.206	7	3	95
Symphyseal face shape	210	91	43.3	-5.197	**<0.001**	69	22	119
Ligamentous outgrowth of the ventral bevelling	165	47	28.5	-3.355	**0.001**	12	35	118

Table 5.15. Number (n) and percentage (%) of asymmetrical pubic symphysis traits from analysed cases (N), and Wilcoxon test results for the Bass female sample, with a Bonferroni correction (p<0.003).

Trait	N	n	%	Wilcoxon test				
				Z	p	n left	n right	Ties
Billowing	97	38	39.2	-0.593	0.553	22	16	59
Superior extremity	82	5	6.1	0.000	1.000	3	2	77
Inferior extremity	106	1	0.9	-1.000	0.317	0	1	105
Dorsal plateau	100	0	0.0	0.000	1.000	0	0	100
Ventral rampart	98	4	4.1	-1.000	0.317	1	3	94
Dorsal body	103	44	42.7	-3.591	**<0.001**	10	34	59
Ventral body	104	35	33.7	-1.947	0.052	11	24	69
Medial aspect of the obturator foramen	106	10	9.4	-1.265	0.206	3	7	96
Symphyseal rim	50	14	28.0	-2.138	0.033	11	3	36
Pubic tubercle	78	9	11.5	-0.577	0.564	6	3	69
Ventral bevelling	110	0	0.0	0.000	1.000	0	0	110
Symphyseal face erosion	57	13	22.8	-1.387	0.166	9	4	44
Symphyseal rim erosion	40	4	10.0	0.000	1.000	2	2	36
Symphyseal face shape	99	46	46.5	-3.169	**0.002**	33	13	53
Ligamentous outgrowth of the ventral bevelling	58	20	34.5	-2.236	0.025	5	15	38

Table 5.16. Number (n) and percentage (%) of asymmetrical pubic symphysis traits from analysed cases (N), and Wilcoxon test results for the Bass male sample, with a Bonferroni correction (p<0.003).

Trait	N	n	%	Wilcoxon test				
				Z	p	n left	n right	Ties
Billowing	110	33	30.0	-1.333	0.182	21	12	77
Superior extremity	106	0	0.0	0.000	1.000	0	0	106
Inferior extremity	105	1	1.0	-1.000	0.317	0	1	104
Dorsal plateau	115	0	0.0	0.000	1.000	0	0	115
Ventral rampart	111	2	1.8	-1.414	0.157	0	2	109
Dorsal body	114	58	50.9	-4.698	**<0.001**	10	48	56
Ventral body	109	50	45.9	-0.623	0.534	23	27	59
Medial aspect of the obturator foramen	118	8	6.8	-0.707	0.480	5	3	110
Symphyseal rim	68	6	8.8	-1.633	0.102	1	5	62
Pubic tubercle	101	0	0.0	0.000	1.000	0	0	101
Ventral bevelling	119	0	0.0	0.000	1.000	0	0	119
Symphyseal face erosion	68	13	19.1	-2.496	0.013	11	2	55
Symphyseal rim erosion	65	6	9.2	-1.633	0.102	5	1	59
Symphyseal face shape	111	45	40.5	-4.101	**<0.001**	36	9	66
Ligamentous outgrowth of the ventral bevelling	107	27	25.2	-2.502	0.012	7	20	80

Only left side pubic symphysis data were used to compute subsequent statistical analyses for both collections, following what was performed for acetabulum and auricular surface morphological traits.

5.3.2. Femoral measurements asymmetry analysis and joint surface area measurements

Descriptive statistics for Coimbra left and right femur and joint surface area measurements are represented at Table 5.17, with significant bilateral differences found only for femoral head vertical diameters, robusticity, and acetabulum and auricular surface area (Table 5.18).

Table 5.17. Descriptive statistics for anthropometric measurements with outliers for the Coimbra collection.

Measurement	Sample	Side	Mean	Median	SD	Minimum	Maximum
Femur maximum length (mm)	Total	Left	426	423	26.5	360	497
	N=259	Right	426	425	26.2	362	484
	Female	Left	407	406	18.8	360	458
	N=119	Right	407	407	19.0	362	458
	Male	Left	442	442	21.1	370	497
	N=140	Right	441	439	20.9	373	484
Vertical diameter of the femoral head (mm)	Total	Left	43	43	3.4	34	51
	N=261	Right	43	43	3.4	34	52
	Female	Left	40	40	2.3	34	49
	N=125	Right	41	41	2.4	34	50
	Male	Left	45	46	2.5	40	51
	N=136	Right	46	46	2.4	40	52
Femoral robusticity	Total	Left	62	62	3.3	54	75
	N=213	Right	61	61	3.3	53	74
	Female	Left	63	63	3.6	55	75
	N=99	Right	61	61	3.5	54	74
	Male	Left	61	61	2.9	54	69
	N=114	Right	61	61	3.0	53	71
Pubic symphysis surface area (mm^2)	Total	Left	402	381	103.7	231	645
	N= 29	Right	387	386	98.6	233	636
	Female	Left	376	317	140.0	255	596
	N= 6	Right	358	322	127.1	254	589
	Male	Left	408	397	94.9	231	645
	N= 23	Right	395	396	91.7	233	636
Auricular surface area (mm^2)	Total	Left	1184	1162	215.3	789	1621
	N= 36	Right	1238	1264	229.1	794	1691
	Female	Left	1106	1080	193.1	789	1570
	N= 21	Right	1161	1145	215.4	794	1637
	Male	Left	1293	1341	201.5	900	1621
	N= 15	Right	1346	1314	208.9	994	1691
Acetabulum surface area (mm^2)	Total	Left	3561	3635	527.6	2230	4634
	N= 60	Right	3600	3625	532.6	2168	4919
	Female	Left	3196	3146	435.3	2230	4634
	N= 29	Right	3241	3199	448.7	2168	4657
	Male	Left	3903	3854	347.4	3153	4634
	N= 31	Right	3936	3921	359.0	3172	4919

Legend: SD- standard deviation.

Table 5.18. Paired-samples t test results for the Coimbra collection, with outliers (significant results in bold).

Measurement	Sample	t	df	p
Femur maximum length (mm)	Total	0.741	258	0.459
	Female	-0.802	118	0.424
	Male	1.561	139	0.121
Vertical diameter of the femoral head (mm)	Total	-3.846	260	**<0.001**
	Female	-3.421	124	**0.001**
	Male	-2.209	135	**0.029**
Femoral robusticity	Total	6.282	212	**<0.001**
	Female	6.203	98	**<0.001**
	Male	3.064	113	**0.003**
Pubic symphysis surface area (mm^2)	Total	1.396	28	0.174
	Female	0.550	5	0.606
	Male	1.296	22	0.208
Auricular surface area (mm^2)	Total	-2.833	35	**0.008**
	Female	-2.033	20	0.056
	Male	-1.975	14	0.068
Acetabulum surface area (mm^2)	Total	-2.244	59	**0.029**
	Female	-1.865	28	0.073
	Male	-1.315	30	0.198

Legend: SD- standard deviation.

Boxplots were produced for measurements with a significant asymmetry to determine possible presence of outliers for the Coimbra collection (Figures 5.2 to 5.4). Presence of outliers was found for femoral vertical head diameters, left and right sides for females, and the right side for males. Additionally, outliers were found for femoral robusticity pooled sex, female and male samples. However, results for paired-samples t-test without outliers (Table 5.19) were similar to the analysis including outliers (Table 5.18).

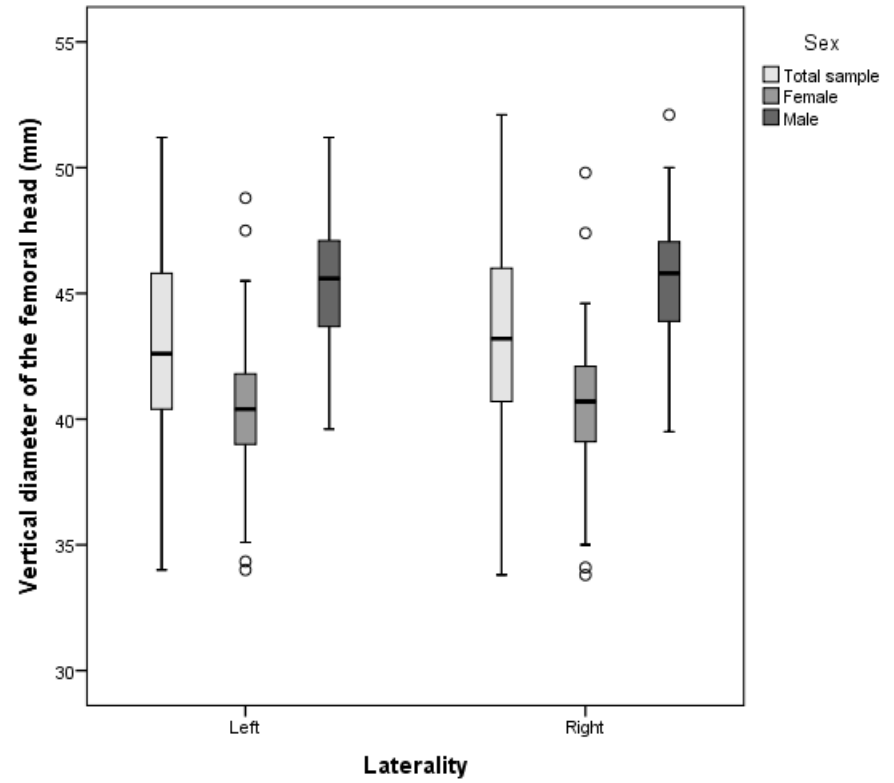

Figure 5.2. Boxplot graphic displaying outliers for vertical diameter of the femoral head data from the Coimbra collection (Total sample n= 261, Female sample n= 125, Male sample n= 136).

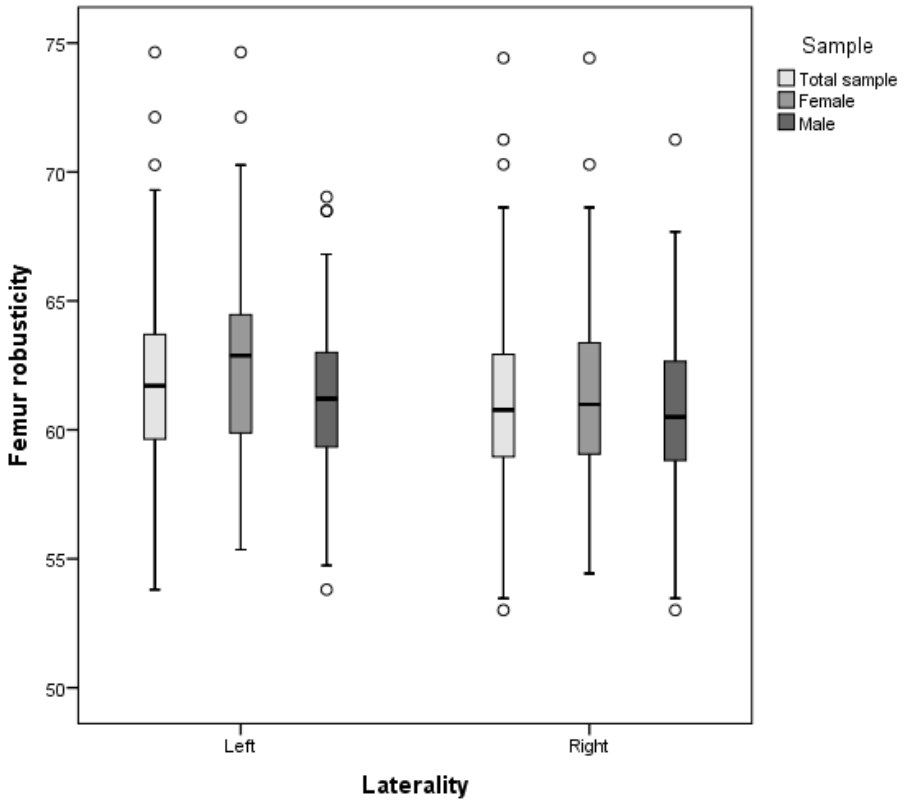

Figure 5.3. Outliers for femur robusticity data from the Coimbra collection (Total sample n= 213, Female sample n= 99, Male sample n= 114).

Table 5.19. Paired-samples t test for femoral head vertical diameters, and robusticity without outliers from the Coimbra collection.

Measurement	Sample	t	df	p
Vertical diameter of the head (mm)	Female	-3.391	120	**0.001**
	Male	-2.102	134	**0.037**
Robusticity	Total	6.714	207	**<0.001**
	Female	6.101	96	**<0.001**
	Male	3.353	107	**0.001**

No outliers were found for acetabulum and auricular surface area, and therefore paired-samples t-test was not repeated (Figure 5.4).

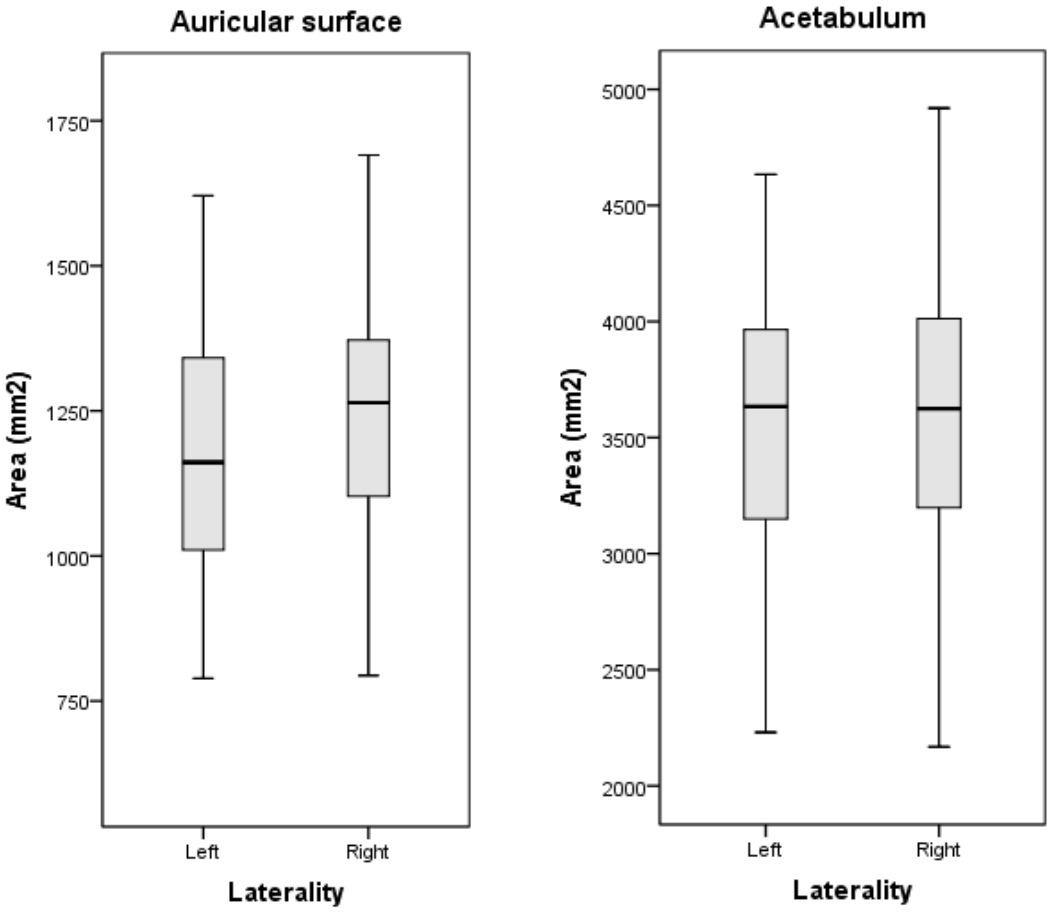

Figure 5.4. Boxplot graphs for auricular surface and acetabulum surface area from Coimbra pooled sex sample (Auricular surface area n= 36, Acetabulum surface area n= 60).

For the Bass collection, descriptive statistics for left and right femur

measurements are presented in Table 5.20, with significant bilateral differences for femoral maximum length and vertical head diameter shown in Table 5.21.

Table 5.20. Femoral measurement descriptive statistics with outliers for Bass collection.

Measurement	Sample	Side	Mean	Median	SD	Minimum	Maximum
Maximum length (mm)	Total	Left	454	453	29.2	380	529
	N=130	Right	453	454	29.3	373	537
	Female	Left	432	432	21.4	380	473
	N=57	Right	431	433	21.5	373	475
	Male	Left	471	468	22.6	423	529
	N=73	Right	469	465	22.9	420	537
Vertical diameter of the head (mm)	Total	Left	45	46	3.6	39	54
	N=131	Right	45	45	3.6	39	54
	Female	Left	42	42	1.6	39	46
	N=57	Right	42	42	1.6	39	46
	Male	Left	48	48	2.3	42	54
	N=74	Right	48	48	2.4	42	54
Robusticity	Total	Left	62	62	3.8	53	74
	N=130	Right	62	62	3.8	51	72
	Female	Left	63	64	3.5	56	74
	N=57	Right	63	64	3.5	56	69
	Male	Left	62	62	3.9	53	73
	N=73	Right	61	61	3.8	51	72

Legend: SD- standard deviation

Table 5.21. Paired-samples t test for femoral measurements with outliers for the Bass collection (significant results in bold).

Measurement	Sample	t	df	p
Maximum length (mm)	Total	3.507	129	**0.001**
	Female	2.492	56	**0.016**
	Male	2.510	72	**0.014**
Vertical diameter of the head (mm)	Total	-2.005	130	**0.047**
	Female	-2.220	56	**0.031**
	Male	-0.770	73	0.444
Robusticity	Total	1.205	129	0.230
	Female	0.826	56	0.412
	Male	0.873	72	0.386

Boxplots (Figure 5.5 and 5.6) showed that outliers were only found for femoral maximum length. However, a significant asymmetry for maximum femoral

length was still obtained after outlier exclusion (Table 5.22).

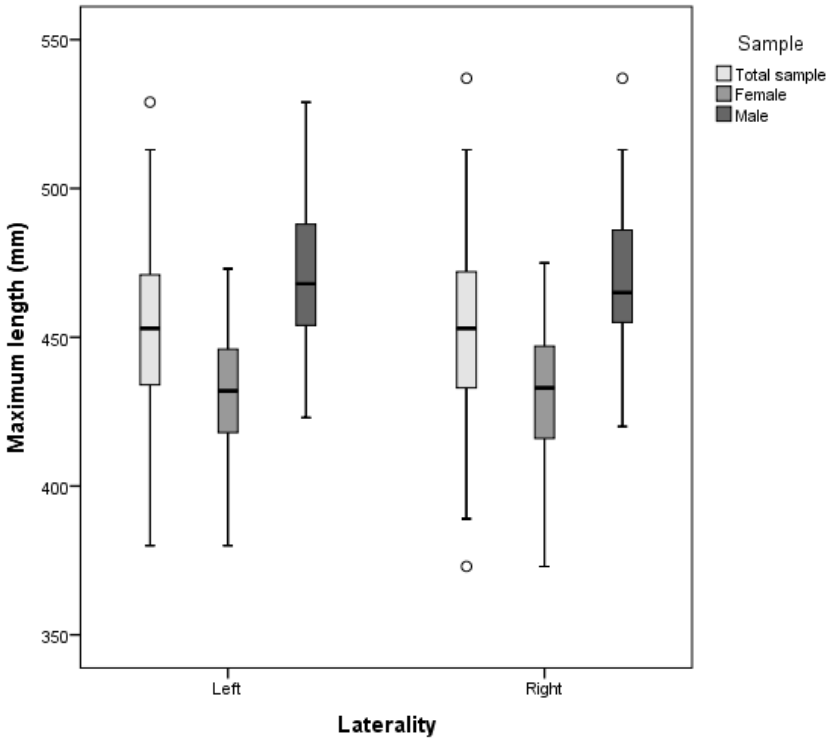

Figure 5.5. Boxplot graphs showing presence of outliers for maximum femur length measurement for Bass collection (Total sample n= 130, Female sample n= 57, Male sample n= 73).

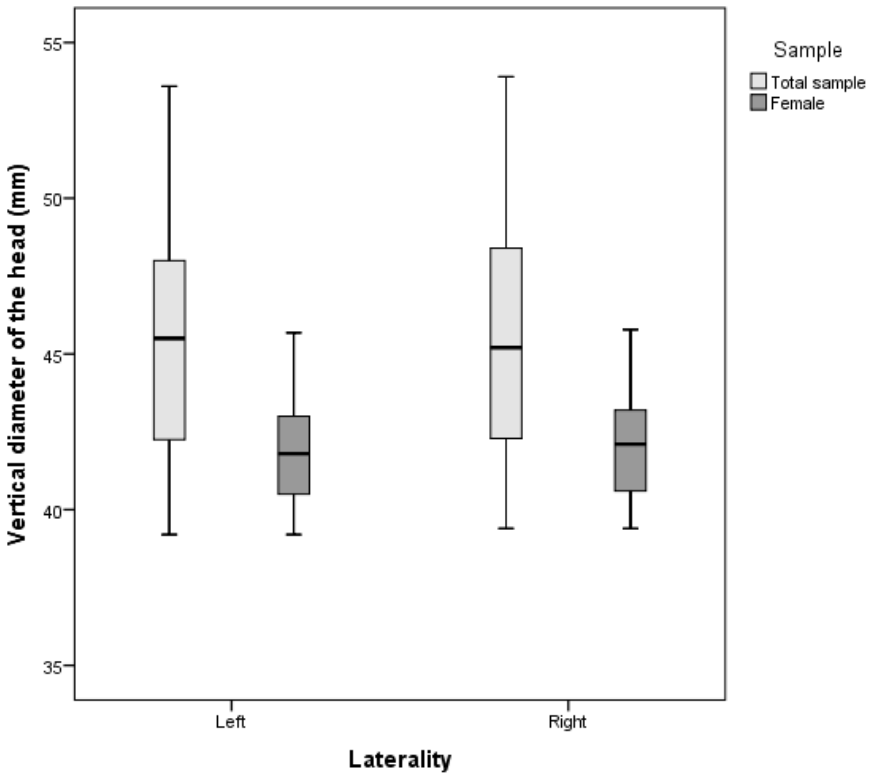

Figure 5.6. Boxplot graphs for vertical diameters of the femoral head, from Bass collection (Total sample n= 131, Female sample n= 57).

Table 5.22. Paired-samples t test for maximum femoral length without outliers, for the Bass collection.

Sample	t	df	p
Total	3.645	127	**<0.001**
Female	2.282	55	**0.026**
Male	2.835	71	**0.006**

Some of the femoral measurements showed a significant asymmetry between left and right side for both collections. Even though outliers were found in the analysis; their elimination did not improved results. Therefore, outliers were maintained, and the average between sides was computed to control for significant asymmetry effects in the present research. Joint surface area analysis was only computed for the Coimbra collection due to technical difficulties with the equipment during data record of the Bass collection. The analysis showed that only the acetabulum and auricular surface area presented significant bilateral differences. However, an average between sides was not performed, because of the reduced number of individuals with both sides measured. Therefore, only the left side was considered in subsequent analyses, for both collections.

5.4. ESTABLISHMENT OF BODY SIZE GROUPS ACCORDING TO FEMORAL AND JOINT SURFACE AREA MEASUREMENTS

In Tables 5.23 and 5.24, descriptive statistics for the anthropometric measurements respectively for Coimbra and Bass collection are presented. The mean value was used as the cut-off point to divide individuals into body size groups for each collection.

A significant difference in measurement values between females and males was obtained with an independent samples t-test (Table 5.25). Males presented a higher mean value compared to females, except for femur robusticity where females were on average more robust than males (Tables 5.23 and 5.24). For the Coimbra collection, female mean femur robusticity was 62 ± 3.4 and male mean was 61 ± 2.8; and for the Bass female sample mean femur robusticity was 63 ± 3.4, and for males 61 ± 3.8. A non-significant difference between sexes was obtained only for pubic symphysis surface areas from the Coimbra collection showed a similar size between sexes (Table 5.25).

Table 5.23. Left side measurements descriptive statistics for the Coimbra collection.

Sample	Measurement	N	Mean	Median	SD	Min	Max
Pooled sex sample	Femur maximum length (mm)	259	**426**	425	26.3	361	487
	Femur vertical diameter of the head (mm)	261	**43**	43	3.4	34	52
	Femur robusticity	213	**61**	61	3.1	54	75
	Acetabulum area (mm^2)	114	**3575**	3630	493.6	2230	4634
	Auricular surface area (mm^2)	81	**1208**	1187	203.9	779	1621
	Pubic Symphysis area (mm^2)	59	**395**	378	102.0	222	645
Females	Femur maximum length (mm)	119	**407**	407	18.8	361	458
	Femur vertical diameter of the head (mm)	125	**41**	41	2.3	34	49
	Femur robusticity	99	**62**	62	3.4	55	75
	Acetabulum area (mm^2)	59	**3245**	3229	376.4	2230	4634
	Auricular surface area (mm^2)	46	**1149**	1108	204.3	779	1570
	Pubic Symphysis area (mm^2)	20	**374**	348	103.9	255	629
Males	Femur maximum length (mm)	140	**442**	440	20.9	372	487
	Femur vertical diameter of the head (mm)	136	**45**	46	2.4	40	52
	Femur robusticity	114	**61**	61	2.8	54	68
	Acetabulum area (mm^2)	55	**3929**	3891	333.6	3153	4634
	Auricular surface area (mm^2)	35	**1286**	1341	177.6	900	1621
	Pubic Symphysis area (mm^2)	39	**406**	397	100.6	222	645

Legend: N- number of individuals, SD- standard deviation, Min- minimum value, Max- maximum value

Table 5.24. Left side measurement descriptive statistics for the Bass collection.

Sample	Measurement	N	Mean	Median	SD	Min	Max
Pooled sex sample	Femur maximum length (mm)	130	**453**	453	29.2	377	533
	Femur vertical diameter of the head (mm)	131	**45**	46	3.6	39	54
	Femur robusticity	130	**62**	62	3.7	52	72
	Acetabulum area (mm2)	143	**4010**	3915	607.9	2947	5750
	Auricular surface area (mm2)	110	**1385**	1401	223.3	931	1923
	Pubic Symphysis area (mm2)	165	**400**	387	116.8	168	778
Females	Femur maximum length (mm)	57	**432**	433	21.4	377	474
	Femur vertical diameter of the head (mm)	57	**42**	42	1.6	39	46
	Femur robusticity	57	**63**	63	3.4	56	71
	Acetabulum area (mm2)	64	**3550**	3579	383.1	2947	4995
	Auricular surface area (mm2)	54	**1266**	1226	197.9	931	1879
	Pubic Symphysis area (mm2)	69	**329**	318	82.4	168	573
Males	Femur maximum length (mm)	73	**470**	465	22.6	423	533
	Femur vertical diameter of the head (mm)	74	**48**	48	2.3	42	54
	Femur robusticity	73	**61**	62	3.8	52	72
	Acetabulum area (mm2)	79	**4382**	4300	490.9	3407	5750
	Auricular surface area (mm2)	56	**1500**	1498	183.8	1039	1923
	Pubic Symphysis area (mm2)	96	**451**	447	111.3	180	778

Legend: N- number of individuals, SD- standard deviation, Min- minimum value, Max- maximum value.

Table 5.25. Independent samples t test between female and male measurements for both Coimbra and Bass collections.

Collection	Measurement	t	df	p
Coimbra	Femur maximum length	-13.754	257.000	**<0.001**
	Femur vertical diameter of the head	-16.480	259.000	**<0.001**
	Femur robusticity	2.484	211.000	**0.014**
	Acetabulum surface area	-10.235	112.000	**<0.001**
	Auricular surface area	-3.173	79.000	**0.002**
	Pubic Symphysis surface area	-1.160	57.000	0.251
Bass	Femur maximum length	-9.852	128.000	**<0.001**
	Femur vertical diameter of the head	-17.381	127.803	**<0.001**
	Femur robusticity	2.682	128.000	**0.008**
	Acetabulum surface area	-11.373	140.821	**<0.001**
	Auricular surface area	-6.421	108.000	**<0.001**
	Pubic Symphysis surface area	-7.716	163.000	**<0.001**

An independent samples t-test (Table 5.26) showed significant mean measurement differences between the collections. The Bass individuals tended to present bigger femoral and joint proportions than Coimbra individuals, except for male femur robusticity and pooled sex sample pubic symphysis surface area, which showed similar mean values. Additionally, pubic symphysis surface mean area was higher for Coimbra females (374 mm^2) when compared with the Bass female cohort (329 mm^2), but the inverse was true for male individuals. However, sample size for Coimbra female pubic symphysis surface area was small (n= 20), which may have influenced the results.

Table 5.26. Independent samples t test results for measurements from left side data between Coimbra and Bass collections.

Measurement	Sample	t	df	p
Femur maximum length	Pooled sex	-7.680	174.000	**<0.001**
	Female	-9.209	211.000	**<0.001**
	Male	-9.364	387.000	**<0.001**
Femur vertical diameter of the head	Pooled sex	-5.896	390.000	**<0.001**
	Female	-4.490	152.630	**<0.001**
	Male	-7.183	208.000	**<0.001**
Femur robusticity	Pooled sex	-2.108	239.235	**0.036**
	Female	-2.146	154.000	**0.033**
	Male	-1.091	121.366	0.277
Acetabulum surface area	Pooled sex	-6.332	254.906	**<0.001**
	Female	-4.459	121.000	**<0.001**
	Male	-6.363	131.942	**<0.001**
Auricular surface area	Pooled sex	-5.609	189.000	**<0.001**
	Female	-2.910	98.000	**0.004**
	Male	-5.459	89.000	**<0.001**
Pubic Symphysis surface area	Pooled sex	-0.253	222.000	0.801
	Female	2.035	87.000	**0.045**
	Male	-2.159	133.000	**0.033**

In Table 5.27, Pearson's product-moment correlation coefficient results between osteological measurements and age at death for both collections are presented. The majority of measurements showed lack of correlation with age ($p>0.05$). For measurements whose p value was significant, the r coefficient ranged between low to moderate (0.163 to 0.435), with a majority of significant results obtained for the Coimbra female sample, and none for the Bass female cohort.

Table 5.27. Pearson's product-moment correlation coefficient between femoral and joint surface area measurements and age at death for both collections.

Collection	Measurement	Pooled sex sample		Female		Male	
		r	p	r	p	r	p
Coimbra	Femur maximum length	-0.107	0.087	0.058	0.534	**-0.193**	**0.022**
	Femur vertical diameter of the head	0.034	0.588	**0.223**	**0.012**	0.027	0.759
	Femur robusticity	**0.182**	**0.008**	**0.275**	**0.006**	0.039	0.680
	Acetabulum surface area	0.107	0.259	**0.435**	**0.001**	-0.021	0.880
	Auricular surface area	0.156	0.163	**0.421**	**0.004**	-0.195	0.260
	Pubic Symphysis surface area	-0.080	0.547	0.200	0.398	-0.256	0.116
Bass	Femur maximum length	-0.157	0.075	-0.066	0.625	-0.105	0.377
	Femur vertical diameter of the head	-0.054	0.542	0.058	0.669	0.090	0.448
	Femur robusticity	0.070	0.432	0.015	0.912	0.054	0.648
	Acetabulum surface area	0.076	0.365	0.094	0.461	**0.326**	**0.003**
	Auricular surface area	-0.060	0.531	-0.139	0.315	0.192	0.155
	Pubic symphysis surface area	**0.163**	**0.036**	0.120	0.327	**0.350**	**<0.001**

Age descriptive statistics for each body size group are presented in Tables 5.28 to 5.33. Similar mean and median values were obtained between groups, with a few exceptions, *e.g.*, for the female Coimbra body mass groups. Additionally, for the Bass collection a distinct minimum age was obtained for: 1) robusticity groups: pooled sex and male samples; 2) male acetabular surface area groups; 3) pooled sex sample and male auricular surface area groups; 4) female pubic symphysis surface area groups. For the Coimbra female sample, only pubic symphysis surface area groups showed a distinct minimum age value (smaller joint surface area group: 29 years; larger joint surface area group: 19 years), however both groups are constituted by very few individuals, which may have influenced the results.

Table 5.28. Age descriptive statistics (in years) for stature groups: shorter *versus* taller individuals.

Collection	Statistics	Shorter individuals group			Taller individuals group		
		Pooled sex	Female	Male	Pooled sex	Female	Male
Coimbra	N	134	60	75	125	59	65
	Mean	43	44	43	42	43	40
	Median	40	39	41	39	40	35
	SD	16.2	16.7	13.2	15.6	17.7	16.2
	Min	19	19	20	19	19	19
	Max	88	88	84	84	77	75
Bass	N	66	28	39	64	29	34
	Mean	55	57	54	53	56	51
	Median	55	58	54	53	54	51
	SD	13.4	14.3	17.3	15.6	12.5	12.5
	Min	25	25	19	19	29	31
	Max	82	82	92	92	78	80

Legend: N- number of individuals, SD- standard deviation, Min- minimum value, Max- maximum value

Table 5.29. Age descriptive statistics (in years) for body mass groups: lighter *versus* heavier individuals.

Collection	Statistics	Lighter individuals group			Heavier individuals group		
		Pooled sex	Female	Male	Pooled sex	Female	Male
Coimbra	N	142	86	65	119	39	71
	Mean	42	41	41	43	50	42
	Median	40	38	42	40	50	39
	SD	16.1	17.0	13.5	15.4	16.2	15.0
	Min	18	18	19	19	22	20
	Max	88	88	75	77	77	73
Bass	N	64	36	45	67	21	29
	Mean	56	56	52	53	57	55
	Median	56	58	51	54	54	55
	SD	13.6	13.2	17.2	15.7	13.8	13.0
	Min	25	25	19	19	34	31
	Max	82	78	92	92	82	83

Legend: N- number of individuals, SD- standard deviation, Min- minimum value, Max- maximum value.

Table 5.30. Age descriptive statistics (in years) for femoral robusticity groups: gracile *versus* robust individuals.

Collection	Statistics	Gracile individuals group			Robust individuals group		
		Pooled sex	Female	Male	Pooled sex	Female	Male
Coimbra	N	100	51	60	113	48	54
	Mean	40	42	40	44	45	42
	Median	38	39	38	42	43	43
	SD	16.3	17.8	15.5	14.9	16.5	12.4
	Min	19	19	19	19	19	20
	Max	77	77	75	88	88	69
Bass	N	58	25	34	72	32	39
	Mean	53	57	49	55	56	55
	Median	55	55	52	54	58	54
	SD	16.8	13.5	15.7	12.4	13.4	14.6
	Min	19	25	19	29	29	26
	Max	92	82	80	81	78	92

Legend: N- number of individuals, SD- standard deviation, Min- minimum value, Max- maximum value.

Table 5.31. Age descriptive statistics (in years) for acetabular surface area groups: smaller joint surface area *versus* larger joint surface individuals.

Collection	Statistics	Smaller surface area group			Larger surface area group		
		Pooled sex	Female	Male	Pooled sex	Female	Male
Coimbra	N	55	31	29	59	28	26
	Mean	38	33	35	38	46	37
	Median	37	34	37	36	42	35
	SD	15.1	11.7	11.9	14.2	18.5	12.7
	Min	18	18	19	19	19	20
	Max	88	64	59	77	88	60
Bass	N	75	31	42	68	33	37
	Mean	54	56	50	56	58	57
	Median	52	52	49	55	58	55
	SD	14.9	14.6	15.1	15.3	13.7	15.6
	Min	26	31	19	19	31	31
	Max	90	88	90	92	90	92

Legend: N- number of individuals, SD- standard deviation, Min- minimum value, Max- maximum value.

Table 5.32. Age descriptive statistics (in years) for auricular surface area groups: smaller joint surface area *versus* larger joint surface individuals.

Collection	Statistics	Smaller surface area group			Larger surface area group		
		Pooled sex	Female	Male	Pooled sex	Female	Male
Coimbra	N	41	25	16	40	21	19
	Mean	37	37	39	39	44	33
	Median	37	34	40	37	40	32
	SD	13.7	15.2	11.7	13.3	14.2	9.0
	Min	19	19	23	20	24	20
	Max	74	74	60	77	77	53
Bass	N	53	31	29	57	23	27
	Mean	56	56	50	51	56	51
	Median	54	54	47	50	54	50
	SD	13.5	12.5	16.6	15.5	13.2	16.0
	Min	29	38	19	19	31	31
	Max	88	88	92	92	82	90

Legend: N- number of individuals, SD- standard deviation, Min- minimum value, Max- maximum value.

Table 5.33. Age descriptive statistics (in years) for pubic symphysis surface area groups: smaller joint surface area *versus* larger joint surface individuals.

Collection	Statistics	Smaller surface area group			Larger surface area group		
		Pooled sex	Female	Male	Pooled sex	Female	Male
Coimbra	N	32	13	19	27	7	20
	Mean	44	44	44	41	44	40
	Median	43	43	44	37	29	38
	SD	10.7	11.3	10.6	16.9	24.8	13.8
	Min	24	29	24	19	19	20
	Max	72	72	62	76	74	76
Bass	N	89	37	48	76	32	48
	Mean	54	58	52	59	60	57
	Median	52	58	50	58	59	55
	SD	14.6	12.1	16.9	15.4	14.7	14.9
	Min	26	39	26	26	29	26
	Max	90	88	92	92	90	88

Legend: N- number of individuals, SD- standard deviation, Min- minimum value, Max- maximum value.

A majority of body size groups did not show a significant mean age difference (Table 5.34), which was in accordance with age descriptive statistics seen in Tables 5.28 to 5.33. The few exceptions were the Coimbra female sample body

mass and acetabulum surface area groups and the Bass male sample acetabulum surface area groups.

Table 5.34. Independent samples t test between mean age at death of stature, body mass, robusticity and pelvic joints surface area groups.

Collection	Body size variable	Samples	t	df	p
Coimbra	Stature	Pooled sex	0.480	257.000	0.631
		Female	0.300	117.000	0.765
		Male	1.112	123.599	0.268
	Body mass	Pooled sex	-0.401	259.000	0.689
		Female	-2.816	123.000	**0.006**
		Male	-0.303	134.000	0.762
	Femur robusticity	Pooled sex	-1.66	211.000	0.098
		Female	-0.732	97.000	0.466
		Male	-0.849	112.000	0.398
	Acetabulum surface area	Pooled sex	0.068	112.000	0.946
		Female	-3.070	44.664	**0.004**
		Male	-0.515	53.000	0.609
	Auricular surface area	Pooled sex	-0.479	79.000	0.633
		Female	-1.693	44.000	0.098
		Male	1.779	33.000	0.084
	Pubic symphysis surface area	Pooled sex	0.866	42.656	0.391
		Female	-0.617	7.969	0.554
		Male	0.697	37.000	0.490
Bass	Stature	Pooled sex	0.808	128.000	0.421
		Female	0.141	55.000	0.888
		Male	0.925	71.000	0.358
	Body mass	Pooled sex	1.038	129.000	0.301
		Female	-0.371	55.000	0.712
		Male	-0.820	72.000	0.415
	Robusticity	Pooled sex	-0.666	102.459	0.507
		Female	0.119	55.000	0.906
		Male	-1.589	71.000	0.117
	Acetabulum surface area	Pooled sex	-0.630	141.000	0.530
		Female	-0.768	62.000	0.445
		Male	-2.677	77.000	**0.009**
	Auricular surface area	Pooled sex	1.933	108.000	0.056
		Female	0.116	52.000	0.908
		Male	-0.241	54.000	0.810
	Pubic symphysis surface area	Pooled sex	-1.842	163.000	0.067
		Female	-0.709	67.000	0.481
		Male	-1.565	94.000	0.121

5.5. AGE-RELATED CRITERIA FOR PELVIC JOINTS

In the present section, data analyses performed on age-related criteria regarding correlation between features on the left side are presented.

5.5.1. Degenerative individual traits

Age description statistics for pelvic joints age-related traits are presented in Appendices 3 and 4 respectively, for Coimbra and Bass total sample and body size groups. For both sexes, age descriptive statistics were calculated only for significant sexual dimorphic degenerative traits. The traits that presented a significant sexual dimorphic metamorphosis are presented in section 5.6. Moreover, the number of individuals may not be coincident between pooled sex sample and the sum of individuals for both sexes for the same group. This divergent number of individuals resulted from use of different mean values as a cut-off point to establish the group, implicated distinct individual distributions by group for pooled sex sample and for each of the sexes. It was not possible to analyse the Bass' ventral bevelling trait (binary variable) in the subsequent investigation, due to lack of individuals without this trait.[22]

5.5.2. Components

5.5.2.1. Acetabulum

In Table 5.35, acetabular traits correlation coefficient patterns from a principal components analysis (PCA) are presented. For the Bass collection, significant r coefficients ranged between low (r = 0.125) and moderate (r = 0.511), with the Coimbra collection showing a similar range (r = 0.131 to 0.615). For the Bass collection, KMO was 0.605, showing an acceptable correlation pattern, and for the Coimbra collection a good correlation pattern was obtained (KMO = 0.718).

In both collections, two clusters of correlated traits were found, traits from

[22] Few age-related traits did not show increasing age means and/or medians with rising sequential scores (represented in bold) - "older scores" had lower mean and/or median age than "younger scores" - which was not in accordance with the aging process sequence. Traits whose mean and/or median age was equal or with only one year difference between subsequent scores were not put in bold, since they were not considered problematic, but reflective of the ageing process variability.

the lunate surface (articular area) and from the acetabular fossa (non-articulated area). For the Coimbra collection, the groove presented a low correlation with rim porosity. However, both traits shared a moderate correlation with rim shape and apex activity. For the Bass collection, low correlations between outer edge of the acetabular fossa and activity and porosity of the fossa existed. Nonetheless, these two traits did not share a correlation with the lunate surface features. Furthermore, for the lunate surface traits, rim shape shared a moderate correlation with the groove, rim porosity and apex activity. However, the groove, rim porosity and apex activity shared low correlations or none at all. For both collections, a Bartlett's test indicated significant correlations between acetabular traits (Coimbra collection: Chi-square approximation= 180.256, df= 15, $p<0.001$; Bass collection: Chi-square approximation= 133.240, df = 15, $p<0.001$).

Table 5.35. Correlation coefficients' pairwise matrix for acetabular traits.

Collection	Trait	Groove	Rim shape	Rim porosity	Apex activity	Outer edge	Activity of the fossa
Coimbra (N= 311)	Groove	1.000	**0.574***	**0.280***	**0.435***	0.069	0.045
	Rim shape	**0.574***	1.000	**0.564***	**0.615***	**0.213***	**0.143***
	Rim porosity	**0.280***	**0.564***	1.000	**0.440***	**0.155***	0.073
	Apex activity	**0.435***	**0.615***	**0.440***	1.000	**0.131***	**0.158***
	Outer edge	0.069	**0.213***	**0.155***	**0.131***	1.000	**0.362***
	Activity of the fossa	0.045	**0.143***	0.073	**0.158***	**0.362***	1.000
Bass (N=235)	Groove	1.000	**0.406***	0.112	**0.275***	0.018	0.103
	Rim shape	**0.406***	1.000	**0.511***	**0.418***	0.112	0.092
	Rim porosity	0.112	**0.511***	1.000	**0.187***	0.071	0.107
	Apex activity	**0.275***	**0.418***	**0.187***	1.000	0.112	0.056
	Outer edge	0.018	0.112	0.071	0.112	1.000	**0.125***
	Activity of the fossa	0.103	0.092	0.107	0.056	**0.125***	1.000

* $p<0.05$

For both collections, the varimax orthogonal rotation of the factorial axes from the correlation matrix also indicated clustering of two main correlated components, between lunate surface traits and between fossa traits (Tables 5.36 and 5.37) .

Table 5.36. Varimax orthogonal rotated component matrix for acetabulum traits from the Coimbra collection left side data.

Trait	Component 1	Component 2
Rim shape	0.880	
Apex activity	0.789	
Groove	0.739	
Rim porosity	0.709	
Activity and porosity of the fossa		0.827
Outer edge		0.811

Table 5.37. Varimax orthogonal rotated component matrix for acetabulum traits from the Bass collection.

Trait	Component 1	Component 2
Rim shape	0.862	
Apex activity	0.661	
Groove	0.637	
Rim porosity	0.621	
Outer edge		0.764
Activity and porosity of the fossa		0.719

In Tables 5.38 to 5.41, r coefficient values for partial correlation between acetabular traits controlling for age at death, and shared variance between traits are presented. Results showed a similar pattern to PCA, with the emergence of the same clusters of correlated traits from the lunate surface and fossa, although, shared variance between correlated traits was small.

Table 5.38. Partial correlation between acetabular traits controlling for age at death for the Coimbra pooled sex sample, with r coefficient above the line and p value below.

Trait	Groove	Rim shape	Rim porosity	Apex activity	Outer edge	Activity of the fossa
Groove		0.412	0.080	0.229	-0.024	-0.021
Rim shape	**<0.001**		0.370	0.356	0.109	0.065
Rim porosity	0.152	**<0.001**		0.211	0.068	0.005
Apex activity	**0.001**	**<0.001**	**0.010**		0.012	0.091
Outer edge	0.351	0.070	0.203	0.437		0.344
Activity of the fossa	0.369	0.194	0.475	0.119	**<0.001**	

Table 5.39. Significant shared variance between acetabular traits controlling for age at death for the Coimbra pooled sex sample.

Trait	Correlated trait	Shared variance (%)
Groove	Rim shape	17.0
	Apex activity	5.2
Rim shape	Groove	17.0
	Rim porosity	13.7
	Apex activity	12.7
Rim porosity	Rim shape	13.7
	Apex activity	4.5
Apex activity	Rim shape	12.7
	Groove	5.2
	Rim porosity	4.5
Outer edge	Activity and porosity of the fossa	11.8
Activity and porosity of the fossa	Outer edge	11.8

Table 5.40. Partial correlation between acetabular traits controlling for age at death for the Bass pooled sex sample, with r coefficient above the line and p value below.

Trait	Groove	Rim shape	Rim porosity	Apex activity	Outer edge	Activity of the fossa
Groove		0.332	0.029	0.193	0.019	0.064
Rim shape	**<0.001**		0.425	0.275	0.131	0.015
Rim porosity	0.342	**<0.001**		0.061	0.076	0.057
Apex activity	**0.002**	**<0.001**	0.201		0.124	-0.011
Outer edge	0.392	0.033	0.157	**0.042**		0.127
Activity of the fossa	0.180	0.419	0.225	0.442	**0.041**	

Table 5.41. Significant shared variance between acetabular traits controlling for age at death for the Bass pooled sex sample.

Trait	Correlated trait	Shared variance (%)
Groove	Rim shape	11.0
	Apex activity	3.7
Rim shape	Rim porosity	18.1
	Groove	11.0
	Apex activity	7.6
	Outer edge	1.7
Rim porosity	Rim shape	18.1
Apex activity	Rim shape	7.6
	Groove	3.7
	Outer edge	1.5
Outer edge	Rim shape	1.7
	Activity and porosity of the fossa	1.6
	Apex activity	1.5
Activity and porosity of the fossa	Outer edge	1.6

Therefore, the analysis indicated establishment of the same two acetabular components for both collections. The first component, designated lunate surface, constituted by groove, rim shape, rim porosity and apex activity, contributed 41.0% and 33.0% to metamorphosis variance, respectively for Coimbra and Bass collection. The second component, designated fossa, was established with outer edge of the fossa and activity and porosity of the fossa, contributed 23.2% and 19.0% of the metamorphosis variance, respectively for Coimbra and Bass collections.

5.5.2.2. Auricular surface

For the Coimbra pooled sex sample, the pairwise matrix of correlation coefficients between auricular surface traits appeared to indicate at least two main clusters of correlated traits (Table 5.42). The first cluster made up by fine and coarse granularity shared a high correlation (r = 0.851); however, granularity features shared a low correlation with transverse organization and lipping. The relation between the other traits was not as clear as for the granularity features, with the second cluster which consisted of microporosity, macroporosity and lipping, sharing a moderate correlation. Lipping also shared a moderate correlation with apical area activity (r= 0.301), however, the correlation was lower than obtained with microporosity (r = 0.377) and macroporosity (r = 0.308). No relationship between dense bone and other auricular surface features was found. The KMO test indicated an acceptable correlation pattern (0.528), and Bartlett's test of sphericity (Chi-square approximation= 102.755; df= 28; p <0.001) indicated a significant correlation between features.

For the Bass pooled sex sample, three clusters of trait correlations emerged in the pairwise matrix of correlation coefficients (Table 5.42). Similar to the Coimbra collection, fine and coarse granularity shared a high correlation (r = 0.899). Fine and coarse granularity also presented low correlations with apical area activity. Furthermore, coarse granularity shared low inverse correlation with microporosity. The second correlation cluster consisted of microporosity and macroporosity, although the correlation coefficient was low (r = 0.233). The third correlation group consisting of apical area activity and lipping had a low correlation coefficient (r = 0.203). However, the correlation between apical area feature and granularity features

Table 5.42. Pairwise matrix of correlations coefficients for auricular surface traits in both Coimbra and Bass collections.

Collection	Trait	Transverse organization	Fine granularity	Coarse granularity	Dense Bone	Microporosity	Macroporosity	Apical area	Lipping
Coimbra (N= 309)	Transverse organization	1.000	**0.133***	**0.136***	0.139	-0.039	0.088	0.059	-0.002
	Fine granularity	**0.133***	1.000	**0.851***	0.037	-0.103	-0.022	0.098	**0.234***
	Coarse granularity	**0.136***	**0.851***	1.000	0.058	-0.021	0.050	0.080	**0.243***
	Dense Bone	0.139	0.037	0.058	1.000	-0.048	0.087	-0.039	0.157
	Microporosity	-0.039	-0.103	-0.021	-0.048	1.000	**0.367***	-0.022	**0.377***
	Macroporosity	0.088	-0.022	0.050	0.087	**0.367***	1.000	0.103	**0.308***
	Apical area	0.059	0.098	0.080	-0.039	-0.022	0.103	1.000	**0.301***
	Lipping	-0.002	**0.234***	**0.243***	0.157	**0.377***	**0.308***	**0.301***	1.000
Bass (N=232)	Transverse organization	1.000	0.000	-0.031	0.030	-0.020	0.095	0.041	0.010
	Fine granularity	0.000	1.000	**0.899***	-0.007	-0.083	-0.068	**0.145***	-0.080
	Coarse granularity	-0.031	**0.899***	1.000	0.012	**-0.126***	-0.027	**0.145***	-0.028
	Dense Bone	0.030	-0.007	0.012	1.000	-0.091	0.120	-0.070	-0.023
	Microporosity	-0.020	-0.083	**-0.126***	-0.091	1.000	**0.233***	-0.083	-0.084
	Macroporosity	0.095	-0.068	-0.027	0.120	**0.233***	1.000	0.009	0.042
	Apical area	0.041	**0.145***	**0.145***	-0.070	-0.083	0.009	1.000	**0.203***
	Lipping	0.010	-0.080	-0.028	-0.023	-0.084	0.042	**0.203***	1.000

* $p<0.05$

was lower than the correlation coefficient shared with lipping. Dense bone and transverse organization did not share a correlation with other auricular surface traits. For the Bass collection, the KMO value (0.489) was slightly below the acceptable cut-off point (0.500); however, Bartlett's test of sphericity indicated a significant correlation between the auricular surface traits (Chi-square approximation= 265.324; df = 28; $p < 0.001$).

For the Coimbra collection, the rotated component matrix showed a clearer correlation pattern, with establishment of three components (Table 5.43). Similar to the correlation matrix, fine and coarse granularity shared the strongest correlation. The second group was constituted by lipping, micro- and macroporosity. Furthermore, the rotated component matrix agglomerated dense bone and transverse organization, although these traits do not shared a correlation before rotation, as shown in Table 5.42. The apical area activity did not cluster with other traits.

Table 5.43. Rotated component matrix for auricular surface components in the Coimbra collection.

Trait	Component 1	Component 2	Component 3	Component 4
Fine granularity	0.958			
Coarse granularity	0.952			
Microporosity		0.828		
Macroporosity		0.728		
Lipping		0.667		
Dense Bone			0.770	
Transverse organization			0.713	
Apical area				0.966

For the Bass collection, the rotated component matrix indicated the formation of four components (Table 5.44). The first component was composed of fine and coarse granularity, which resonates with the correlation matrix. Furthermore, similar to the correlation matrix, lipping was grouped with apical area activity as the second component, and microporosity and macroporosity as the third component. Macroporosity was also included in the fourth component with dense bone and transverse organization, although in the correlation matrix these traits do not shared a significant correlation.

Table 5.44. Rotated component matrix for auricular surface components for the Bass collection.

Trait	Component 1	Component 2	Component 3	Component 4
Fine granularity	0.969			
Coarse granularity	0.964			
Lipping		0.754		
Apical area		0.742		
Microporosity			0.816	
Macroporosity			0.714	0.437
Dense Bone				0.804
Transverse organization				0.480

For the Coimbra collection, the partial correlation controlling for age (Table 5.45) suggested the same correlation pattern as the pairwise matrix of correlations coefficients. Similarly, fine and coarse granularity shared the highest metamorphosis variance: 72.2% (Table 5.46). The remaining age-related traits shared a small variance among them. Again, no relationship was found between dense bone and other auricular surface features. Additionally, transverse organization continues to share a low correlation with fine and coarse granularity, when age was controlled.

Table 5.45. Partial correlation between auricular surface traits controlling for age at death for the Coimbra pooled sex sample, with r coefficient above the line and p value below.

Trait	TO	FG	CG	DB	Mi	Ma	Apical area	Lipping
TO		0.127	0.128	0.144	-0.049	0.072	0.045	-0.024
FG	**0.027**		0.850	0.042	-0.116	-0.047	0.081	0.219
CG	**0.031**	**<0.001**		0.066	-0.040	0.015	0.053	0.215
DB	0.053	0.320	0.231		-0.041	0.106	-0.027	0.182
Mi	0.308	0.118	0.343	0.341		0.347	-0.053	0.356
Ma	0.228	0.316	0.438	0.141	**<0.001**		0.048	0.248
Apical area	0.268	0.123	0.232	0.385	0.300	0.312		0.253
Lipping	0.410	**0.018**	**0.020**	0.078	**0.004**	**0.029**	**0.006**	

Legend: TO- transverse organization; FG – Fine granularity; CG – Coarse granularity; DB – Dense bone; Mi – microporosity; Ma - macroporosity

Table 5.46. Significant shared variance between auricular surface traits, controlling for age at death for Coimbra pooled sex sample.

Trait	Correlated trait	Shared variance (%)
Transverse organization	Fine granularity	1.6
	Coarse granularity	1.6
Fine granularity	Coarse granularity	72.2
	Lipping	4.8
	Transverse organization	1.6
Coarse granularity	Fine granularity	72.2
	Lipping	4.6
	Transverse organization	1.6
Microporosity	Lipping	12.7
	Macroporosity	12.0
Macroporosity	Microporosity	12.0
	Lipping	6.2
Apical area	Lipping	6.4
Lipping	Microporosity	12.7
	Apical area	6.4
	Macroporosity	6.2
	Fine granularity	4.8
	Coarse granularity	4.6

For the Bass collection, the same correlation patterns were obtained for partial correlation controlling for age (Table 5.47) as for pairwise matrix of correlations coefficients. Again, only fine and coarse granularity shared the highest percentage of metamorphosis variance: 81.4% (Table 5.48). Lipping, apical area, microporosity and macroporosity shared a small degenerative variance among them, although the correlation was significant. The only traits that did not correlate were transverse organization and dense bone.

Table 5.47. Partial correlation between auricular surface traits controlling for age for the Bass pooled sex sample, with r coefficient above the line and p value below.

Trait	TO	FG	CG	DB	Mi	Ma	Apical area	Lipping
TO		0.006	-0.035	0.027	-0.020	0.073	0.018	-0.031
FG	0.464		0.902	-0.006	-0.083	-0.061	0.156	-0.070
CG	0.306	**<0.001**		0.011	-0.127	-0.034	0.141	-0.041
DB	0.359	0.469	0.443		-0.091	0.117	-0.077	-0.034
Mi	0.394	0.134	**0.046**	0.115		0.237	-0.085	-0.089
Ma	0.161	0.206	0.323	0.058	**0.001**		-0.026	-0.015
Apical area	0.398	**0.012**	**0.022**	0.152	0.134	0.365		0.158
Lipping	0.345	0.183	0.301	0.342	0.146	0.427	**0.021**	

Legend: TO- transverse organization; FG – Fine granularity; CG – Coarse granularity; DB – Dense bone; Mi – microporosity; Ma - macroporosity.

Table 5.48. Shared variance between auricular surface traits controlling for age at death for the Bass pooled sex sample.

Trait	Correlated trait	Shared variance (%)
Fine granularity	Coarse granularity	81.4
	Apical area	2.4
Coarse granularity	Fine granularity	81.4
	Apical area	2.0
	Microporosity	1.6
Microporosity	Macroporosity	5.6
	Coarse granularity	1.6
Macroporosity	Microporosity	5.6
Apical area	Lipping	2.5
	Fine granularity	2.4
	Coarse granularity	2.0
Lipping	Apical area	2.5

Established auricular surface components and respective designations are presented in Table 5.49. Even though the number of components was different between collections – with two components for the Coimbra collection and three for the Bass collection – clustering of traits pattern was similar. Fine and coarse granularities formed the component granularity for both collections, and contributed to highest metamorphic variance at the auricular surface (24% for both Coimbra and Bass collections). For the Coimbra collection, the second component established comprised microporosity, macroporosity and lipping as suggested by the rotated component matrix, contributed to 21.1% of degenerative variance. For the Bass collection, microporosity and macroporosity were clustered as a component (15.4% of degenerative variance), and lipping was clustered with apical area activity (15.5% of degenerative variance). Therefore, the attribution of lipping by components was different between collections. Even though for the Coimbra sample, lipping correlated with apical area activity, lipping exhibited a slightly higher correlation with porosity traits. Even though the rotated component matrices suggested a total of four components for both collections, not all were considered as components in the present research if no significant correlation was found between traits in pairwise matrix of correlations coefficients and partial correlation controlling for age. For the Coimbra collection, the rotated component matrix considered clustering of dense bone and transverse organization, although they did not share a significant correlation. Therefore, it was not considered as a component. For the Bass

collection, the agglomeration of macroporosity, dense bone, and transverse organization was also not considered as a component - as suggested by the rotated component matrices - because none of the traits are significantly correlated.

Table 5.49. Established components for the auricular surface criteria for both collections.

Coimbra collection		Bass collection	
Component	**Trait**	**Component**	**Trait**
Granularity	Fine granularity Coarse granularity	Granularity	Fine granularity Coarse granularity
Porosity + Lipping	Microporosity Macroporosity Lipping	Porosity	Microporosity Macroporosity
—	—	Osteophytic changes	Apical area Lipping

5.5.2.3. Pubic symphysis

For the Coimbra collection, ventral bevelling was excluded from establishment of components. The inclusion of ventral bevelling in the pairwise matrix of correlations coefficients resulted in one or more negative eigenvalues, which precluded PCA testing. The pairwise matrix of correlation coefficients between Coimbra pubic symphysis traits is presented in Table 5.50. The correlation matrix did not show a clear correlation pattern, since not all traits correlated with each other. However, the following clusters emerged between traits that shared moderate (r coefficient from 0.300 to 0.564) to high correlations (r coefficient from 0.605 to 0.684): 1) billowing, superior extremity, inferior extremity, dorsal plateau, ventral rampart, symphyseal rim, pubic tubercle and symphyseal face shape; 2) dorsal body and ventral body of the pubic bone, medial aspect of the *obturator foramen* and LOVBe; and 3) erosion of the symphyseal face and rim. Furthermore, a KMO test showed an acceptable correlation pattern (0.579), and Bartlett's test of sphericity indicated a significant correlation (Chi-square approximation = 175.616; df = 91; $p < 0.001$).

For the Bass collection, inferior extremity and dorsal body were not included alongside ventral bevelling, because that hindered PCA testing since it resulted in one or more negative eigenvalues. The pairwise matrix of correlation coefficients between pubic symphysis traits (Table 5.51) displayed a more scattered and unclear

Table 5.50. Pairwise matrix of correlations coefficients for pubic symphysis traits from the Coimbra collection (*p<0.05).

Trait	Billowing	SE	IE	DP	VR	DBPB	VBPB	MAOF	SR	PT	ESF	ESR	SFS	LOVBe
Billowing	1.000	0.135	**0.127***	**0.281***	**0.403***	0.070	0.067	**0.145***	**0.442***	**0.169***	**-0.205***	0.129	**0.545***	0.101
SE	0.135	1.000	-0.032	**0.519***	**0.433***	0.134	**0.192***	**0.281***	**0.300***	**0.634***	0.110	0.174	0.133	0.103
IE	**0.127***	-0.032	1.000	**0.605***	**0.457***	**0.134***	**0.251***	**0.245***	**0.226***	**0.302***	0.055	0.063	**0.253***	0.068
DP	**0.281***	**0.519***	**0.605***	1.000	**0.632***	0.114	**0.270***	**0.387***	**0.514***	**0.413***	0.112	0.161	**0.394***	0.116
VR	**0.403***	**0.433***	**0.457***	**0.632***	1.000	-0.026	**0.225***	**0.168***	**0.684***	**0.564***	-0.075	0.110	**0.504***	0.131
DBPB	0.070	0.134	**0.134***	0.114	-0.026	1.000	**0.372***	**0.204***	**0.200***	**0.241***	0.011	0.024	0.058	**0.327***
VBPB	0.067	**0.192***	**0.251***	**0.270***	**0.225***	**0.372***	1.000	**0.345***	**0.271***	**0.266***	0.079	0.094	**0.207***	0.148
MAOF	**0.145***	**0.281***	**0.245***	**0.387***	**0.168***	**0.204***	**0.345***	1.000	0.131	**0.197***	-0.088	0.039	**0.190***	0.069
SR	**0.442***	**0.300***	**0.226***	**0.514***	**0.684***	**0.200***	**0.271***	0.131	1.000	**0.537***	-0.181	0.017	**0.555***	**0.222***
PT	**0.169***	**0.634***	**0.302***	**0.413***	**0.564***	**0.241***	**0.266***	**0.197***	**0.537***	1.000	-0.085	0.000	**0.196***	0.069
ESF	**-0.205***	0.110	0.055	0.112	-0.075	0.011	0.079	-0.088	-0.181	-0.085	1.000	**0.504***	**-0.174***	0.006
ESR	0.129	0.174	0.063	0.161	0.110	0.024	0.094	0.039	0.017	0.000	**0.504***	1.000	0.132	0.190
SFS	**0.545***	0.133	**0.253***	**0.394***	**0.504***	0.058	**0.207***	**0.190***	**0.555***	**0.196***	**-0.174***	0.132	1.000	0.131
LOVBe	0.101	0.103	0.068	0.116	0.131	**0.327***	0.148	0.069	**0.222***	0.069	0.006	0.190	0.131	1.000

Legend: SE – superior extremity; IE – inferior extremity; DP – dorsal plateau; VR – Ventral rampart; DBPB - Dorsal body of the pubic bone; VBPB – Ventral body of the pubic bone; MAOF - Medial aspect of the obturator foramen; SR – Symphyseal rim; PT – pubic tubercle; ESF – erosion of the symphyseal face; ESR – erosion of the symphyseal erosion; SFS – symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling.

Table 5.51. Pairwise matrix of correlations coefficients for pubic symphysis traits from the Bass collection (*p<0.05).

Trait	Billowing	SE	VR	DBPB	VBPB	MAOF	SR	PT	ESF	ESR	SFS	LOVBe
Billowing	1.000	-0.007	**0.123***	**0.116***	-0.046	-0.094	**0.156***	0.082	0.015	**0.161***	**0.275***	0.020
SE	-0.007	1.000	**0.576***	-0.113	**0.227***	0.022	**0.576***	**0.740***	0.074	0.052	0.106	**0.164***
VR	**0.123***	**0.576***	1.000	0.011	**0.162***	0.098	**0.642***	**0.468***	0.060	-0.005	**0.214***	**0.172***
DBPB	**0.116***	-0.113	0.011	1.000	**0.150***	0.035	-0.005	-0.052	**0.160***	0.125	0.032	**0.209***
VBPB	-0.046	**0.227***	**0.162***	**0.150***	1.000	0.108	**0.264***	**0.152***	0.126	0.039	0.071	**0.158***
MAOF	-0.094	0.022	0.098	0.035	0.108	1.000	-0.005	-0.088	0.043	**0.179***	0.015	0.013
SR	**0.156***	**0.576***	**0.642***	-0.005	**0.264***	-0.005	1.000	**0.545***	0.082	-0.084	**0.371***	**0.179***
PT	0.082	**0.740***	**0.468***	-0.052	**0.152***	-0.088	**0.545***	1.000	0.110	0.056	**0.233***	**0.169***
ESF	0.015	0.074	0.060	**0.160***	0.126	0.043	0.082	0.110	1.000	**0.393***	-0.042	**0.199***
ESR	**0.161***	0.052	-0.005	0.125	0.039	**0.179***	-0.084	0.056	**0.393***	1.000	0.094	**0.197***
SFS	**0.275***	0.106	**0.214***	0.032	0.071	0.015	**0.371***	**0.233***	-0.042	0.094	1.000	0.063
LOVBe	0.020	**0.164***	**0.172***	**0.209***	**0.158***	0.013	**0.179***	**0.169***	**0.199***	**0.197***	0.063	1.000

Legend: SE – superior extremity; VR – Ventral rampart; DBPB - Dorsal body of the pubic bone; VBPB – Ventral body of the pubic bone; MAOF - Medial aspect of the obturator foramen; SR – Symphyseal rim; PT – pubic tubercle; ESF – erosion of the symphyseal face; ESR – erosion of the symphyseal erosion; SFS – symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling.

pattern, with fewer traits shared significant correlations than for the Coimbra collection. Nevertheless, two clusters emerged for traits with moderate (r coefficient from 0.371 to 0.576) to high correlations (r coefficient from 0.642 to 0.740): 1) superior extremity, ventral rampart, symphyseal rim and symphyseal face shape, and 2) erosion of the symphyseal face and rim. Low correlations were obtained between billowing, medial aspect of the *obturator foramen*, LOVBe and dorsal body and ventral body of the pubic bone. An acceptable correlation pattern for the KMO test (0.685) was obtained, and additionally, Bartlett's test of sphericity indicated a significant correlation between traits (Chi-square approximation= 357.775; df= 66; p <0.001).

The rotated component matrix (Tables 5.52 and 5.53) provided a better discrimination pattern for pubic symphysis traits clustering than the pairwise matrix of correlations coefficients. For the Coimbra collection, the rotated matrix suggested formation of five components, although symphyseal rim, ventral rampart, dorsal plateau and ventral body of the pubic body were placed in more than one component. The first PCA component shared 18.1% of degenerative variance, the second 15.9%, the third 14.0%, the fourth 11.4% and the fifth 11.2%. For the Bass collection, the establishment of four components was suggested, with the exclusion of medial aspect of the *obturator foramen* in a component. The first component shared 24.2% of degenerative variance, the second 12.3%, the third 11.5%, and the fourth 11.1%.

Table 5.52. Rotated component matrix for the Coimbra collection.

Trait	Component				
	1	2	3	4	5
Symphyseal face shape	0.814				
Billowing	0.793				
Symphyseal rim	0.683	0.444			
Ventral rampart	0.616	0.524			
Superior extremity		0.899			
Pubic tubercle		0.826			
Inferior extremity			0.839		
Dorsal plateau		0.454	0.633		
Medial aspect of the obturator foramen			0.580		
Erosion of the symphyseal rim				0.861	
Erosion of the symphyseal face				0.837	
Dorsal body of the pubic bone					0.817
Ligamentous outgrowth of the ventral bevelling					0.669
Ventral body of the pubic bone			0.500		0.525

Table 5.53. Rotated component matrix for the Bass collection.

Trait	Component				
	1	2	3	4	5
Superior extremity	0.886				
Pubic tubercle	0.829				
Symphyseal rim	0.797				
Ventral rampart	0.757				
Erosion of the symphyseal rim		0.831			
Erosion of the symphyseal face		0.763			
Billowing			0.797		
Symphyseal face shape			0.734		
Dorsal body of the pubic bone				0.762	
Ventral body of the pubic bone				0.615	
Ligamentous outgrowth of the ventral bevelling				0.540	
Medial aspect of the obturator foramen					0.928

For the Coimbra pooled sex sample, partial correlations between pubic symphysis traits controlling for age at death, and degenerative variance shared between traits are presented in Tables 5.54 and 5.55. Even though ventral bevelling will not be included in established components because it was not incorporated in the PCA test, ventral bevelling was integrated in the partial correlation analysis to provide an idea how it correlated with others traits when age was controlled. Results showed ventral bevelling did not correlate with LOVBe, which is expected since LOVBe can only be recorded if ventral bevelling was present. Furthermore, the partial correlation between traits did not provide a clear correlation pattern, with a mismatch among traits that shared a moderate correlation. For example, a moderate correlation was shared between billowing with the ventral rampart, symphyseal rim and symphyseal face shape. However, a moderate correlation was also shared between symphyseal rim with dorsal plateau, pubic tubercle and symphyseal face shape, and has a high correlation with ventral rampart. Exceptions were dorsal and ventral body of the pubic bone, and LOVBe, which did not share moderate or high correlations with other traits. A decrease in the r coefficient value for a majority of traits was obtained when age was controlled, in comparison to the pairwise matrix of correlations coefficients. Additionally, for some cases, correlation coefficients no longer were significant when age was controlled (*e.g.*, correlation between dorsal plateau and ventral body of the pubic body). For the Coimbra collection, degenerative variance shared between pubic symphysis traits ranged between low (1.6%) and moderate (43.3%).

Table 5.54. Partial correlation between pubic symphysis traits controlling for age at death for the Coimbra pooled sex sample, with r coefficient above the line and p value below.

Trait	Bi	SE	IE	DP	VR	DBPB	VBPB	MAOF	SR	PT	VBe	ESF	ESR	SFS	LOVBe
Bi		0.126	0.042	**0.207**	**0.362**	-0.001	-0.071	0.086	**0.403**	0.125	**0.125**	**-0.232**	0.070	**0.514**	0.053
SE	0.066		-0.055	**0.544**	**0.435**	0.124	**0.193**	**0.277**	**0.297**	**0.638**	0.059	0.106	0.166	0.123	0.094
IE	0.286	0.264		**0.536**	**0.400**	0.028	0.072	**0.162**	0.138	**0.247**	**0.629**	0.026	-0.040	**0.172**	-0.010
DP	**0.002**	**<0.001**	**<0.001**		**0.594**	-0.005	0.075	**0.316**	**0.457**	**0.367**	**0.414**	0.087	0.061	**0.325**	0.036
VR	**<0.001**	**<0.001**	**<0.001**	**<0.001**		-0.115	0.102	0.103	**0.658**	**0.539**	**0.418**	-0.102	0.041	**0.465**	0.079
DBPB	0.493	0.074	0.351	0.471	0.073		**0.268**	**0.136**	0.128	**0.192**	-0.019	-0.014	-0.059	-0.022	**0.284**
VBPB	0.165	**0.013**	0.176	0.159	0.102	**<0.001**		**0.249**	**0.153**	**0.188**	0.111	0.042	-0.056	0.081	0.046
MAOF	0.114	**0.001**	**0.014**	**<0.001**	0.097	**0.019**	**<0.001**		0.061	**0.149**	**0.247**	-0.115	-0.035	**0.127**	0.014
SR	**<0.001**	**0.001**	0.066	**<0.001**	**<0.001**	0.082	**0.051**	0.255		**0.510**	**0.263**	**-0.213**	-0.062	**0.519**	0.174
PT	0.075	**<0.001**	**0.003**	**<0.001**	**<0.001**	**0.014**	**0.018**	**0.046**	**<0.001**		**0.198**	-0.105	-0.059	**0.148**	0.027
VBe	**0.036**	0.243	**<0.001**	**<0.001**	**<0.001**	0.389	0.059	**<0.001**	**0.001**	**0.011**		0.029	0.007	**0.187**	—
ESF	**0.012**	0.175	0.404	0.207	0.177	0.448	0.349	0.140	**0.038**	0.180	0.394		**0.502**	**-0.204**	-0.012
ESR	0.303	0.108	0.383	0.324	0.381	0.331	0.339	0.397	0.326	0.334	0.478	**0.001**		0.065	0.142
SFS	**<0.001**	0.072	**0.009**	**<0.001**	**<0.001**	0.375	0.128	**0.035**	**<0.001**	**0.043**	**0.003**	**0.024**	0.313		0.079
LOVBe	0.315	0.219	0.465	0.374	0.237	**0.005**	0.338	0.449	0.090	0.413	—	0.467	0.211	0.231	

Legend: Bi – Billowing; SE – superior extremity; IE- Inferior extremity; DP – Dorsal plateau; VR – Ventral rampart; DBPB - Dorsal body of the pubic bone; VBPB – Ventral body of the pubic bone; MAOF - Medial aspect of the obturator foramen; SR – Symphyseal rim; PT – pubic tubercle; VBe – Ventral bevelling; ESF – erosion of the symphyseal face; ESR – erosion of the symphyseal erosion; SFS – symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling.

Table 5.55. Significant shared variance between pubic symphysis traits, controlling for age at death for the Coimbra pooled sex sample.

Trait	Correlated trait	Shared variance (%)	Trait	Correlated trait	Shared variance (%)	Trait	Correlated trait	Shared variance (%)
DP	VR	35.3	**PT**	SE	40.7	**SFS**	SR	26.9
	SE	29.6		VR	29.1		Bi	26.4
	IE	28.7		SR	26.0		VR	21.6
	SR	20.9		DP	13.5		DP	10.6
	VBe	17.1		IE	6.1		ESF	4.2
	PT	13.5		VBe	3.9		VBe	3.5
	SFS	10.6		DBPB	3.7		IE	3.0
	MAOF	10.0		SFS	2.2		PT	2.2
	Bi	4.3		VBPB	2.2		MAOF	1.6
VR	SR	43.3	**MAOF**	DP	10.0	**SR**	VR	43.3
	DP	35.3		SE	7.7		SFS	26.9
	SE	29.6		VBPB	6.2		PT	26.0
	PT	29.1		VBe	6.1		DP	20.9
	IE	28.7		IE	2.6		Bi	16.2
	SFS	21.6		PT	2.2		SE	8.8
	VBe	17.5		DBPB	1.8		VBe	6.9
	Bi	4.3		SFS	1.6		ESF	4.5
VBe	IE	39.6	**Bi**	SFS	26.4	**SE**	PT	40.7
	VR	17.5		SR	16.2		DP	29.6
	DP	17.1		VR	13.1		VR	18.9
	SR	6.9		ESF	5.4		SR	8.8
	MAOF	6.1		DP	4.3		MAOF	7.7
	PT	3.9		VBe	1.6		VBPB	3.7
	SFS	3.5						
	Bi	1.6						
IE	VBe	39.6	**DBPB**	LOVBe	8.1	**ESF**	ESR	25.2
	DP	28.7		VBPB	7.2		Bi	5.4
	VR	16.0		PT	3.7		SR	4.5
	PT	6.1		MAOF	1.8		SFS	4.2
	SFS	3.0						
	MAOF	2.6						
VBPB	DBPB	7.2	**ESR**	ESF	25.2	**LOVBe**	DBPB	8.1
	MAOF	6.2						
	SE	3.7						

Legend: Bi – Billowing; SE – superior extremity; IE- Inferior extremity; DP- Dorsal plateau; VR – Ventral rampart; DBPB - Dorsal body of the pubic bone; VBPB – Ventral body of the pubic bone; MAOF - Medial aspect of the obturator foramen; VBe- Ventral bevelling; SR – Symphyseal rim; PT – pubic tubercle; ESF – erosion of the symphyseal face; ESR – erosion of the symphyseal erosion; SFS – symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling.

For the Bass pooled sex sample, partial correlations between pubic symphysis traits controlling for age at death and degenerative variance shared between the traits are presented in Tables 5.56 and 5.57. Inferior extremity and dorsal plateau were included in the partial correlation test to inform how these traits correlated with other traits when age was controlled, even though these two traits will not be incorporated in establishing components. However, partial correlations between inferior extremity and dorsal plateau, and dorsal body of the pubic bone were not computable. Inferior extremity and dorsal plateau shared a high correlation and shared moderate to high correlations with superior extremity, symphyseal rim and pubic tubercle. Similar correlation patterns between pubic symphysis traits were obtained, when the partial correlation and the pairwise matrix of correlations coefficients were compared. Nevertheless, small differences among tests existed: some traits shared low correlations at the pairwise matrix no longer correlated when age was controlled, but the inverse was also observable. Additionally, a moderate correlation between billowing and pubic tubercle was obtained when age was controlled but was non-significant for the pairwise matrix. Degenerative variance shared among pubic symphysis traits ranged from very low (0.3%) to high (100.0%). However, most traits shared low to moderate degenerative variance.

For the present study, four components for the Coimbra collection and three for the Bass collection were established (Table 5.58). Despite differences in the number of components, trait clustering into components was similar for both collections. For the Coimbra collection, the rotated component matrix suggested clustering of symphyseal face shape, billowing, symphyseal rim and ventral rampart as the first component, but symphyseal rim and ventral rampart were also included in the second component with superior extremity, pubic tubercle and dorsal plateau. Based on these results, symphyseal face shape and billowing were considered a single component in the present dissertation. Symphyseal rim and ventral rampart were clustered with superior extremity, pubic tubercle and dorsal plateau in a second component. When age was controlled, symphyseal rim and ventral rampart shared higher degenerative variance with superior extremity, pubic tubercle and dorsal plateau, than with symphyseal face shape and billowing. Additionally, dorsal plateau was also included in the second component, because that trait shared its highest variance with other joint margin traits rather than with the medial aspect of the *obturator foramen*, and none with ventral body of the pubic bone, as suggested by the rotated correlation matrix. Erosion of symphyseal rim and face constituted another

Table 5.56. Partial correlations between pubic symphysis traits controlling for age at death from the Bass pooled sex sample, with r coefficient above the line and p value below.

Trait	Bi	SE	IE	DP	VR	DBPB	VBPB	MAOF	SR	PT	ESF	ESR	SFS	LOVBe
Bi		-0.037	0.049	0.050	0.077	0.004	-0.097	-0.101	0.118	**0.053**	-0.053	**0.139**	**0.262**	-0.069
SE	0.296		**0.752**	**0.752**	**0.568**	**-0.183**	**0.211**	0.020	**0.568**	**0.736**	0.046	0.040	0.096	**0.135**
IE	0.237	**<0.001**		**1.000**	**0.465**	—	**0.253**	0.006	**0.504**	**0.359**	-0.001	0.009	**0.121**	0.021
DP	0.233	**<0.001**	**<0.001**		**0.465**	—	**0.254**	0.006	**0.519**	**0.359**	0.000	0.009	**0.122**	0.022
VR	0.130	**<0.001**	**<0.001**	**<0.001**		-0.087	**0.130**	0.097	**0.630**	**0.456**	0.010	-0.027	**0.201**	0.116
DBPB	0.477	**0.004**	—	—	0.102		0.077	0.032	-0.092	**-0.120**	0.054	0.086	-0.008	0.076
VBPB	0.076	**0.001**	**<0.001**	**<0.001**	**0.028**	0.129		0.108	**0.240**	**0.133**	0.083	0.019	0.056	0.105
MAOF	0.067	0.385	0.466	0.467	0.077	0.321	0.057		-0.007	-0.090	0.041	**0.178**	0.014	0.008
SR	0.071	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.128	**0.001**	0.463		**0.535**	0.040	-0.105	**0.363**	0.133
PT	**0.023**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.046**	**0.031**	0.102	**<0.001**		0.082	0.043	**0.225**	**0.137**
ESF	0.248	0.284	0.497	0.498	0.448	0.251	0.148	0.304	0.327	0.158		**0.380**	-0.067	0.126
ESR	**0.047**	0.313	0.457	0.457	0.374	0.152	0.409	**0.015**	0.106	0.302	**<0.001**		0.086	0.172
SFS	**<0.001**	0.082	**0.037**	**0.037**	**0.001**	0.453	0.205	0.416	**<0.001**	**0.001**	0.197	0.152		0.036
LOVBe	0.167	**0.031**	0.387	0.381	0.052	0.142	0.069	0.452	0.054	**0.031**	0.062	0.021	0.305	

Legend: Bi – Billowing; SE – superior extremity; IE- Inferior extremity; DP- Dorsal plateau; VR – Ventral rampart; DBPB - Dorsal body of the pubic bone; VBPB – Ventral body of the pubic bone; MAOF - Medial aspect of the obturator foramen; SR – Symphyseal rim; PT – pubic tubercle; ESF – erosion of the symphyseal face; ESR – erosion of the symphyseal erosion; SFS – symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling.

Table 5.57. Significant shared variance between pubic symphysis traits, controlling for age at death for the Bass pooled sex sample.

Trait	Correlated trait	Shared variance (%)	Trait	Correlated trait	Shared variance (%)	Trait	Correlated trait	Shared variance (%)
PT	SE	54.2	**SE**	IE	56.6	**IE**	DP	100.0
	SR	28.6		DP	56.6		SE	56.6
	VR	20.8		PT	54.2		SR	25.4
	IE	12.9		VR	32.3		VR	21.6
	DP	12.9		SR	32.3		PT	12.9
	SFS	5.1		VBPB	4.5		VBPB	6.4
	LOVBe	1.9		DBPB	3.3		SFS	1.5
	VBPB	1.8		LOVBe	1.8			
	DBPB	1.4						
	Bi	0.3						
DP	IE	100.0	**VR**	SR	39.7	**SR**	VR	39.7
	SE	56.6		SE	32.3		SE	32.3
	SR	26.9		IE	21.6		PT	28.6
	VR	21.6		DP	21.6		DP	26.9
	PT	12.9		PT	20.8		IE	25.4
	VBPB	6.5		SFS	4.0		SFS	13.2
	SFS	1.5		VBPB	1.7		VBPB	5.8
VBPB	DP	6.5	**SFS**	SR	13.2	**Bi**		
	IE	6.4		Bi	6.9		SFS	6.9
	SR	5.8		PT	5.1		ESR	1.9
	SE	4.5		VR	4.0		PT	0.3
	PT	1.8		IE	1.5			
	VR	1.7		DP	1.5			
ESR	ESF	14.4	**DBPB**	SE	3.3	**LOVBe**	PT	1.9
	MAOF	3.2		PT	1.4		SE	1.8
	Bi	1.9						
MAOF	RE	3.2	**ESF**	RE	14.4			

Legend: Bi – Billowing; SE – superior extremity; IE- Inferior extremity; DP- Dorsal plateau; VR – Ventral rampart; DBPB - Dorsal body of the pubic bone; VBPB – Ventral body of the pubic bone; MAOF - Medial aspect of the obturator foramen; SR – Symphyseal rim; PT – pubic tubercle; ESF – erosion of the symphyseal face; ESR – erosion of the symphyseal erosion; SFS – symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling.

component showing agreement in both PCA and partial correlation tests, as both traits shared a moderate correlation. Dorsal body of the pubic bone was placed in the same component with LOVbe, but without including ventral body of the pubic bone, which did not correlate with LOVBe (Tables 5.50 and 5.54). Lastly, inferior extremity, medial aspect of the *obturator foramen*, and ventral body of the pubic

bone were not clustered as a component. Inferior extremity shared a higher correlation with the component margin changes traits, than with medial aspect of the *obturator foramen* and ventral body of the pubic bone. Additionally, the correlation between medial aspect of the *obturator foramen* and ventral body of the pubic bone was moderate for the pairwise correlation matrix, but lower when age was controlled.

The three components established for the Bass collection (Table 5.58) coincide with the first three components suggested by the rotated component matrix, between traits that shared the highest r coefficients. Dorsal and ventral body of the pubic body and LOVBe were not clustered together into a component as suggested by the rotated component matrix, since these three traits shared low correlations (Tables 5.51 and 5.56). Additionally, medial aspect of the *obturator foramen* was not included in none of the components as shown in the rotated component matrix. This is also in agreement with the partial correlation test results, showed only a low correlation shared between medial aspect of the *obturator foramen* and erosion of the symphyseal rim.

Table 5.58. Established components for pubic symphysis degenerative criteria for both collections.

Coimbra		**Bass**	
Component	**Trait**	**Component**	**Trait**
Erosion	Erosion of the symphyseal face Erosion of the symphyseal rim	Erosion	Erosion of the symphyseal face Erosion of the symphyseal rim
Face topography	Billowing Symphyseal face shape	Face topography	Billowing Symphyseal face shape
Margin changes Coimbra	Superior extremity Dorsal plateau Ventral rampart Symphyseal rim Pubic tubercle	Margin changes Bass	Superior extremity Ventral rampart Symphyseal rim Pubic tubercle
Dorsal body + LOVBe	Dorsal body of the pubic bone Ligamentous outgrowth of the ventral bevelling	—	—

For the total sample and body size groups, the number of individuals by component sum values is presented in Appendix 5 for all pelvic joints. Some of the

component sum values exhibited a low number of individuals; therefore, sums were clustered creating stages. A similar clustering of component sum values between collections was performed (Appendix 5). Age descriptive statistics for component stages - mean, median, standard deviation, minimum and maximum age - are presented in Appendices 6 and 7, respectively for the Coimbra and the Bass collection.

5.5.3. Composite score

The composite score sums all scores attributed for left pelvic joint traits per individual. Only individuals with all traits recorded for a joint were employed in calculating composite scores, which reduced the number of individuals analysed (Table 5.59).

Table 5.59. Number of individuals used in calculating composite scores for both collections.

Collection	Acetabulum			Auricular surface			Pubic symphysis		
	Female	Male	Total	Female	Male	Total	Female	Male	Total
Coimbra	53	47	100	32	21	53	4	20	24
Bass	79	85	164	72	69	141	41	69	110

For the Coimbra pooled sex sample, a much-reduced number of individuals was obtained for auricular surface and pubic symphysis composite scores. Such a low number of individuals may compromise the subsequent statistical analyses. Therefore, traits with a higher frequency of non-observation due to *post-mortem* destruction were eliminated from the composite score sum to increase the number of individuals. Consequently, lipping data for the auricular surface, and erosion of the symphyseal face and rim, and LOVBe data for the pubic symphysis were eliminated. Elimination of those traits increased the number of individuals for the auricular surface to 97 (female n= 54; male n= 43), and for the pubic symphysis to 90 (female n= 30; male n= 60). Those traits were also eliminated from the composite score sum for the Bass collection to allow comparisons between collections. However, for the Bass collection a second composite score was calculated which included all traits, designated "composite score total"[23].

[23] For composite score calculation ventral bevelling was included in both composite score and total composite score for the Bass Collection.

The number of individuals by composite score sum values for each joint is presented in Appendix 5. The number of individuals was low for some cases; therefore, sum values were clustered, forming stages. Clustering was performed as similarly as possible between collections. Age descriptions (mean, median, standard deviation, minimum and maximum age) for composite score stages are presented in Appendices 6 and 7, for the total sample and by body size groups.

In Table 5.60, results for Kendall's W coefficient of concordance, measuring the level of agreement between traits in each joint are presented. Moderate agreement was obtained for acetabular and auricular surface traits in both collections. Between pubic symphysis traits, coefficients of agreement (W^a) were higher, especially for the Bass collection. Similar coefficients of agreement were obtained between auricular surface and pubic symphysis composite score and composite score total, except for the Coimbra pubic symphysis traits in female individuals.

Table 5.60. Level of agreement between degenerative traits calculated with Kendall's W coefficient of concordance ($p < 0.001$).

Articulation	Coimbra collection			Bass collection		
	Female	Male	Total	Female	Male	Total
Acetabulum	0.533	0.464	0.493	0.550	0.573	0.554
Auricular surface without lipping	0.602	0.588	0.587	0.498	0.458	0.471
Auricular surface with all 8 traits	0.564	0.535	0.543	0.432	0.413	0.408
Pubic symphysis with 12 traits	0.573	0.683	0.636	0.787	0.810	0.800
Pubic symphysis with all 15 traits	0.803	0.677	0.689	0.789	0.816	0.803

5.6. BONE DEGENERATION ASSOCIATION WITH AGE AT DEATH AND SEXUAL DIMORPHISM

5.6.1. Acetabulum

In Table 5.61, the ANOVA results for the effect of sex and age on acetabular degenerative criteria are presented for both collections. The Levene's test results are presented in Appendix 8. There were no significant effects of sex and sex by age in acetabulum degenerative criteria. Age at death appeared to have an effect on the majority of degenerative criteria, except for component fossa in both collections, activity and porosity of the fossa for the Coimbra collection and outer edge of the fossa for the Bass collection.

Table 5.61. Factorial ANOVA testing for the effect of sex and age at death in acetabular degenerative criteria for the Coimbra collection (Bonferroni correction of $p \leq 0.008$ – only for traits).

Criteria	Sex			Age at death			Sex x Age at death		
	F	df	p	F	df	p	F	df	p
Groove	5.319	(1, 291)	0.022	**35.745**	**(2, 291)**	**<0.001**	0.059	(2, 291)	0.942
Rim shape	0.048	(1, 201)	0.826	**78.950**	**(2, 201)**	**<0.001**	1.587	(2, 201)	0.207
Rim porosity	0.053	(1, 172)	0.818	**14.244**	**(2, 172)**	**<0.001**	0.026	(2, 172)	0.974
Apex activity	4.440	(1, 188)	0.036	**64.531**	**(2, 188)**	**<0.001**	0.373	(2, 188)	0.689
Outer edge	2.023	(1, 268)	0.156	**5.771**	**(2, 268)**	**0.004**	2.568	(2, 268)	0.079
Activity and porosity of the fossa	0.186	(1, 248)	0.667	1.804	(2, 248)	0.167	0.205	(2, 248)	0.815
Component lunate surface	1.057	(1, 114)	0.306	**49.299**	**(2, 114)**	**<0.001**	0.319	(2, 114)	0.728
Component fossa	0.456	(1, 232)	0.500	2.579	(2, 232)	0.078	0.681	(2, 232)	0.507
Composite score	0.014	(1, 94)	0.906	**19.976**	**(2, 94)**	**<0.001**	1.327	(2, 94)	0.270

Table 5.62. Factorial ANOVA testing for the effect of sex and age at death in acetabular degenerative criteria for Bass collection (Bonferroni correction of $p \leq 0.008$ – only for traits).

Criteria	Sex			Age at death			Sex x Age at death		
	F	df	p	F	df	p	F	df	p
Groove	6.293	(1, 228)	0.013	**12.332**	**(2, 228)**	**<0.001**	3.909	(2, 228)	0.021
Rim shape	1.491	(1, 219)	0.223	**25.668**	**(2, 219)**	**<0.001**	0.697	(2, 219)	0.499
Rim porosity	0.478	(1, 193)	0.490	**5.363**	**(2, 193)**	**0.005**	0.910	(2, 193)	0.404
Apex activity	1.373	(1, 213)	0.243	**30.012**	**(2, 213)**	**<0.001**	0.916	(2, 213)	0.402
Outer edge	0.000	(1, 202)	0.997	0.568	(2, 202)	0.568	0.623	(2, 202)	0.537
Activity and porosity of the fossa	3.085	(1, 199)	0.081	**6.791**	**(2, 199)**	**0.001**	1.469	(2, 199)	0.233
Component lunate surface	0.133	(1, 187)	0.716	**35.085**	**(2, 187)**	**<0.001**	0.258	(2, 187)	0.773
Component fossa	1.549	(1, 184)	0.215	1.953	(2, 184)	0.145	0.212	(2, 184)	0.809
Composite score	0.431	(1, 158)	0.513	**18.053**	**(2, 158)**	**<0.001**	0.017	(2, 158)	0.983

The Spearman correlation coefficients between acetabular degenerative criteria and age at death ranged from low (0.135) to high (0.633) for the Coimbra collection, and from low (0.184) to moderate (0.586) for the Bass collection (Table 5.63). Spearman's rank correlation analysis agreed with the Factorial ANOVA results. Similarly, the composite score r coefficient was higher for the Coimbra collection (r= 0.633) than for the Bass collection (r= 0.449). For the Coimbra sample, lowest correlation coefficients were obtained for outer edge of the fossa, activity and porosity of the fossa and consequently for the component fossa. Similarity, for the Bass collection, activity and porosity of the fossa also presented low correlations with age. In contrast, for outer edge of the fossa and the component fossa the r coefficient was not significant.

Table 5.63. Spearman's rank correlations between acetabular degenerative criteria and age at death for the Coimbra and Bass pooled sex samples.

Criteria	Coimbra collection		Bass collection	
	r	p	r	p
Groove	**0.466**	**<0.001**	**0.267**	**<0.001**
Rim shape	**0.683**	**<0.001**	**0.483**	**<0.001**
Rim porosity	**0.473**	**<0.001**	**0.313**	**<0.001**
Apex activity	**0.620**	**<0.001**	**0.406**	**<0.001**
Outer edge	**0.178**	**0.003**	0.010	0.890
Activity and porosity of the fossa	**0.135**	**0.032**	**0.184**	**0.008**
Component lunate surface	**0.737**	**<0.001**	**0.586**	**<0.001**
Component fossa	**0.164**	**0.011**	0.105	0.149
Composite score	**0.633**	**<0.001**	**0.449**	**<0.001**

For the Coimbra collection, a similar r coefficient was obtained by partial correlation between acetabular degenerative criteria and age by controlling for body size effect (Table 5.64) and by Spearman's rank correlation analysis. However, a greater decrease in the r coefficient value (from 0.132 to 0.223) was obtained when all body size variables were controlled. Additionally, some cases no longer showed correlation with age when body size was controlled (*e.g.*, rim porosity). For the Bass collection, the r coefficient was also similar to the Spearman's rank correlation and the partial correlation analysis, except for the component fossa which showed a low significant correlation with age when stature was controlled.

Table 5.64. Partial correlation between acetabular degenerative criteria and age at death controlling for body size for the Coimbra and Bass pooled sex samples.

Collection	Criteria	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
		r	p	r	p	r	p	r	p	r	p
Coimbra	Groove	**0.392**	**<0.001**	**0.438**	**<0.001**	**0.424**	**<0.001**	**0.400**	**<0.001**	**0.306**	**0.004**
	Rim shape	**0.646**	**<0.001**	**0.647**	**<0.001**	**0.633**	**<0.001**	**0.618**	**<0.001**	**0.551**	**<0.001**
	Rim porosity	**0.435**	**<0.001**	**0.484**	**<0.001**	**0.410**	**<0.001**	**0.386**	**<0.001**	0.224	0.066
	Apex activity	**0.608**	**<0.001**	**0.577**	**<0.001**	**0.574**	**<0.001**	**0.462**	**<0.001**	**0.397**	**0.001**
	Outer edge	**0.197**	**0.003**	**0.191**	**0.004**	**0.172**	**0.019**	0.058	0.561	0.071	0.527
	Activity and porosity of the fossa	**0.143**	**0.040**	**0.157**	**0.023**	0.128	0.095	0.001	0.993	0.021	0.856
	Component lunate surface	**0.667**	**<0.001**	**0.679**	**<0.001**	**0.646**	**<0.001**	**0.638**	**<0.001**	**0.522**	**<0.001**
	Component fossa	**0.176**	**0.014**	**0.188**	**0.009**	0.148	0.062	0.016	0.875	0.053	0.645
	Composite score	**0.588**	**<0.001**	**0.572**	**<0.001**	**0.552**	**<0.001**	**0.537**	**<0.001**	**0.465**	**0.001**
Bass	Groove	**0.352**	**<0.001**	**0.297**	**0.001**	**0.339**	**<0.001**	**0.228**	**<0.001**	**0.345**	**<0.001**
	Rim shape	**0.521**	**<0.001**	**0.499**	**<0.001**	**0.508**	**<0.001**	**0.459**	**<0.001**	**0.494**	**<0.001**
	Rim porosity	**0.286**	**0.002**	**0.287**	**0.002**	**0.268**	**0.004**	**0.322**	**<0.001**	**0.282**	**0.003**
	Apex activity	**0.472**	**<0.001**	**0.462**	**<0.001**	**0.474**	**<0.001**	**0.367**	**<0.001**	**0.442**	**<0.001**
	Outer edge	0.041	0.661	-0.008	0.930	0.041	0.663	-0.016	0.823	0.061	0.524
	Activity and porosity of the fossa	**0.289**	**0.002**	**0.219**	**0.019**	**0.215**	**0.021**	**0.164**	**0.019**	**0.268**	**0.005**
	Component lunate surface	**0.619**	**<0.001**	**0.591**	**<0.001**	**0.609**	**<0.001**	**0.504**	**<0.001**	**0.461**	**<0.001**
	Component fossa	**0.190**	**0.050**	0.110	0.259	0.142	0.146	0.008	0.928	0.139	0.233
	Composite score	**0.534**	**<0.001**	**0.458**	**<0.001**	**0.497**	**<0.001**	**0.337**	**<0.001**	**0.395**	**0.001**

5.6.2. Auricular surface

In Tables 5.65 and 5.66, Factorial ANOVA results for the effect of sex and age at death in the auricular surface degenerative criteria are presented for the Coimbra and Bass collections respectively. Results of Levene's test are presented in Appendix 8. Sex and age had a low influence on the auricular surface degenerative criteria for both collections. Lack of an effect was more evident for the Coimbra collection than for the Bass collection, since sex and age only influenced the apical area changes and the composite score in the latter sample. However, no significant results were obtained when the joint effect of sex and age was tested, except for Bass dense bone.

Correlations between auricular surface degenerative criteria and age at death ranged between low to moderate (Coimbra collection: 0.137 to 0.370; Bass collection: 0.179 to 0.327; Table 5.67). For the composite score, the Coimbra collection showed a higher correlation than the Bass collection. Compared with Factorial ANOVA results, Spearman's rank correlations indicated that more auricular surface criteria were affected by age, especially for the Coimbra collection. In the Bass collection dense bone was not significantly correlated with age according to Spearman's rank correlation test. In addition, dense bone was not correlated with age when the analysis was performed by sex (Table 5.68). For the Coimbra females, the apical area presented a low correlation, and the composite score a moderate relationship with age. Inversely, the Coimbra males showed a significant moderate correlation between the apical area and age.

For the Coimbra pooled sex sample, the r coefficient for partial correlations between auricular surface degenerative criteria and age at death controlling for body size are presented in Table 5.69. Similar r values were obtained from partial correlations with the Spearman's rank correlation analysis, except for when joint surface area and all body size variables were controlled, which led to an increase in the r value between 0.100 and 0.240. Additionally, fine granularity showed a low correlation with age when all body size variables were controlled (r= 0.263). In addition, some auricular surface degenerative criteria were no longer correlated with age (*e.g.*, composite score). For dimorphic degenerative criteria, no major differences were obtained for the r coefficient from the partial correlation (Table 5.70) and Spearman's rank correlations, except for females' apical area changes, whose r coefficient showed an increase of 0.167 when all body size variables were controlled.

Table 5.65. Factorial ANOVA testing for the effect of sex and age at death in auricular surface degenerative criteria for the Coimbra collection (Bonferroni correction of $p \leq 0.006$ – only for traits).

Criteria	Sex			Age at death			Sex x Age at death		
	F	df	p	F	df	p	F	df	p
Transverse organization	1.047	(1, 230)	0.307	1.053	(2, 230)	0.351	2.475	(2, 230)	0.086
Fine granularity	0.587	(1, 253)	0.444	1.289	(2, 253)	0.277	0.720	(2, 253)	0.488
Coarse granularity	0.088	(1, 229)	0.767	2.338	(2, 229)	0.099	1.041	(2, 229)	0.355
Dense bone	0.236	(1, 125)	0.628	0.332	(2, 125)	0.718	0.733	(2, 125)	0.483
Microporosity	0.157	(1, 102)	0.692	0.695	(2, 102)	0.501	1.955	(2, 102)	0.147
Macroporosity	0.139	(1, 109)	0.710	1.395	(2, 109)	0.252	1.079	(2, 109)	0.343
Apical area	**21.478**	**(1, 239)**	**<0.001**	**7.771**	**(2, 239)**	**0.001**	2.180	(2, 239)	0.115
Lipping	0.058	(1, 99)	0.809	3.772	(2, 99)	0.026	0.520	(2, 99)	0.596
Component granularity	0.031	(1, 229)	0.859	1.798	(2, 229)	0.168	0.825	(2, 229)	0.440
Component porosity + lipping	0.013	(1, 50)	0.909	1.068	(2, 50)	0.351	1.645	(2, 50)	0.203
Composite score	**4.931**	**(1, 91)**	**0.029**	**3.918**	**(2, 91)**	**0.023**	0.861	(2, 91)	0.426

Table 5.66. Factorial ANOVA testing for the effect of sex and age at death in auricular surface degenerative criteria for the Bass collection (Bonferroni correction of $p \leq 0.006$ – only for traits).

Criteria	Sex			Age at death			Sex x Age at death		
	F	df	p	F	df	p	F	df	p
Transverse organization	0.006	(1, 211)	0.940	1.557	(2, 211)	0.213	0.086	(2, 211)	0.917
Fine granularity	2.105	(1, 214)	0.148	1.383	(2, 214)	0.253	0.114	(2, 214)	0.892
Coarse granularity	1.795	(1, 210)	0.182	0.958	(2, 210)	0.386	0.257	(2, 210)	0.774
Dense bone	**13.723**	**(1, 182)**	**<0.001**	**6.716**	**(2, 182)**	**0.002**	**9.338**	**(2, 182)**	**<0.001**
Microporosity	0.418	(1, 174)	0.519	0.947	(2, 174)	0.390	0.321	(2, 174)	0.726
Macroporosity	0.003	(1, 183)	0.955	**6.223**	**(2, 183)**	**0.002**	0.586	(2, 183)	0.558
Apical area	0.366	(1, 215)	0.546	4.044	(2, 215)	0.019	0.082	(2, 215)	0.922
Lipping	5.977	(1, 168)	0.016	4.627	(2, 168)	0.011	1.207	(2, 168)	0.302
Component granularity	2.391	(1, 210)	0.124	0.434	(2, 210)	0.648	0.512	(2, 210)	0.600
Component osteophytic changes	1.381	(1, 162)	0.242	**5.198**	**(2, 162)**	**0.006**	0.667	(2, 162)	0.515
Component porosity	0.166	(1, 173)	0.684	**3.589**	**(2, 173)**	**0.030**	0.402	(2, 173)	0.670
Composite score	0.736	(1, 168)	0.392	**5.210**	**(2, 168)**	**0.006**	0.414	(2, 168)	0.661
Composite score total	0.000	(1, 135)	0.995	**5.054**	**(2, 135)**	**0.008**	0.540	(2, 135)	0.584

Table 5.67. Spearman's rank correlation between auricular surface degenerative criteria and age at death for the Coimbra and Bass pooled sex samples.

Criteria	Coimbra collection		Bass collection	
	r	p	r	p
Transverse organization	0.086	0.190	0.122	0.072
Fine granularity	0.092	0.141	-0.032	0.632
Coarse granularity	**0.137**	**0.035**	0.036	0.599
Dense bone	-0.074	0.402	0.033	0.657
Microporosity	0.113	0.243	0.040	0.598
Macroporosity	**0.265**	**0.004**	**0.203**	**0.005**
Apical area	**0.233**	**<0.001**	**0.179**	**0.007**
Lipping	**0.286**	**0.003**	**0.312**	**<0.001**
Component granularity	**0.137**	**0.035**	0.030	0.664
Component porosity + lipping	**0.282**	**0.035**	—	—
Component porosity	—	—	0.099	0.186
Component osteophytic changes	—	—	**0.327**	**<0.001**
Composite score	**0.370**	**<0.001**	**0.200**	**0.008**
Composite score total	—	—	**0.242**	**0.004**

Table 5.68. Spearman's rank correlation between auricular surface degenerative criteria with significant sexual dimorphism and age at death for the Coimbra and Bass collections.

Collection	Criteria	Female		Male	
		r	p	r	p
Coimbra	Apical area	0.183	**0.038**	0.325	**<0.001**
	Composite score	0.517	**<0.001**	0.205	0.186
Bass	Dense bone	-0.042	0.690	0.118	0.252

For the Bass pooled sex sample, partial correlations between auricular surface degenerative criteria and age controlling for body size are presented in Table 5.71. Similar r coefficient values to Spearman's rank correlation results were obtained. However, when all body size variables were controlled, none of the auricular surface degenerative criteria showed correlation with age. For each sex, the r coefficient for dense bone continued to be non-significant when body size was controlled (Table 5.72). For the female individuals, the r coefficient was not computable when joint surface area and all body size variables were controlled.

Table 5.69. Partial correlations between auricular surface degenerative criteria and age at death controlling for body size for Coimbra pooled sex sample.

Criteria	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
	r	p	r	p	r	p	r	p	r	p
Transverse organization	0.029	0.688	0.090	0.206	0.023	0.769	0.126	0.271	0.048	0.715
Fine granularity	0.086	0.212	0.107	0.115	0.129	0.086	0.191	0.094	**0.263**	**0.042**
Coarse granularity	**0.142**	**0.047**	**0.144**	**0.041**	**0.178**	**0.023**	**0.271**	**0.017**	**0.296**	**0.023**
Dense bone	-0.085	0.370	-0.143	0.124	-0.144	0.163	0.026	0.849	0.058	0.715
Microporosity	0.165	0.112	0.149	0.143	0.147	0.190	0.128	0.367	0.133	0.414
Macroporosity	**0.289**	**0.004**	**0.267**	**0.006**	**0.310**	**0.004**	**0.373**	**0.006**	**0.365**	**0.017**
Apical area	**0.233**	**0.001**	**0.206**	**0.003**	**0.209**	**0.006**	0.123	0.302	0.034	0.800
Lipping	**0.314**	**0.002**	**0.297**	**0.004**	**0.360**	**0.001**	**0.526**	**<0.001**	**0.488**	**0.005**
Component granularity	0.121	0.089	0.131	0.063	**0.185**	**0.018**	**0.261**	**0.022**	**0.314**	**0.015**
Component porosity + lipping	**0.341**	**0.014**	**0.327**	**0.018**	**0.347**	**0.023**	**0.449**	**0.015**	0.370	0.099
Composite score	**0.340**	**0.001**	**0.348**	**0.001**	**0.375**	**0.001**	0.280	0.054	0.288	0.079

Table 5.70. Partial correlations between auricular surface degenerative criteria and age at death controlling for body size for the Coimbra female and male samples.

sex	Criteria	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
		r	p	r	p	r	p	r	p	r	p
Female	Apical area	**0.245**	**0.011**	**0.204**	**0.032**	**0.235**	**0.025**	0.271	0.072	**0.350**	**0.046**
	Composite score	**0.509**	**<0.001**	**0.449**	**0.001**	**0.580**	**<0.001**	**0.543**	**0.002**	**0.519**	**0.013**
Male	Apical area	**0.305**	**0.002**	**0.312**	**0.002**	**0.262**	**0.017**	0.004	0.968	-0.260	0.268
	Composite score	0.168	0.305	0.187	0.247	0.148	0.402	0.109	0.678	-0.017	0.958

Table 5.71. Partial correlation between auricular surface degenerative criteria and age at death controlling for body size for the Bass pooled sex sample.

Criteria	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
	r	p	r	p	r	p	r	p	r	p
Transverse organization	0.096	0.292	0.073	0.422	0.080	0.382	**0.210**	**0.029**	0.162	0.209
Fine granularity	0.060	0.292	0.073	0.422	0.027	0.768	-0.003	0.974	0.139	0.280
Coarse granularity	0.134	0.143	0.149	0.102	0.113	0.216	0.039	0.692	0.158	0.221
Dense bone	0.147	0.125	0.143	0.133	0.144	0.133	-0.064	0.520	-0.036	0.786
Microporosity	0.065	0.506	0.064	0.512	0.076	0.437	0.003	0.973	-0.062	0.640
Macroporosity	**0.248**	**0.009**	**0.207**	**0.029**	**0.225**	**0.018**	0.108	0.273	0.191	0.144
Apical area	**0.230**	**0.011**	**0.240**	**0.007**	**0.210**	**0.020**	0.181	0.060	0.146	0.258
Lipping	**0.251**	**0.013**	**0.284**	**0.004**	**0.255**	**0.011**	**0.283**	**0.007**	0.249	0.095
Component granularity	0.107	0.245	0.088	0.336	0.079	0.389	0.023	0.812	0.155	0.229
Component osteophytic changes	**0.343**	**0.001**	**0.342**	**0.001**	**0.334**	**0.001**	**0.277**	**0.009**	0.229	0.126
Component porosity	0.178	0.069	0.181	0.064	0.166	0.090	0.072	0.469	0.090	0.498
Composite score	**0.254**	**0.010**	**0.244**	**0.013**	**0.229**	**0.020**	0.183	0.067	0.220	0.093
Composite score total	**0.303**	**0.005**	**0.309**	**0.004**	**0.272**	**0.013**	**0.309**	**0.004**	0.212	0.168

Table 5.72. Partial correlation between dense bone and age at death controlling for body size for the Bass female and male samples.

sex	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
	r	p	r	p	r	p	r	p	r	p
Female	0.055	0.712	0.080	0.595	0.057	0.706	—	—	—	—
Male	0.193	0.129	0.142	0.265	0.195	0.126	-0.060	0.664	-0.059	0.740

5.6.3. Pubic symphysis

In Tables 5.73 and 5.74, Factorial ANOVA results for the effect of sex and age in pubic symphysis degenerative criteria are presented for the Coimbra and Bass collections, respectively. Levene's test results are presented in Appendix 8. Results showed that sex has a very small effect in the pubic symphysis degeneration, with different criteria being affected in both collections. Inversely, age affected more pubic symphysis criteria than sex, especially for the Coimbra collection. No sex by age effect was found for the Coimbra collection, but for the Bass collection five degenerative criteria were affected.

Spearman's rank correlations between pubic symphysis degenerative criteria and age at death for the pooled sex sample range between low to moderate (Table 5.57; Coimbra collection: r ranged between 0.222 and 0.564; Bass collection: r ranged between 0.152 and 0.554). The r coefficient for the composite score was moderate for both collections, although slightly higher for the Bass collection. Not all pubic symphysis degenerative criteria were correlated with age at death, which was more noticeable for the Bass collection.

For the Coimbra female and male samples, superior extremity and component margin changes were not correlated with age (Table 5.76), similarly to the pooled sex sample. For the composite score, the r coefficient was moderate for both sexes but higher for the female sample. For the Bass female sample, the composite score was high while the male sample showed a moderate score. However, the Bass collection r values were higher than those obtained for the Coimbra female and male samples. The r coefficient for inferior extremity and dorsal plateau was not computed for Bass female sample. However, the correlation for inferior extremity and dorsal plateau was not significant for the Bass male sample.

Table 5.73. Factorial ANOVA for the effect of sex and age at death in pubic symphysis criteria for the Coimbra collection (Bonferroni correction of p≤ 0.003 – only for traits).

Criteria	Sex			Age at death			Sex x Age at death		
	F	Df	p	F	df	p	F	df	p
Billowing	1.036	(1, 213)	0.310	4.626	(2, 213)	0.011	1.297	(2, 213)	0.276
Superior extremity	**9.457**	**(1, 141)**	**0.003**	1.082	(2, 141)	0.342	1.681	(2, 141)	0.190
Inferior extremity	0.026	(1, 196)	0.872	**33.925**	**(2, 196)**	**<0.001**	0.018	(2, 196)	0.982
Dorsal plateau	7.014	(1, 192)	0.009	**38.178**	**(2, 192)**	**<0.001**	4.481	(2, 192)	0.013
Ventral rampart	3.269	(1, 170)	0.072	**12.547**	**(2, 170)**	**<0.001**	0.300	(2, 170)	0.741
DBPB	8.554	(1, 246)	0.004	**7.255**	**(2, 246)**	**0.001**	0.088	(2, 246)	0.916
VBPB	0.574	(1, 229)	0.450	**55.490**	**(2, 229)**	**<0.001**	2.178	(2, 229)	0.116
MAOF	4.829	(1, 260)	0.029	**6.600**	**(2, 260)**	**<0.001**	0.024	(2, 260)	0.976
Symphyseal rim	2.382	(1, 122)	0.125	5.841	(2, 122)	0.004	0.147	(2, 122)	0.864
Pubic tubercle	4.022	(1, 132)	0.047	4.628	(2, 132)	0.011	1.512	(2, 132)	0.224
Ventral bevelling	0.063	(1, 236)	0.802	**33.979**	**(2, 236)**	**<0.001**	0.417	(2, 236)	0.660
ESF	0.063	(1, 89)	0.803	1.111	(2, 89)	0.334	1.857	(2, 89)	0.162
ESR	0.823	(1, 53)	0.368	1.680	(2, 53)	0.196	0.309	(2, 53)	0.735
SFS	0.008	(1, 222)	0.930	**11.651**	**(2, 222)**	**<0.001**	0.231	(2, 222)	0.794
LOVBe	0.021	(1, 84)	0.884	1.500	(2, 84)	0.229	0.045	(2, 84)	0.956
Component face topography	0.740	(1, 210)	0.391	**9.281**	**(2, 210)**	**<0.001**	0.348	(2, 210)	0.707
Component margin changes	**9.115**	**(1, 96)**	**0.003**	3.010	(2, 96)	0.054	0.756	(2, 96)	0.472
Component erosion	0.562	(1, 34)	0.459	2.030	(2, 34)	0.147	2.097	(2, 34)	0.138
Component dorsal body + LOVBe	**6.389**	**(1, 76)**	**0.014**	**3.552**	**(2, 76)**	**0.034**	1.917	(2, 76)	0.154
Composite score	**14.002**	**(1, 84)**	**<0.001**	**8.209**	**(2, 84)**	**0.001**	1.650	(2, 84)	0.198

Legend: DBPB – Dorsal plateau of the pubic bone; VBPB – Ventral plateau of the pubic bone; MAOF – Medial aspect of the obturator foramen; ESF – Erosion of the symphyseal face; ESR – Erosion of the symphyseal rim; SFS – Symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling

Table 5.74. Factorial ANOVA for the effect of sex and age at death in pubic symphysis criteria for the Bass collection (Bonferroni correction of p≤ 0.003 – only for traits).

Criteria	Sex			Age at death			Sex x Age at death		
	F	Df	p	F	df	p	F	df	p
Billowing	0.024	(1, 220)	0.877	4.318	(2, 220)	0.014	0.915	(2, 220)	0.402
Superior extremity	3.895	(1, 207)	0.050	1.788	(2, 207)	0.170	2.444	(2, 207)	0.089
Inferior extremity	**13.409**	**(1, 216)**	**<0.001**	**7.094**	**(2, 216)**	**0.001**	**7.094**	**(2, 216)**	**0.001**
Dorsal plateau	**13.336**	**(1, 215)**	**<0.001**	**7.060**	**(2, 215)**	**0.001**	**7.060**	**(2, 215)**	**0.001**
Ventral rampart	1.103	(1, 216)	0.295	2.144	(2, 216)	0.120	3.094	(2, 216)	0.047
DBPB	2.596	(1, 217)	0.109	**14.899**	**(2, 217)**	**<0.001**	3.065	(2, 217)	0.049
VBPB	0.100	(1, 217)	0.752	3.689	(2, 217)	0.027	0.290	(2, 217)	0.749
MAOF	0.038	(1, 221)	0.846	0.102	(2, 221)	0.903	1.843	(2, 221)	0.161
Symphyseal rim	1.609	(1, 152)	0.207	1.709	(2, 152)	0.185	**6.503**	**(2, 152)**	**0.002**
Pubic tubercle	0.657	(1, 198)	0.419	0.342	(2, 198)	0.711	0.882	(2, 198)	0.416
ESF	0.220	(1, 161)	0.640	5.754	(2, 161)	0.004	0.522	(2, 161)	0.471
ESR	0.060	(1, 144)	0.807	0.422	(2, 144)	0.657	1.040	(2, 144)	0.356
SFS	0.679	(1, 221)	0.411	2.217	(2, 221)	0.111	3.578	(2, 221)	0.030
LOVBe	1.324	(1, 199)	0.251	**6.220**	**(2, 199)**	**0.002**	0.504	(2, 199)	0.605
Component margin changes	2.174	(1, 149)	0.142	1.983	(2, 149)	0.141	**4.069**	**(2, 149)**	**0.019**
Component erosion	0.592	(1, 123)	0.443	**4.774**	**(2, 123)**	**0.010**	0.599	(2, 123)	0.440
Component face topography	0.209	(1, 219)	0.648	2.236	(2, 219)	0.109	2.977	(1, 219)	0.053
Composite score	0.000	(1, 141)	0.984	**8.770**	**(2, 141)**	**<0.001**	**3.987**	**(2, 141)**	**0.021**
Composite score total	**7.263**	**(1, 105)**	**0.008**	**14.826**	**(2, 105)**	**<0.001**	1.503	(1, 105)	0.223

Legend: DBPB – Dorsal plateau of the pubic bone; VBPB – Ventral plateau of the pubic bone; MAOF – Medial aspect of the obturator foramen; ESF – Erosion of the symphyseal face; ESR – Erosion of the symphyseal rim; SFS – Symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling.

Table 5.75. Spearman's rank correlations between pubic symphysis degenerative criteria and age at death for the Coimbra and Bass pooled sex samples.

Criteria	Coimbra collection		Bass collection	
	r	p	r	P
Billowing	**0.258**	**<0.001**	**0.237**	**<0.001**
Superior extremity	0.052	0.530	0.082	0.232
Inferior extremity	**0.372**	**<0.001**	0.116	0.085
Dorsal plateau	**0.416**	**<0.001**	0.116	0.085
Ventral rampart	**0.291**	**<0.001**	**0.173**	**0.010**
DBPB	**0.291**	**<0.001**	**0.458**	**<0.001**
VBPB	**0.564**	**<0.001**	**0.152**	**0.023**
MAOF	**0.305**	**<0.001**	0.013	0.851
Symphyseal rim	**0.289**	**0.001**	0.103	0.200
Pubic tubercle	**0.222**	**0.009**	0.097	0.167
Ventral bevelling	**0.337**	**<0.001**	—	—
ESF	0.117	0.258	**0.273**	**<0.001**
ESR	**0.258**	**0.048**	0.115	0.162
SFS	**0.296**	**<0.001**	0.081	0.221
LOVBe	**0.237**	**0.025**	**0.322**	**<0.001**
Component face topography	**0.306**	**<0.001**	**0.185**	**0.005**
Component margin changes	0.160	0.108	0.140	0.083
Component erosion	0.208	0.197	**0.334**	**<0.001**
Component dorsal body + LOVBe	**0.335**	**0.002**	—	—
Composite score	**0.387**	**<0.001**	**0.346**	**<0.001**
Composite score total	—	—	**0.554**	**<0.001**

Legend: DBPB – Dorsal plateau of the pubic bone; VBPB – Ventral plateau of the pubic bone; MAOF – Medial aspect of the obturator foramen; ESF – Erosion of the symphyseal face; ESR – Erosion of the symphyseal rim; SFS – Symphyseal face shape; LOVBe – Ligamentous outgrowth of the ventral bevelling.

Table 5.76. Spearman's rank correlations between pubic symphysis degenerative criteria with significant sexual dimorphism and age at death.

Collection	Criteria	Female		Male	
		R	p	r	P
Coimbra	Superior extremity	0.201	0.137	-0.117	0.269
	Component margin changes	0.272	0.132	0.115	0.362
	Composite score	**0.504**	**0.005**	**0.352**	**0.006**
Bass	Inferior extremity	—	—	0.161	0.086
	Dorsal plateau	—	—	0.159	0.086
	Composite score total	**0.714**	**<0.001**	**0.532**	**<0.001**

For the Coimbra pooled sex sample, partial correlation r coefficients between pubic symphysis degenerative criteria and age, controlling for body size, are presented in Table 5.77. Similar r coefficient values to partial correlation and Spearman's rank correlations were obtained, except for r values with joint surface area and all body size variables controlled, which showed differences between 0.102 and 0.255. For component margin changes, the correlation was significant - even if the r coefficient was low - when robusticity, surface area and all body size variables were controlled. Inversely, some morphological criteria stop being correlated with age, when body size was controlled. When the analysis was performed by sex, the r coefficient was similar, except for the female sample, with a higher correlation with age when the effect of the joint surface area was controlled. Additionally, for males the correlation between composite score and age was non-significant with the control of robusticity, joint surface area and all body size variables.

For the Bass pooled sex sample, the partial correlation between pubic symphysis degenerative criteria and age by controlling for body size is presented in Table 5.79. A similar r coefficient was obtained for a majority of cases when compared with partial correlation and Spearman's rank correlation analyses. However, two major differences were achieved when body size was controlled: 1) component face topography was no longer correlated with age, and 2) superior extremity, inferior extremity, dorsal plateau, symphyseal rim, pubic tubercle, erosion of the symphyseal rim and component margin changes' correlations with age became significant, even if the r coefficient was low. The r coefficient was computable for inferior extremity and dorsal plateau in females when body size was controlled (Table 5.80). For males, the r coefficient was significant, even with low correlation. The r coefficient was not computable for males' inferior extremity and dorsal plateau when only joint surface area and all body size variables were controlled. For composite score total, partial correlation r coefficient was similar to Spearman's rank correlation for both sexes.

Table 5.77. Partial correlation between pubic symphysis criteria and age at death controlling for body size for the Coimbra pooled sex sample.

Criteria	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
	r	p	r	p	r	p	r	p	r	p
Billowing	**0.294**	**<0.001**	**0.245**	**0.001**	**0.339**	**<0.001**	0.152	0.253	0.189	0.213
Superior extremity	0.064	0.477	0.048	0.587	0.068	0.482	0.205	0.162	0.143	0.393
Inferior extremity	**0.331**	**<0.001**	**0.373**	**<0.001**	**0.379**	**<0.001**	**0.436**	**0.001**	**0.400**	**0.008**
Dorsal plateau	**0.372**	**<0.001**	**0.402**	**<0.001**	**0.398**	**<0.001**	**0.533**	**<0.001**	**0.518**	**<0.001**
Ventral rampart	**0.306**	**<0.001**	**0.259**	**0.001**	**0.301**	**0.001**	**0.394**	**<0.001**	**0.314**	**0.046**
DBPB	**0.262**	**<0.001**	**0.270**	**<0.001**	**0.241**	**0.001**	0.231	0.090	-0.006	0.970
VBPB	**0.467**	**<0.001**	**0.483**	**<0.001**	**0.470**	**<0.001**	**0.334**	**0.014**	**0.309**	**0.046**
MAOF	**0.195**	**0.003**	**0.209**	**0.002**	**0.205**	**0.005**	0.150	0.280	0.034	0.832
Symphyseal rim	**0.322**	**0.001**	**0.309**	**0.001**	**0.344**	**0.001**	**0.356**	**0.018**	0.312	0.064
Pubic tubercle	**0.220**	**0.016**	**0.211**	**0.020**	**0.255**	**0.009**	**0.376**	**0.008**	0.295	0.069
Ventral bevelling	**0.313**	**<0.001**	**0.333**	**<0.001**	**0.342**	**<0.001**	**0.398**	**0.002**	**0.354**	**0.017**
ESF	0.077	0.482	0.088	0.421	0.093	0.432	0.070	0.679	0.054	0.781
ESR	**0.320**	**0.016**	0.217	0.108	0.234	0.096	0.341	0.088	**0.458**	**0.037**
SFS	**0.276**	**<0.001**	**0.233**	**0.001**	**0.291**	**<0.001**	0.236	0.078	0.248	0.105
LOVBe	**0.218**	**0.048**	**0.241**	**0.031**	0.158	0.194	0.194	0.278	0.311	0.140
Component face topography	**0.322**	**<0.001**	**0.275**	**<0.001**	**0.353**	**<0.001**	0.210	0.116	0.210	0.116
Component margin changes	0.204	0.053	0.193	0.065	**0.233**	**0.046**	**0.324**	**0.041**	**0.324**	**0.041**
Component erosion	0.193	0.246	0.195	0.233	0.176	0.305	0.238	0.326	0.238	0.326
Component dorsal body + LOVBe	**0.334**	**0.003**	**0.343**	**0.003**	**0.294**	**0.019**	0.055	0.770	0.055	0.770
Composite score	**0.372**	**0.001**	**0.389**	**<0.001**	**0.366**	**0.001**	**0.367**	**0.030**	0.253	0.203

Table 5.78. Partial correlation between pubic symphysis criteria and age at death controlling for body size for the Coimbra female and male samples.

sex	Criteria	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
		r	p	r	p	r	p	r	p	r	p
Female	Superior extremity	0.184	0.216	0.167	0.250	0.134	0.417	**0.601**	**0.030**	0.400	0.373
	Component margin changes	0.281	0.148	0.268	0.159	0.316	0.132	**0.722**	**0.043**	-0.604	0.587
	Composite score	**0.508**	**0.008**	**0.496**	**0.010**	**0.518**	**0.013**	**0.789**	**0.035**	—	—
Male	Superior extremity	-0.107	0.346	-0.141	0.219	0.007	0.958	0.023	0.898	0.023	0.909
	Component margin changes	0.114	0.380	0.110	0.394	0.148	0.275	0.151	0.416	0.051	0.809
	Composite score	**0.289**	**0.032**	**0.313**	**0.021**	0.277	0.051	0.137	0.494	0.013	0.956

Table 5.79. Partial correlation between pubic symphysis criteria and age at death controlling for body size variables for the Bass pooled sex sample.

Criteria	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
	r	p	r	p	r	p	R	p	r	p
Billowing	**0.269**	**0.003**	**0.268**	**0.003**	**0.249**	**0.005**	**0.221**	**0.004**	**0.227**	**0.028**
Superior extremity	**0.227**	**0.012**	**0.215**	**0.017**	**0.221**	**0.015**	0.122	0.123	0.132	0.213
Inferior extremity	**0.224**	**0.013**	**0.219**	**0.015**	**0.223**	**0.013**	—	—	—	—
Dorsal plateau	**0.221**	**0.013**	**0.216**	**0.015**	**0.216**	**0.015**	—	—	—	—
Ventral rampart	**0.201**	**0.026**	**0.204**	**0.023**	**0.200**	**0.026**	**0.167**	**0.033**	0.196	0.061
DBPB	**0.405**	**<0.001**	**0.400**	**<0.001**	**0.414**	**<0.001**	**0.406**	**<0.001**	**0.369**	**<0.001**
VBPB	**0.219**	**0.014**	**0.227**	**0.011**	**0.207**	**0.021**	0.128	0.107	0.060	0.568
MAOF	0.065	0.471	0.058	0.520	0.052	0.567	-0.016	0.839	0.032	0.759
Symphyseal rim	**0.231**	**0.020**	**0.218**	**0.028**	0.187	0.061	0.106	0.217	0.116	0.299
Pubic tubercle	**0.190**	**0.040**	0.165	0.074	0.155	0.094	0.111	0.166	0.145	0.173
ESF	**0.294**	**0.003**	**0.264**	**0.008**	**0.270**	**0.007**	**0.354**	**<0.001**	0.308	0.005
ESR	0.164	0.113	0.122	0.238	0.118	0.258	0.110	0.207	**0.254**	**0.027**
SFS	0.019	0.832	0.003	0.969	0.003	0.972	-0.009	0.910	-0.120	0.254
LOVBe	**0.417**	**<0.001**	**0.412**	**<0.001**	**0.388**	**<0.001**	**0.332**	**<0.001**	**0.433**	**<0.001**
Component margin changes	0.156	0.122	**0.258**	**0.010**	**0.242**	**0.016**	**0.170**	**0.046**	0.190	0.085
Component erosion	**0.287**	**0.010**	**0.236**	**0.034**	**0.232**	**0.038**	**0.324**	**<0.001**	**0.329**	**0.005**
Component face topography	0.172	0.056	0.161	0.073	0.145	0.108	0.124	0.113	0.059	0.569
Composite score	**0.360**	**<0.001**	**0.355**	**0.001**	**0.340**	**0.001**	**0.360**	**<0.001**	**0.322**	**0.003**
Composite score total	**0.600**	**<0.001**	**0.573**	**<0.001**	**0.561**	**<0.001**	**0.545**	**<0.001**	**0.555**	**<0.001**

Table 5.80. Partial correlation between pubic symphysis criteria and age at death controlling for body size variables for the Bass female and male samples.

sex	Criteria	Stature		Body mass		Robusticity		Joint surface area		All body size variables	
		r	p	r	p	r	p	r	p	r	p
Female	Inferior extremity	—	—	—	—	—	—	—	—	—	—
	Dorsal plateau	—	—	—	—	—	—	—	—	—	—
	Composite score total	0.773	<0.001	0.765	<0.001	0.777	<0.001	0.721	<0.001	0.772	<0.001
Male	Inferior extremity	0.281	0.021	0.261	0.032	0.275	0.024	—	—	—	—
	Dorsal plateau	0.275	0.021	0.257	0.031	0.257	0.037	—	—	—	—
	Composite score total	0.551	<0.001	0.536	<0.001	0.565	<0.001	0.485	<0.001	0.491	0.001

5.7. COMPARISON OF PELVIC JOINT DEGENERATION RATES ACCORDING TO BODY SIZE VARIABLES

In the present section, results obtained for the logistic regression test to determine if body size variables affected aging in the acetabulum, auricular surface and pubic symphysis will be presented. No outliers were eliminated from the analysis, and only significant models ($p<0.05$) - and consequently, valid constants - are presented in this section. For scores with no individuals or just one or two individuals recorded it was not possible to compute the logistic regression test and to calculate the median age of transition between specific scores. For example, the acetabular rim shape in the Bass collection did not permitted analysis between scores 1 and 2, since no individuals were scored as grade 1. However, logistic regression test was performed between score 2 and 3, and between 3 and 4.

5.7.1. Acetabulum

5.7.1.1. Stature

For the Coimbra collection, only five acetabular criteria presented significant and valid constants in both stature groups (Table 5.81). By comparing the median ages of transition (50^{th} percentile - p 0.50) between stature groups, it was show that three acetabular traits had a lower median age for taller individuals: apex activity (score 1 to 2), component lunate surface (score 1 to 2), and the composite score (score 2 to 3). The opposite was obtained for acetabular groove (score 1 to 2) and acetabular rim shape (score 2 to 3). However, a significant difference in the median age of transition between shorter and taller individuals was only obtained for apex activity (Table 5.82), with taller individuals showed an earlier transition between scores at four decades of life (33 years), compared to shorter individuals, whose transition occurred in the fifth decades of life (47 years). The majority of median ages of transition occurred in the fourth and fifth decades of life, with percentiles 25^{th} and 75^{th} indicated a high variability around percentile 50^{th}, except for taller individuals' apex activity (Table 5.81). By treating stature as a continuous variable in the logistic regression model it showed an effect on apex activity from score 1 to 2 (Wald = 6.497; p of Wald= 0.011), and outer edge of the fossa from score 3 to 4 (Wald = 4.841; p of Wald= 0.028). The mean age for apex activity in score 1 was 33 years (n= 73), and for the score 2 48 years (n= 67), while for outer edge of the fossa: stage 3 mean age = 42 years (n= 108); stage 4 mean age = 47 years (n=31).

Table 5.81. Acetabular criteria with significant constants and interquartile range (in years) for stature groups from the Coimbra collection.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Shorter individuals	Groove	1-2	-1.855	0.050	10.331	13.687	0.001	<0.001	15	37	59
	Rim shape	2-3	-3.662	0.090	11.761	12.888	0.001	<0.001	28	41	53
	Apex activity	1-2	-2.977	0.064	13.766	11.794	<0.001	0.001	29	47	64
	Component lunate surface	1-2	-5.001	0.119	10.919	9.899	0.001	0.002	33	42	51
	Composite score	2-3	-5.055	0.066	7.943	4.584	0.005	0.032	60	77	93
Taller individuals	Groove	1-2	-3.170	0.075	21.351	21.525	<0.001	<0.001	28	42	57
	Rim shape	2-3	-3.250	0.070	10.250	9.031	0.001	0.003	31	46	62
	Apex activity	1-2	-5.452	0.163	14.257	14.002	<0.001	<0.001	27	33	40
	Component lunate surface	1-2	-3.930	0.101	8.995	8.736	0.003	0.003	28	39	50
	Composite score	2-3	-3.794	0.056	5.790	3.841	0.016	0.050	48	68	87

Legend: c – formula constant

Table 5.82. Wald and p of Wald for acetabular criteria with a valid logistic regression test between stature groups from the Coimbra collection.

Criteria	Stage	Wald	p
Groove	1-2	1.148	0.284
Rim shape	2-3	1.079	0.299
Apex activity	1-2	**5.370**	**0.020**
Component lunate surface	1-2	0.549	0.459
Composite score	2-3	1.011	0.315

For the Bass collection, four age-related criteria presented significant logistic regression models for both stature groups (Table 5.83). Even though the composite score (score 2 to 3) has a p equal to 0.051, it was considered significant. A majority of median ages of transition occurred between the sixth and eight decades of life, and percentiles 25^{th} and 75^{th} indicated high variability around the median age of transition (Table 5.83). The median ages of transition (p 0.50) from stages 2 to 3 for the component lunate surface were similar between stature groups (Table 5.84). Additionally, younger median ages of transition for taller individuals were obtained for rim shape and composite score. In contrast, transitions from scores 2 to 3 for apex activity occurred earlier for shorter individuals. However, a significant difference in median age of transition between shorter and taller individuals was obtained only for the composite score (Table 5.84), with taller individuals showing a seventeen years younger median age of transition from the second to the third scores.

For the Bass collection, the following significant effect ($p<0.050$) of stature, treated as a continuous variable in the logistic regression model, was encountered:

- Acetabular rim shape from scores 3 to 4 (Wald= 5.041; p = 0.025). Stage 3 mean age= 53 years (n=65); Stage 4 mean age= 63 years (n=37);

- Component fossa from scores 1 to 2 (Wald= 9.081; p = 0.003). Stage 1 mean age= 50 years (n=35); Stage 2 mean age= 55 years (n=72);

- Composite score from scores 2 to 3 (Wald= 5.537; p = 0.019). Stage 2 mean age= 50 years (n= 39); Stage 3 mean age= 64 years (n=23).

Even though significant (Wald= 5.035; p = 0.025) for activity and porosity of the fossa (score 2 to 3), it was not considered a valid logistic regression model, because the mean age for "older score" (Score 3 mean age= 49 years, n= 29) was lower than for "younger score" (Score 2 mean age= 54 years, n= 31).

Table 5.83. Acetabular criteria with significant constants and interquartile range (in years) for stature groups from the Bass collection.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range (years)		
			C	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Shorter individuals	Rim shape	3-4	-4.291	0.060	7.097	5.220	0.008	0.022	53	72	90
	Apical activity	2-3	-4.232	0.062	6.638	5.155	0.010	0.023	51	68	86
	Component lunate surface	2-3	-5.803	0.081	9.190	7.003	0.002	0.008	58	72	85
	Composite score	2-3	-4.132	0.057	5.630	3.814	0.018	0.051	*53*	*72*	*92*
Taller individuals	Rim shape	3-4	-2.882	0.079	3.992	5.876	0.046	0.015	46	63	79
	Apical activity	2-3	-3.698	0.049	6.902	4.324	0.009	0.038	53	75	98
	Component lunate surface	2-3	-4.098	0.058	6.159	4.445	0.013	0.035	52	71	90
	Composite score	2-3	-4.043	0.073	6.731	6.580	0.009	0.010	40	55	70

Legend: c – formula constant

Table 5.84. Wald and p of Wald for the acetabular criteria with a valid logistic regression test between stature groups from the Bass collection.

Criteria	Stage	Wald	p
Rim shape	3-4	1.217	0.270
Apical activity	2-3	0.236	0.627
Component lunate surface	2-3	0.500	0.479
Composite score	2-3	4.337	0.037

5.7.1.2. Body mass

For the Coimbra body mass groups, significant constants for the pooled sex sample were obtained for the same age-related criteria affected by stature groups (Table 5.85). Similar median ages of transition between body mass groups were obtained for acetabular groove (scores 1 to 2) and component lunate surface (scores 1 to 2). In contrast, the remaining three age-related criteria showed a high difference between median ages of transition, especially for the composite score (scores 2 to 3) with an eighteen years difference. However, a significant difference between median ages of transition was only encountered for acetabular rim shape and the composite score (Table 5.86). For rim shape, transition between scores occurred earlier for lighter individuals than for heavier specimens, but the inverse was obtained for the composite score. Mostly, the median age of transition occurred between the fourth and sixth decades of life. Furthermore, percentiles 25^{th} and 75^{th} indicated high variability around the median age of transition (50^{th} percentile) except for the lighter individuals' component lunate surface (Table 5.85).

For the Coimbra pooled sex sample the following age-related criteria were influenced by body mass, when the predictor was treated as a continuous variable in the logistic regression analysis:

- Acetabular rim shape from scores 3 to 4 (Wald= 6.024; p = 0.014). Score 3 mean age= 56 years (n= 63); Score 4 mean age= 58 years (n= 32);
- Apex activity from scores 1 to2 (Wald= 4.876; p = 0.027). Score 1 mean age= 32 years (n= 74); Score 2 mean age= 48 years (n= 70).

For the Bass collection, only two age-related criteria presented valid logistic regression models when body mass was treated as a categorical variable (Table 5.87). Despite acetabular rim shape and the component lunate surface presented a valid model for both collections, different scores were affected. No significant difference between the median ages of transition was obtained in body mass groups from the Bass collection (Table 5.88), although acetabular rim shape showed a "younger transition" from stages 3 to 4 in heavier individuals. Twenty fifth and 75^{th} percentiles indicate high variability around the median age of transition.

Table 5.85. Acetabular criteria with significant constants and interquartile range (in years) for body mass groups from the Coimbra pooled sex sample.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Lighter individuals	Groove	1-2	-2.276	0.057	15.498	17.631	<0.001	<0.001	21	40	59
	Rim shape	2-3	-4.004	0.101	13.314	15.188	<0.001	<0.001	29	40	51
	Apex activity	1-2	-3.864	0.090	19.106	17.780	<0.001	<0.001	31	43	55
	Component Lunate surface	1-2	-7.087	0.171	12.313	11.389	0.001	<0.002	35	41	48
	Composite score	2-3	-7.826	0.101	7.131	5.133	0.008	0.023	67	77	88
Heavier individuals	Groove	1-2	-3.635	0.087	22.273	22.953	<0.001	<0.001	29	42	54
	Rim shape	2-3	-3.291	0.064	10.549	7.885	0.001	0.005	34	51	69
	Apex activity	1-2	-2.432	0.069	7.066	8.499	0.008	0.004	19	35	51
	Component Lunate surface	1-2	-2.780	0.073	5.602	6.111	0.018	0.013	23	38	53
	Composite score	2-3	-3.879	0.066	5.631	4.353	0.018	0.037	42	59	75

Legend: c – formula constant

Table 5.86. Wald and p of Wald for acetabular criteria with a valid logistic regression test between body mass groups from the Coimbra collection.

Criteria	Stage	Wald	p
Groove	1-2	0.258	0.612
Rim shape	2-3	4.269	0.039
Apex activity	1-2	2.754	0.097
Component Lunate surface	1-2	0.948	0.330
Composite score	2-3	5.780	0.016

Table 5.87. Acetabular criteria with significant constants and interquartile range (in years) for body mass groups from the Bass collection.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Lighter individuals	Rim shape	3-4	-3.935	0.055	6.363	4.706	0.012	0.030	52	72	92
	Component lunate surface	2-3	-4.873	0.067	7.391	5.497	0.007	0.019	56	73	89
Heavier individuals	Rim shape	3-4	-3.796	0.057	6.660	5.528	0.010	0.019	47	67	86
	Component lunate surface	2-3	-4.158	0.056	7.137	4.696	0.008	0.030	55	74	94

Legend: c – formula constant

Table 5.88. Wald and p of Wald for acetabular criteria with valid logistic regression test between body mass groups from the Bass collection.

Criteria	Stage	Wald	p
Rim shape	3-4	0.445	0.505
Component lunate surface	2-3	0.010	0.919

Two significant results were obtained for the Bass collection pooled sex sample, showing a significant effect of body mass when the predictor was treated as a continuous variable in the logistic regression model:

- Component fossa from scores 1 to 2 (Wald= 11.672; p= 0.001). Stage 1 mean age= 51 years (n= 36); Stage 2 mean age= 55 years (n= 72);
- Composite score from scores 2 to 3 (Wald= 5.153; p= 0.023). Stage 2 mean age= 51 years (n= 56); Stage 3 mean age= 60 years (n= 33).

Despite activity and porosity of the fossa showing a significant effect of body mass (continuous variable) from scores 2 to 3 (Wald= 5.509; p = 0.019), it was not considered valid, because the mean age was younger for score 3 than for score 2 (Score 2 mean age= 55 years, n= 32; Score 3 mean age= 49 years, n= 29).

5.7.1.3. Femoral robusticity

Acetabular criteria with significant constants and interquartile range for the Coimbra pooled sex sample's robusticity groups are presented in Table 5.89. For the valid logistic regression models, similar median ages of transition were obtained between groups, except for apex activity (scores 1 to 2), with a lower median age of transition for gracile individuals. However, differences in median ages of transition between robusticity groups were not significant (Table 5.90). Most median ages of transition occurred at the end of the fourth and fifth decades of life, with the 25^{th} and 75^{th} percentiles showed high variability around the 50^{th} percentile. By treating robusticity as a continuous variable no significant result was obtained, showing null effect of robusticity on acetabular degenerative criteria.

For the Bass pooled sex sample, only two significant models were obtained for rim shape and apex activity in both robusticity groups (Table 5.91). For the rim shape and apex activity, the median age of transition between scores occurred earlier for robust individuals, yet the difference was not significant (Table 5.92). The median age of transition for these criteria occurred at the seventh and eighth decades of life. Additionally, the 25^{th} and 75^{th} percentiles showed a high variability around the 50^{th} percentile. By incorporating robusticity as a continuous variable for the pooled sex sample, only one significant result was obtained for apex activity (scores 1 to 2), with Wald = 6.910 and p = 0.009. In score 1 (n= 15) mean age was 38 years, and for score 2 (n= 74) it was 53 years. No significant logistic regression models were obtained for both sexes when robusticity was treated as a continuous or as a categorical variable.

Table 5.89. Acetabular criteria with significant constants and interquartile range (in years) for robusticity groups from the Coimbra pooled sex sample.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Gracile individuals	Groove	1-2	-2.384	0.060	12.491	13.161	<0.001	<0.001	21	40	58
	Rim shape	2-3	-3.362	0.072	8.647	7.324	0.003	0.007	31	47	62
	Apex activity	1-2	-2.917	0.079	9.048	8.939	0.003	0.003	23	37	51
	Component lunate surface	1-2	-4.396	0.107	8.772	7.624	0.003	0.006	31	41	51
Robust individuals	Groove	1-2	-3.070	0.074	16.373	18.298	<0.001	<0.001	27	41	56
	Rim shape	2-3	-4.088	0.096	12.005	12.793	0.001	<0.001	31	43	54
	Apex activity	1-2	-4.014	0.094	12.693	12.200	<0.001	<0.001	31	43	54
	Component lunate surface	1-2	-4.336	0.105	8.498	8.416	0.004	0.004	31	41	52

Legend: c – formula constant

Table 5.90. Wald and p of Wald for acetabular criteria with a valid logistic regression test between robusticity groups for the Coimbra pooled sex sample.

Criteria	Stage	Wald	p
Groove	1-2	0.179	0.672
Rim shape	2-3	0.370	0.543
Apex activity	1-2	1.593	0.207
Component lunate surface	1-2	0.001	0.979

Table 5.91. Significant constants and interquartile ranges (in years) for acetabular criteria between gracile and robust individuals from the Bass collection's pooled sex sample.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			C	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Gracile individuals	Rim shape	3-4	-5.266	0.076	7.837	6.542	0.005	0.011	55	69	84
	Apex activity	2-3	-4.580	0.059	6.837	4.598	0.009	0.032	59	78	96
Robust individuals	Rim shape	3-4	-3.601	0.055	6.133	4.914	0.013	0.027	45	65	85
	Apex activity	2-3	-3.838	0.057	7.052	5.364	0.008	0.021	48	67	87

Legend: c – formula constant

Table 5.92. Wald and p of Wald for acetabular criteria with a valid logistic regression test between the robusticity groups for the Bass collection.

Criteria	Stage	Wald	p
Rim shape	3-4	0.708	0.400
Apex activity	2-3	1.758	0.185

5.7.1.4. Acetabulum surface area

Significant logistic models were obtained only for acetabular groove, apex activity and the component lunate surface for younger stages, in both acetabular surface area groups for the Coimbra collection (Table 5.93). For the acetabular groove and component lunate surface, median age of transition occurred earlier for individuals with a smaller acetabular surface area. In contrast, the median age of transition for apex activity was lower for individuals with a larger acetabulum. However, no significant differences for the median ages of transition between both groups were encountered (Table 5.94). The vast majority of median age of transition occurred in the fifth decade of life, and the 25^{th} and 75^{th} percentiles showed high variability around the 50^{th} percentile, except for the component lunate surface for the smaller acetabular area group (Table 5.93). For Coimbra female, male and pooled sex samples, no significant results were obtained when joint surface area was treated as a continuous variable into the logistic regression model.

For the Bass female, male and pooled sex samples, no significant logistic models were obtained for both acetabular surface area groups. However, when acetabular surface area was treated as a continuous variable, four acetabular criteria showed a significant effect at specific stages for the pooled sex sample:

- Acetabular rim shape from scores 3 to 4 (Wald= 7.021; p = 0.008). Stage 3 mean age= 55 years (n= 79); Stage 4 mean age= 63 years (n= 38);
- Apex activity from scores 2 to 3 (Wald= 7.681; p = 0.006). Stage 2 mean age= 55 years (n= 95); Stage 3 mean age= 62 years (n= 26);
- Component lunate surface from scores 2 to 3 (Wald= 7.438; p = 0.006). Stage 2 mean age= 54 years (n= 89); Stage 3 mean age= 64 years (n= 26);
- Composite score from scores 2 to 3 (Wald= 7.049; p = 0.008). Stage 2 mean age= 46 years (n= 71); Stage 3 mean age= 52 years (n= 46).

Table 5.93. Acetabular criteria with significant constants and interquartile range (in years) for individuals with smaller and larger acetabular surface areas from the Coimbra collection.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Smaller joint surface area	Groove	1-2	-1.859	0.051	4.388	4.706	0.036	0.030	15	36	58
	Apex activity	1-2	-3.154	0.069	7.404	5.666	0.007	0.017	30	46	62
	Component lunate surface	1-2	-10.33	0.257	5.690	5.327	0.017	0.021	36	40	44
Larger joint surface area	Groove	1-2	-3.659	0.087	12.403	11.589	<0.001	0.001	29	42	55
	Apex activity	1-2	-4.348	0.105	11.366	10.456	0.001	0.001	31	41	52
	Component lunate surface	1-2	-2.994	0.063	5.538	4.123	0.019	0.042	30	48	65

Legend: c – formula constant.

Table 5.94. Wald and p of Wald values for acetabular criteria with a valid logistic regression model between acetabular surface area groups for the Coimbra collection.

Criteria	Stage	Wald	p
Groove	1-2	1.067	0.302
Apex activity	1-2	0.120	0.729
Component lunate surface	1-2	0.035	0.851

5.7.1.5. Summary

For both collections, only stature and body mass treated as a categorical variable affected some acetabular criteria (Tables 5.95 and 5.96). It is also evident that different acetabular age-related criteria were affected between the Coimbra and Bass collections. For those cases, mean age of transition from "younger" to "older" stage occurred earlier for larger individuals (taller and heavier). Except for acetabular rim shape (scores 2 to 3) for the Coimbra pooled sex sample, whose median age of transition is lower on lighter individuals.

Table 5.95. Significant median age of transition between stages (in years) obtained for shorter and taller individuals in both collections.

Sample	Trait	Stage	Shorter individuals	Taller individuals
Coimbra	Apex activity	1-2	47	33
Bass	Composite score	2-3	73	55

Table 5.96. Significant median age of transition between stages (in years) obtained for lighter and heavier individuals in the Coimbra collection.

Trait	Stage	Lighter individuals	Heavier individuals
Rim shape	2-3	40	51
Composite score	2-3	77	59

Table 5.97 shows the acetabular age-related criteria affected by different body size proportions for both collections' pooled sex sample, when treated as a continuous variable. It is evident that different acetabular criteria were affected by stature and body mass between the Coimbra and Bass collections. On the contrary, robusticity and acetabular surface area had no significant effect in degeneration for the Coimbra sample. For the Bass collection, robusticity had the least effect, with only apex activity being affected. It was also evident that some acetabular criteria within a collection were affected by more than one body size variable. For example, the composite score (scores 2 to 3) was affected by stature, body mass and surface area for the Bass collection.

Table 5.97. Acetabular criteria with a **s**ignificant effect from body size proportions (continuous variables) for both collections' pooled sex sample.

Body size	Coimbra collection		Bass collection	
	Criteria	Stage	Criteria	Stage
Stature	Apex activity	1-2	Rim shape	3-4
	Outer edge	3-4	Component fossa	1-2
			Composite score	2-3
Body mass	Rim shape	1-2	Component fossa	1-2
	Rim shape	2-3	Composite score	2-3
	Apex activity	1-2		
Robusticity	Non-significant		Apex activity	1-2
Acetabulum surface area	Non-significant		Rim shape	3-4
			Apex activity	2-3
			Component lunate surface	2-3
			Composite score	2-3

5.7.2. Auricular surface

5.7.2.1. Stature

For the Coimbra pooled sex, female and male samples, no significant logistic models were obtained for both stature groups. However, when stature was incorporated into the logistic regression model as a continuous variable only a significant effect was obtained for the apical area activity for the pooled sex sample (pooled sex sample: Wald= 7.854; p= 0.005; Score1 mean age= 41 years, n= 171; Score 2 mean age= 50 years, n= 38).

Similarly, for the Bass pooled sex, female and male samples, no significant logistic models were encountered for the two stature groups. In contrast, when stature was treated as a continuous variable, three auricular surface criteria are significantly affected in the pooled sex sample:

- Fine granularity from scores 1 to 2 (Wald= 4.923; p = 0.027). Score 1 mean age= 53 years (n= 95); Score 2 mean age= 54 years (n= 29);
- Coarse granularity from scores 2 to 3 (Wald= 4.062; p = 0.044). Score 2 mean age= 54 years (n= 89); Score 3 mean age= 54 years (n= 28);
- Component granularity from scores 1 to 2 (Wald= 3.892; p = 0.049). Score 1 mean age= 53 years (n= 94); Score 2 mean age= 54 years (n= 28).

Additionally, for each sex, no significant logistic regression model was obtained when stature was treated as a continuous variable.

5.7.2.2. Body mass

For Coimbra pooled sex sample, no significant valid logistic models were obtained for both body mass groups. Even though Wald is significant for the apical area (Table 5.98), this result was not considered valid, since the 50th percentile was 102 years and 75th percentile for lighter individuals was 133 years, and therefore, not reflective of when apical area suffered metamorphose in the average human life expectancy. Additionally, only one significant logistic regression model was obtained for apical area activity in males when the analysis was performed by sex (Table 5.98). However, the median age of transition was significantly equal between lighter and heavier males individuals (Wald= 0.506; p = 0.477). By treating body mass as a continuous variable only one significant valid logistic regression model was obtained for the apical area in the pooled sex sample (Wald= 10.202; p= 0.001; Score1 mean age= 41 years, n= 168; Score 2 mean age= 50 years, n= 41). Although, coarse granularity (scores 1 to 2) presented a significant Wald value (6.109; p = 0.013), it was also not considered valid, because no individuals were recorded for score 1. No significant value by sex was obtained when body mass was treated as a continuous variable.

For the Bass pooled sex, female and male samples, no significant logistic models were obtained for the body mass groups. Nonetheless, when body mass was treated as a continuous variable, the following auricular surface criteria are significantly affected in the pooled sex sample:

- Fine granularity from scores 1 to 2 (Wald= 7.317; p = 0.007). Score 1 mean age= 53 years (n= 95); Score 2 mean age= 54 years (n= 29);
- Coarse granularity from scores 2 to 3 (Wald= 6.140; p = 0.013). Score 2 mean age= 54 years (n= 89); Score 3 mean age= 54 years (n= 28);
- Component granularity from scores 1 to 2 (Wald= 6.019; p = 0.014). Score 1 mean age= 53 years (n= 94); Score 2 mean age= 55 years (n= 29);
- Composite score from scores 1 to 2 (Wald= 4.011; p = 0.014). Score 1 mean age= 45 years (n= 19); Score 2 mean age= 51 years (n= 55).

For each sex, no significant logistic regression model was obtained when body mass was treated as a continuous variable.

Table 5.98. Significant Wald, p of Wald and interquartile range (years) values for apical area in lighter and heavier individuals from the Coimbra collection.

Sample	Group	Constant		Wald		p of Wald		Interquartile range		
		c	Age	C	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Pooled sex sample	Lighter individuals	-3.556	0.035	15.563	3.94	<0.001	0.047	70	102	133
	Heavier individuals	-2.417	0.034	9.275	4.527	0.002	0.033	39	71	103
Males	Lighter individuals	-4.058	0.070	5.886	3.791	0.015	0.052	42	58	74
	Heavier individuals	-2.530	0.044	6.816	4.702	0.009	0.030	33	58	82

5.7.2.3. Robusticity

For the Coimbra and Bass pooled sex, female and male samples, no significant logistic models were obtained for robusticity groups. However, a significant effect of robusticity (as a continuous variable) was obtained for the pooled sex sample:

- Coimbra collection: coarse granularity (scores 1 to 2), Wald= 4.149; p= 0.042; Score 1 mean age= 32 years, n= 4; Score 2 mean age= 41 years, n= 153;
- Bass collection: dense bone (scores 1 to 2), Wald= 4.652; p= 0.031; Score 1 mean age= 52 years, n= 103; Score 2 mean age= 59 years, n= 9.

For each sex, no significant logistic regression model was obtained when robusticity was treated as a continuous variable in both collections.

5.7.2.4. Auricular surface area

Only for the Bass pooled sex sample was a significant effect of joint surface area (continuous variable) on auricular surface morphological criteria obtained for specific stages:

- Fine granularity from scores 1 to 2 (Wald= 5.586; p = 0.018). Score 1 mean age= 54 years (n= 79); Score 2 mean age= 53 years (n= 31);
- Coarse granularity from scores 2 to 3 (Wald= 4.408; p = 0.036). Score 2 mean age= 43 years (n= 77); Score 3 mean age= 53 years (n= 30);
- Component granularity from scores 1 to 2 (Wald= 4.117; p = 0.042). Score 1 mean age= 53 years (n= 79); Score 2 mean age= 53 years (n= 30);
- Composite score from scores 1 to 2 (Wald= 4.716; p = 0.030). Score 1 mean age= 52 years (n= 61); Score 2 mean age= 54 years (n= 41);
- Composite score total from scores 2 to 3 (Wald= 5.648; p = 0.017). Score 2 mean age= 52 years (n= 36); Score 3 mean age= 61 years (n= 11).

5.7.2.5. Summary

By incorporating body size proportions as categorical variables into the logistic regression no significant model was obtained on either collection. However, significant results were encountered for the pooled sex samples by incorporating body size proportions in the logistic regression model as a continuous variable,

although different criteria were affected in both collections (Table 5.99). The effect of body size proportions was minimal or null for the Coimbra collection, since stature, body mass and robusticity only affected two traits, and joint surface area had no effect. For the Bass collection, granularity features and composite score were affected by stature, body mass and joint surface area. In contrast, robusticity had a small effect in Bass auricular surface data, since it only affected dense bone. No significant logistic regression model was obtained by sex.

Table 5.99. Auricular surface age-related criteria, and respective stages, with a **s**ignificant effect from body size variables (as a continuous variable on the logistic regression model) for both collections.

Body size	Coimbra collection		Bass collection	
	Criteria	Stage	Criteria	Stage
Stature	Apical area	1-2	Fine granularity	1-2
			Coarse granularity	2-3
			Component granularity	1-2
Body mass	Apical area	1-2	Fine granularity	1-2
			Coarse granularity	2-3
			Component granularity	1-2
			Composite score	1-2
Robusticity	Coarse granularity	1-2	Dense Bone	1-2
Auricular surface area	Non-significant		Fine granularity	1-2
			Coarse granularity	2-3
			Component granularity	1-2
			Composite score	1-2
			Composite score total	2-3

5.7.3. Pubic symphysis

5.7.3.1. Stature

For the Coimbra pooled sex sample, only three pubic symphysis morphological criteria had significant constants for both stature groups (Table 5.100). Non-significant differences were found when considering the median age of transition from "younger" to "older" stages between shorter and taller individuals (Table 5.101). Most median ages of transition occurred in the third and fourth decades of

life. Additionally, the 25th and 75th percentiles (Table 5.100) indicated a low variability around the 50th percentile, except for ventral bevelling.

Stature only affected the following five morphological criteria for the Coimbra pooled sex sample when treated as a continuous variable in the logistic regression model:

- Superior extremity from scores 2 to 3 (Wald= 4.734; p = 0.030). Score 2 mean age= 46 years (n= 8); Score 3 mean age= 46 years (n= 119);
- Dorsal body of the pubic bone from scores 1 to 2 (Wald= 9.599; p = 0.002). Score 1 mean age= 40 years (n= 115); Score 2 mean age= 47 years (n= 92);
- Dorsal body of the pubic bone from scores 2 to 3 (Wald= 5.320; p = 0.021). Score 2 mean age= 47 years (n= 92); Score 3 mean age= 54 years (n= 7);
- Pubic tubercle from scores 1 to 2 (Wald= 7.359; p = 0.007). Score 1 mean age= 39 years (n= 21); Score 2 mean age= 47 years (n= 100);
- Component dorsal plateau of the pubic bone + ligamentous outgrowth of the ventral bevelling from scores 1 to 2 (Wald= 4.446; p = 0.035). Score1 mean age= 46 years (n= 59); Score 2 mean age= 54 years (n= 56).

No significant logistic regression model was obtained by sex by treating stature as a categorical or as a continuous variable for the Coimbra collection. For the Bass pooled sex sample, only LOVBe presented valid constants for both stature groups (Table 5.102). The median age of transition between scores occurred earlier for taller individuals (fifth decade of life) than for shorter individuals (seventh decade of life). However, the difference between median ages of transition was not significant (Wald= 2.985; p = 0.084). Twenty fifth and 75th percentiles (Table 5.102) indicated high variability around the 50th percentile. No significant logistic regression model was obtained for each sex with stature as a categorical or as a continuous variable. Additionally, no significant logistic regression model for the Bass pooled sex sample was obtained with stature as a continuous variable.

Table 5.100. Significant constants and interquartile ranges (in years) for pubic symphysis age-related criteria by stature groups from Coimbra pooled sex sample.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Shorter individuals	Dorsal plateau	1-2	-7.621	0.301	5.411	7.577	0.020	0.006	22	25	29
	Ventral body of the pubic body	2-3	-2.027	0.054	6.763	9.447	0.009	0.002	17	38	58
	Ventral bevelling	1-2	-5.813	0.257	3.962	6.603	0.047	0.010	18	23	27
Taller individuals	Dorsal plateau	1-2	-13.03	0.521	5.671	6.472	0.017	0.011	23	25	27
	Ventral body of the pubic body	2-3	-3.396	0.096	8.942	12.189	0.003	<0.001	24	35	47
	Ventral bevelling	1-2	-4.982	0.231	4.795	8.124	0.029	0.004	17	22	26

Legend: c – formula constant.

Table 5.101. Wald and p of Wald for acetabular criteria with a valid logistic regression test between the stature groups for the Coimbra collection.

Criteria	Stage	Wald	p
Dorsal plateau	1-2	0.704	0.402
Ventral body of the pubic body	2-3	0.912	0.339
Ventral bevelling	1-2	0.019	0.890

Table 5.102. Significant constants and interquartile range (in years) for ligamentous outgrowth of the ventral bevelling by stature groups from the Bass pooled sex sample.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			C	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Shorter individuals	Ligamentous outgrowth of the ventral bevelling	1-2	-3.000	0.050	4.636	4.293	0.031	0.038	38	60	82
Taller individuals	Ligamentous outgrowth of the ventral bevelling	1-2	-4.016	0.082	10.620	12.096	0.001	0.001	36	49	62

Legend: c – formula constant

5.7.3.2. Body mass

For the Coimbra pooled sex sample, only dorsal plateau (scores 1 to 2) presented significant constants in both body mass groups (Table 5.103). No significant difference in median ages of transition between lighter and heavier groups were recorded (Wald= 1.095; p = 0.295). Twenty fifth and 75th percentiles (Table 3.103) indicated low variability around median age of transition in both groups. Treating body mass as a continuous variable in the logistic regression model significantly affected the following nine degenerative criteria for the pooled sex sample:

- Ventral rampart from scores 2 to 3 (Wald= 4.244; p = 0.039). Score 2 mean age= 41 years (n= 22); Score 3 mean age= 50 years (n= 122);
- Dorsal body of the pubic bone from scores 1 to 2 (Wald= 12.003; p = 0.001). Score 1 mean age= 47 years (n= 118); Score 2 mean age= 51 years (n= 86);
- Medial aspect of the obturator foramen from scores 1 to 2 (Wald= 6.317; p = 0.012). Score 1 mean age= 25 years (n= 16); Score 2 mean age= 43 years (n= 195);
- Medial aspect of the obturator foramen from scores 2 to 3 (Wald= 4.927; p = 0.026). Score 2 mean age= 43 years (n= 195); Score 3 mean age= 42 years (n= 12);
- Pubic tubercle from scores 1 to 2 (Wald= 5.416; = 0.020). Score 1 mean age= 39 years (n= 21); Score 2 mean age= 50 years (n= 101);
- Component margin changes from scores 1 to 2 (Wald= 10.879; p = 0.001). Score 1 mean age= 44 years (n= 28); Score 2 mean age= 47 years (n= 65);
- Component face topography from scores 4 to 5 (Wald= 4.654; p = 0.031). Score 4 mean age= 49 years (n= 67); Score 5 mean age= 49 years (n= 24);
- Composite score from scores 1 to 2 (Wald= 4.383; p = 0.036). Score 1 mean age= 40 years (n= 20); Score 2 mean age= 45 years (n= 37);
- Composite score from scores 2 to 3 (Wald= 6.165; p = 0.013). Score 2 mean age= 45 years (n= 37); Score 3 mean age= 52 years (n= 25).

No significant logistic regression model was obtained for each sex by treating body mass as a categorical or as a continuous variable.

Table 5.103. Significant constants and interquartile ranges (in years) for dorsal plateau (scores 1 to 2) by body mass groups from the Coimbra pooled sex sample.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	C	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Lighter individuals	Dorsal plateau	1-2	-8.116	0.311	7.737	9.755	0.005	0.002	23	26	30
Heavier individuals	Dorsal plateau	1-2	-6.872	0.294	4.004	5.860	0.045	0.015	20	23	27

Legend: c – formula constant.

For the Bass pooled sex sample, only three age-related criteria presented valid models for both body mass groups (Table 5.104). Dorsal body of the pubic bone had similar median ages of transition between groups. However, an earlier transition between scores occurred for LOVBe and composite score total (scores 2 to 3) in heavier individuals. The only significant difference between the median ages of transition for lighter and heavier groups was obtained for LOVBe (Table 5.105). The vast majority of the age transition between scores occurred in the seventh decade of life, with the 25^{th} and 75^{th} percentiles indicating a high variability around the 50^{th} percentile. No significant logistic regression model was obtained by treating body mass as a categorical variable for each sex, except for composite score total (scores 2 to 3) for the male sample (Table 5.105). However, no significant difference existed in the median age of transition for the composite score total between lighter and heavier male individuals (Wald= 0.293; p = 0.588). By treating body mass as a continuous variable only the symphyseal rim (scores 3 to 4) showed a significant effect from body mass, for the pooled sex sample (Wald= 4.773; p = 0.029; Score 3 mean age= 52 years, n= 20; Score 4 mean age= 55 years, n= 82). For males, body mass significantly affected the composite score total from scores 2 to 3 (Wald= 5.784; p = 0.016; Score 2 mean age= 39, n= 26; Score 3 mean age= 47, n= 18).

Table 5.104. Significant constants and interquartile ranges (in years) for pubic symphysis morphological criteria by body mass groups from the Bass pooled sex and male sample.

Sample	Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
				c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Pooled sex	Lighter individuals	Dorsal body of the pubic bone	2-3	-3.956	0.063	5.300	4.971	0.021	0.026	45	63	80
		Ligamentous outgrowth of the ventral bevelling	1-2	-3.997	0.063	6.833	6.037	0.009	0.014	46	63	81
		Composite score total	2-3	-14.49	0.212	4.977	4.835	0.026	0.028	63	68	74
	Heavier individuals	Dorsal body of the pubic bone	2-3	-4.811	0.073	9.792	8.096	0.002	0.004	51	66	81
		Ligamentous outgrowth of the ventral bevelling	1-2	-3.898	0.084	10.316	12.411	0.001	<0.001	33	46	59
		Composite score total	2-3	-4.707	0.081	8.513	7.949	0.004	0.005	45	58	72
Males individuals	Shorter individuals	Composite score total	2-3	-3.663	0.063	5.677	5.023	0.017	0.025	41	58	76
	Taller individuals	Composite score total	2-3	-10.488	0.176	4.035	3.897	0.045	0.048	53	60	66

Legend: c – formula constant

Table 5.105. Wald and p of Wald between body mass groups for acetabular criteria with a valid logistic regression test from the Bass collection.

Criteria	Stage	Wald	p
Dorsal body of the pubic bone	2-3	0.293	0.588
Ligamentous outgrowth of the ventral bevelling	1-2	7.460	0.006
composite score total	2-3	3.666	0.056

5.7.3.3. Robusticity

For the Coimbra pooled sex sample, only two pubic symphysis morphological criteria presented significant constants for both robusticity groups (Table 5.106). However, no significant differences between groups' median ages were encountered (Table 5.107). The 25^{th} and 75^{th} percentiles (Table 5.106) indicated high variability around the median age of transition. By treating robusticity as a continuous variable in the logistic regression model only the pubic tubercle (scores 1 to 2) was significantly affected in the Coimbra pooled sex sample (Wald= 5.497; p = 0.019; Score 1 mean age= 38 years, n= 19; Score 2 mean age= 46 years, n= 85). No significant model was obtained for each sex by treating robusticity as a categorical or as a continuous variable.

In Table 5.108 significant constants and interquartile range values for the Bass robusticity groups are presented. Composite score (scores 2 to 3) presented similar median age of transition between robusticity groups. A lower median age of transition was encountered for dorsal body of the pubic bone (scores 2 to 3) and LOVBe in robust individuals. Despite this, no significant differences between median ages of transition were obtained (Table 5.109). All median ages of transition between scores occurred during the seventh decade of life, and the 25^{th} and 75^{th} percentiles indicate high variability around the 50^{th} percentile (Table 5.108). Only pubic tubercle (scores 1 to 2), for the pooled sex sample, was significantly affected by robusticity when the predictor variable was treated as continuous (Wald= 8.107; p = 0.004; Score 1 mean age= 52 years, n=83; Score 2 mean age= 58 years, n=12). Additionally, no significant logistic regression model was obtained for each sex by treating robusticity as a categorical or as a continuous variable for the Bass collection.

5.7.3.4. Pubic symphysis surface area

For the Coimbra collection, no significant result (p > 0.05; data not shown) was obtained by treating pubic symphysis surface area as a categorical or continuous variable in the logistic regression analysis.

In Table 5.110 only significant logistic regression constants and interquartile ranges obtained for pubic symphysis morphological criteria affected by both joint surface area groups are presented. A lower median age of transition (50^{th} percentile) was obtained for dorsal body of the pubic bone (scores 2 to 3), and erosion of the

Table 5.106. Significant constants and interquartile ranges (in years) for pubic symphysis morphological criteria by robusticity groups from the Coimbra pooled sex sample.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Gracile individuals	Billowing	1-2	-2.875	0.064	10.681	10.851	0.001	0.001	28	45	62
	Ventral body of the pubic bone	2-3	-3.010	0.078	8.692	11.147	0.003	0.001	25	39	53
Robusticity individuals	Billowing	1-2	-1.761	0.037	5.085	4.956	0.024	0.026	18	48	77
	Ventral body of the pubic bone	2-3	-2.837	0.077	6.610	9.052	0.010	0.003	23	37	51

Legend: c – formula constant

Table 5.107. Wald and p of Wald for pubic symphysis criteria with a valid logistic regression test between the robusticity groups for the Coimbra collection.

Criteria	Stage	Wald	p
Billowing	1-2	0.091	0.763
Ventral body of the pubic bone	2-3	0.126	0.723

Table 5.108. Significant constants and interquartile ranges (in years) for pubic symphysis morphological criteria by gracile and robust groups from the Bass collection pooled sex sample.

Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
			c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Gracile individuals	Dorsal body of the pubic bone	2-3	-3.875	0.057	5.987	4.872	0.014	0.027	49	68	87
	Ligamentous outgrowth of the ventral bevelling	1-2	-3.377	0.056	8.269	7.554	0.004	0.006	41	60	80
	composite score total	2-3	-6.167	0.097	7.067	6.403	0.008	0.011	52	64	75
Robust individuals	Dorsal body of the pubic bone	2-3	-6.612	0.111	11.677	11.038	<0.001	<0.001	50	60	69
	Ligamentous outgrowth of the ventral bevelling	1-2	-3.666	0.074	6.662	7.963	0.010	0.005	35	50	64
	composite score total	2-3	-4.740	0.076	5.239	4.577	0.022	0.032	48	62	77

Legend: c – formula constant

Table 5.109. Wald and p of Wald for the comparison of median ages of transition between the robusticity groups for the Bass collection pubic symphysis criteria.

Criteria	Stage	Wald	p
Dorsal body of the pubic bone	2-3	0.835	0.361
Ligamentous outgrowth of the ventral bevelling	1-2	2.594	0.107
composite score total	2-3	0.162	0.688

symphyseal face (scores 1 to 2) for smaller joint surface group. The inverse was true for LOVBe and composite score total (scores 2 to 3), with lower median age of transition for individuals with larger surface area. However, a significant difference in ageing rate was obtained for LOVBe (Table 5.11), with 34 years of difference in median ages of transition between groups. The vast majority of median age of transition occurred during the eight decades of life, and the 25^{th} and 75^{th} percentiles indicated high variability around the 50^{th} percentile. For female individuals, no valid model was obtained, and for males, only the composite score total, (scores 2 to 3) showed a valid model for both groups (Table 5.110). Median age of transition was smaller for individuals with larger pubic symphysis surface, although the difference between groups was non-significant (Wald= 0.559; p = 0.455). Twenty fifth and 75^{th} percentiles indicated high variability around the 50^{th} percentile for the composite score total in the Bass males sample.

The following six degenerative pubic symphysis criteria were affected by joint surface area treated as a continuous variable in the logistic regression model:

- Dorsal body of the pubic bone from scores 1 to 2 (Wald= 8.434; p = 0.004); Stage 1 mean age= 50 years (n= 42); Stage 2 mean age= 52 years (n= 63);
- Ventral body of the pubic bone from scores 3 to 4 (Wald= 7.639; p = 0.006). Stage 3 mean age= 55 years (n= 97); Stage 4 mean age= 59 years (n= 61);
- Erosion of the symphyseal rim from scores 1 to 2 (Wald= 6.674; p = 0.010). Stage 1 mean age= 55 years (n= 123); Stage 2 mean age= 63 years (n= 11);
- Ligamentous outgrowth of the ventral bevelling from scores 1 to 2 (Wald= 17.402; p <0.001). Stage 1 mean age= 51 years (n= 70); Stage 2 mean age= 62 years (n= 82);
- Component face topography from scores 2 to 3 (Wald= 4.558; p = 0.033). Stage 2 mean age= 50 years (n= 17); Stage 3 mean age= 56 years (n= 37);
- Composite score from scores 2 to 3 (Wald= 3.958; p = 0.047). Stage 2 mean age= 51 years (n= 46); Stage 3 mean age= 59 years (n= 86).

No significant logistic regression model was obtained for pubic symphysis morphological criteria for each sex by treating surface area as a continuous variable for the Bass collection.

Table 5.110. Significant constants and interquartile ranges (in years) for pubic symphysis criteria by joint surface area groups from the Bass collection pooled sex and male samples.

Sample	Group	Criteria	Stage	Constant		Wald		p of Wald		Interquartile range		
				c	Age	c	Age	c	Age	P(0.25)	P(0.50)	P(0.75)
Pooled sex	Smaller joint surface area	Dorsal body of the pubic bone	2-3	-3.208	0.055	7.231	7.301	0.007	0.007	38	58	78
		Erosion of the symphyseal face	1-2	-5.284	0.071	14.35	9.621	<0.001	0.002	59	74	90
		Ligamentous outgrowth of the ventral bevelling	1-2	-2.671	0.035	7.103	4.302	0.008	0.038	45	76	108
		composite score total	2-3	-4.982	0.071	9.350	7.148	0.002	0.008	55	70	86
	Larger joint surface area	Dorsal body of the pubic bone	2-3	-5.349	0.086	12.888	12.952	<0.001	<0.001	49	62	75
		Erosion of the symphyseal face	1-2	-3.974	0.050	8.179	5.537	0.004	0.019	58	79	101
		Ligamentous outgrowth of the ventral bevelling	1-2	-4.151	0.099	7.979	11.91	0.005	0.001	31	42	53
		composite score total	2-3	-6.031	0.102	10.661	10.692	0.001	0.001	48	59	70
Males	Smaller joint surface area	composite score total	2-3	-5.027	0.077	6.605	4.780	0.010	0.029	51	65	80
	Larger joint surface area	composite score total	2-3	-4.906	0.083	5.871	5.679	0.015	0.017	46	59	72

Legend: c – formula constant

Table 5.111. Wald and p of Wald values for median age of transition comparisons between joint surface area groups for Bass collection pubic symphysis criteria.

Criteria	Stage	Wald	P
Dorsal body of the pubic bone	2-3	0.573	0.449
Erosion of the symphyseal face	1-2	0.002	0.962
Ligamentous outgrowth of the ventral bevelling	1-2	23.478	<0.001
composite score total	2-3	2.646	0.104

5.7.3.5. Summary

Only LOVBe was affected by pubic symphysis surface area and by body mass for the Bass pooled sex sample, when predictor variables were treated as categorical in logistic regression analysis. Median age of transition from "younger" to "older" stages occurred earlier for individuals with larger proportions:

- Body mass: lighter individuals= 63 years; heavier individuals= 46 years;
- Surface area: smaller area= 76 years; larger area= 42 years.

Table 5.112 shows the affected pubic symphysis morphological criteria by body size (continuous variable) for the Coimbra and Bass pooled sex samples. It is evident that different age-related criteria were affected, showing a different pattern between collections. Stature and body mass affected age-related pubic symphysis criteria for the Coimbra sample. In contrast, for the Bass sample stature did not affect pubic symphysis degeneration and body mass had a very minimum effect, only affecting the symphyseal rim (scores 3 to 4). Inversely, the joint surface area had an effect on the Bass collection, but not on the Coimbra collection. Once again, the only similarity between collections was the minimum effect of femoral robusticity on age-related criteria, although the affected traits were different. Results suggested some pubic symphysis morphological criteria within a collection were affected by more than one body size variable. For example, stature, body mass and robusticity had an effect on the pubic tubercle in the Coimbra collection. Only one significant result was obtained when the analysis was broken down by sex, with body mass (continuous variable) affecting the composite score (scores 2 to 3) for the Bass male sample.

Table 5.112. Pubic symphysis morphological criteria and respective stages with a significant effect from body size proportions (continuous variables) for both collections.

Body size	Coimbra collection		Bass collection	
	Criteria	Stage	Criteria	Stage
Stature	Superior extremity	2-3	Non-significant	
	Dorsal body of the pubic bone	1-2		
	Dorsal body of the pubic bone	2-3		
	Pubic tubercle	1-2		
	Component dorsal body + LOVBe	1-2		
Body mass	Ventral rampart	2-3	Symphyseal rim	3-4
	Dorsal body of the pubic bone	1-2		
	Medial aspect of the obturator foramen	1-2		
	Medial aspect of the obturator foramen	2-3		
	Pubic tubercle	1-2		
	Component margin changes	1-2		
	Component face topography	4-5		
	Composite score	1-2		
	Composite score	2-3		
Robusticity	Pubic tubercle	1-2	Erosion of the symphyseal rim	1-2
Joint surface area	Non-significant		Dorsal body	1-2
			Ventral body	3-4
			Erosion of the symphyseal rim	1-2
			LOVBe	1-2
			Component face topography	2-3
			Composite score	2-3

Legend: LOVBe – Ligamentous outgrowth of the ventral bevelling.

CHAPTER 6
DISCUSSION

The present dissertation examined the effects body size has on age-related criteria at the pubic symphysis, iliac auricular surface and acetabulum. The focus was specifically on the influence stature, body mass, robusticity and joints' surface area had on ageing at the pelvic joints at the Coimbra and Bass collections. A three level degenerative analysis was performed focussing on individual traits, correlated traits (components), and a composite score (sum of all traits' scores at a joint per individual) in two skeletal reference collections. In the present chapter, a critical appraisal of the most important findings of the dissertation will be presented and placed in context through a comparison with other published findings, and suggestions for further research will be provided.

6.1. INTRA-OBSERVER ERROR

6.1.1. Repeatability in scoring bone degeneration traits

An overall low observation error for bone degeneration traits was obtained (Tables 5.1. to 5.3), suggesting a small effect of error in the data variance. Despite this, a few auricular surface and pubic symphysis traits exhibited moderate to high observation error (kappa <0.60). A lower repeatability may have resulted from the small size of traits (*e.g.*, coarse granularity), difficulty in distinguishing subsequent scores with small morphological differences and difficulty in distinguishing acetabular outer edge of the fossa scores 2 and 3 by touch.

Observation error when evaluating bone degeneration traits is not always presented in the literature, although feature repeatability should be assessed to better understand which traits may be more difficult to record. When observation error is presented, comparison among studies is challenging due to the lack of agreement on two main issues. Firstly, there are different methodological and statistical approaches to assess whether observation error exist. Usually, the observation error is evaluated by phase attribution discrepancies, and not by individual traits as performed in the current study. Additionally, trait scoring systems tend to be different among studies. Secondly, when the observation error was evaluated with

kappa a different evaluation criterion was followed due to the lack of agreement in interpreting kappa values. For the present study, the observation error was considered low when kappa was higher than 0.60, showing a substantial to almost perfect agreement (Landis and Koch 1977). However, Buckberry and Chamberlain (2002) reported that a small error was obtained with kappa higher or equal to 0.45. Comparison with other studies also indicated high observation error for specific traits such as microporosity, lipping and coarse granularity (Campanacho 2010), and for microporosity (Rougé-Maillart *et al.* 2009). In contrast, a low intra-observer error for the pubic tubercle (k= 0.77), and erosion of the symphyseal face (k= 0.66) was reported by Campanacho *et al.* (2012).

6.1.2. Repeatability of anthropometric measurements

For the femoral measurements, a low intra-observation error was obtained (Table 5.5). In addition, the percentage of observation error variance was equally low for the joint surface area measurements (1.6% for acetabulum surface area to 5.6% for pubic symphysis surface area). In contrast, technical error of measurement (TEM) and the mean average difference (MAD) are higher for the auricular surface and acetabulum (Table 5.6). Despite this, greater weight was given to the percentage of observation error variation that is dimensionless and more comparable between joints of different sizes, than to TEM and MAD. The 5.6% of error variation for pubic symphysis surface area may be attributable to pubic symphyses' smaller size and more irregular shape, when compared to auricular surface and acetabulum. However, delineating a joint border is possibly more challenging with a monochromatic three dimensional (3D) polygon model as performed in the present study. Therefore, it would be advised to test the measurement error with coloured and textured 3D polygon models, which may provide a clearer joint outline. The quality of the 3D polygon models was not accountable for the observation error, since a small deviation between models was obtained, which highlights the models high quality.

Few comparative studies report precision and reproducibility of area measurements from 3D polygon objects (Sholts *et al.* 2010), especially for pelvic joint surface area. Macaluso Jr. (2011), Lottering *et al.* (2014) and Villa *et al.* (2015) also obtained low area measurement errors. However, their analyses were performed with different aims and equipment (photogrammetry, CT-scan and laser scanners),

which may not be comparable with the present study. Additionally, Macaluso Jr. (2011) circumvented the original outline of the acetabular joint excluding any bony projections in surface area computation to diagnose sex, whereas bony projections were included in the present study. The inclusion of exuberant bony projections reflects a high increase of the surface area in life, which in turn may have affected acetabulum ageing, as shown for the Bass collection.

6.2. ASYMMETRY OF THE MORPHOLOGICAL TRAITS AT THE PELVIC JOINTS

It is important to establish whether or not there is asymmetry in the morphological traits examined so not to bias the data. Without determining if bilateral differences exist, an indiscriminate use of bilateral data according to bone preservation has been reported in the literature. Usually, researchers show preference for the left side due to usually being the non-leading limb, but in case of *post-mortem* damage it is substituted by right side (*e.g.*, Mulhern and Jones 2005; Calce and Rogers 2011; Calce 2012; Godde and Hens 2012; Hens and Belcastro 2012). Consequently, if significant degenerative bilateral differences are not investigated and controlled, they may create bias.

For the Coimbra collection only two traits – acetabular fossa and medial aspect of the *obturator foramen* – had significant asymmetry. The Bass collection in contrast presented more age-related traits with significant bilateral differences, in particular for the acetabulum (as shown in Tables 5.8, 5.10, 5.14 to 5.16). Few researchers have systematically investigated if significant metamorphic bilateral differences exist at the pelvic joints. Contrary to the current investigation, most studies usually analyse possible asymmetries for age estimation method phases rather than for each trait. In the literature, a lack of significant auricular surface and acetabular metamorphosis asymmetry has been reported (Buckberry and Chamberlain 2002; Igarashi *et al.* 2005; Falys *et al.* 2006; Rougé-Maillart *et al.* 2009; Campanacho 2010). In contrast, significant bilateral differences were stated by Hens *et al.* (2008) for the female auricular surface sample and by Overbury *et al.* (2009) for applying the S-B system in the pubic symphysis.

A careful analysis and data selection by sides is suggested, since some bone degeneration traits were significantly asymmetrical. The aetiology of significant trait

bilateralism should also be explored for a better understanding. Even though in the present study the side that presented a higher score was reported, the data were not further explored to understand if asymmetry has a fluctuating or directional nature. Additionally, different results for both collections may suggest an effect due to different factors, such as disease, ageing, biomechanical stress on the dominant leg, and physical activity, which possibly resulted in various asymmetry patterns among populations, premises that needs further examination. For instance, Overbury *et al.* (2009) found an association between asymmetry and age on the pubic symphysis metamorphosis.

6.3. CORRELATION BETWEEN MORPHOLOGICAL TRAITS AND DEGENERATION INDEPENDENCE

The correlation between age-related traits was accessed for a better understanding of the bone degeneration process at the pelvic joints. The level of correlation among features within the same joint was measured, and clearly not all features were correlated, and this indicated some level of metamorphosis independence. Similar results were obtained for both the Coimbra and Bass collections. Acetabular traits shared a moderate agreement (Kendall's coefficient for total sample: Coimbra W_a = 0.493; Bass W_a = 0.554). Principal components analysis (PCA) and the partial correlation between traits (controlling for age at death) clustered acetabular traits into two components: traits from the lunate surface (articular area), and traits from the fossa (non-articular area). However, not all of the clustered traits shared a high or moderate correlation, suggesting some level of independence may exist even among the traits that were clustered together. For example, in the Coimbra collection, the acetabular rim porosity shared a moderate correlation with rim shape and apex activity, but a low correlation with the groove (Table 5.35). The groove also shared a moderate correlation with rim shape and apex activity, and thus was included into the component lunate surface along with rim porosity. This correlation pattern also occurred among the clustered traits from the auricular surface and pubic symphysis in both collections.

For auricular surface traits, similar components were established for both collections (Table 5.49). Small differences were found concerning the allocation of apical area activity and lipping. For the Coimbra sample, lipping was grouped with

micro- and macroporosity while apical area activity was not included in any component reflecting high independence. In contrast, in the Bass sample, lipping clustered with apical area activity. Auricular surface traits presented moderate independence in both collections (W_a from 0.408 to 0.543). However, a lower level of independence (W_a= 0.691) was reported by Buckberry and Chamberlain (2002). Additionally, lack of or low correlation between auricular surface traits, controlling for age, were stated by Buckberry and Chamberlain (2002) and Moraitis *et al.* (2014), although different correlation values within the present study may result from the distinct scoring systems employed. Nevertheless, a more comprehensive analysis was performed in the present study, by analysing surface texture features (*i.e.* dense bone, fine and coarse granularity) separately, contra to Buckberry and Chamberlain (2002), and Moraitis *et al.* (2014). By performing the analysis by trait, it was possible to discern a high correlation between fine and coarse granularity, and great independence of dense bone to other traits.

For the pubic symphysis, similar components for both collections were established (Table 5.58). However, lower independence among pubic symphysis traits (W_a from 0.636 to 0.803) was obtained compared to auricular surface and acetabular traits. Lower independence among traits possibly explains the initial allocation of some traits in more than one component in the Coimbra rotated component matrix (Table 5.52). Nonetheless, the exclusion of inferior extremity and dorsal plateau for the Bass collection and ventral bevelling for both collections possibly resulted in a loss of some information toward component establishment. A similar correlation matrix coefficient between ventral rampart and symphyseal rim (r = 0.636) was reported by Katz and Suchey (1986). However, Katz and Suchey (1986) achieved higher correlation coefficients between dorsal plateau and ventral rampart (r = 0.872), and dorsal plateau and symphyseal rim (r = 0.797) than was observed for the Coimbra collection (r = 0.632 and r = 0.514, respectively).

6.4. SEXUAL DIMORPHISM IN BONE AGEING

Sex influence in the metamorphosis of the pelvic joints was investigated to further understand possible dimorphic patterns in bone ageing (traits, components and composite score). It is unknown what causes sexual variability in bone ageing. It has been suggested that sexual dimorphism differences in the metamorphosis of the

auricular surface and pubic symphysis may be caused by pregnancy and childbirth (Meindl *et al.* 1985; Igarashi *et al.* 2005). However, Hoppa (2000) did not encounter significant differences between women with low birth parity and high parity for the Spitalfields' pubic symphysis data. Sex differences in body size could potentially cause sex differences in rates of ageing, but Wescott and Drew (2015) did not find a significant difference between sexes for the auricular surface and pubic symphysis' metamorphosis among groups of different body mass index (BMI).

Sex showed a minimum effect since for both collections only a few traits and components presented a significant dimorphic metamorphosis at the pubic symphysis and auricular surface (Tables 5.65, 5.66, 5.73 and 5.74). For the composite score - which corresponds to the sum of all traits' scores per joint - significant sexual dimorphism was only found for the pubic symphysis in both collections and for the auricular surface in the Coimbra data. For the acetabulum, no significant influence of sex was found in either collection. For the pelvic joints, discordant results have been reported regarding sexual dimorphism differences in ageing. Some studies have shown a significant difference between sexes (*acetabulum*: Mays 2012; Miranker 2015; *auricular surface*: Hens and Belcastro 2012; *pubic symphysis*: Hoppa 2000; Miranker 2015), while other studies have found lack of significant sexual dimorphism (*acetabulum*: Stull and James 2010; Calce 2012; Mays 2014; Miranker 2015; *auricular surface*: Murray and Murray 1991; Buckberry and Chamberlain 2002; Schmitt *et al.* 2002; Osborne *et al.* 2004; Schmitt 2005; Rissech *et al.* 2012; Moraitis *et al.* 2014; Wescott and Drew 2015; *pubic symphysis*: Schmitt *et al.* 2002; Rissech *et al.* 2012; Godde and Hens 2015; Wescott and Drew 2015). These divergent results suggest variability in the effect of sexual dimorphism in ageing among different reference skeletal collections, as well as the effects of different sample sizes. The present results seem to be in concordance with Wescott and Drew (2015) since only few morphological criteria present a significant sexual dimorphism in ageing, although significant sex differences in body size variables exist in both collections.

6.5. AGE EFFECT ON THE PELVIC JOINTS' DEGENERATION

In the present study, the correlation between morphological criteria (traits, components and composite score) was further explored for the Coimbra and Bass

collections. For the Coimbra acetabular morphological criteria, between 1.8% and 54.3% of the degenerative variance could be explained by age (significant r from 0.135 to 0.737). Slightly lower correlation values were obtained for the Bass collection (significant r from 0.184 to 0.586 – Table 5.63) indicating only 3.4% to 34.3% of the degeneration was associated with age. Higher correlation values with age were obtained for lunate surface features than for the fossa features in both collections. The results for the fossa features were in concordance with other studies (Stull and James 2010; Calce 2012; Mays 2012). In contrast, Rougé-Maillart *et al.* (2007) stated a greater correlation of fossa traits with age (r = 0.71). The higher correlation with age may possibly reflect a greater degeneration in the lunate surface (acetabular articular area) with advancing age, compared with the fossa (non-articular area). Furthermore, other major differences were obtained by Miranker (2015), who reported r values of -0.02 and -0.05, although the p-values were not specified. Additionally, a non-significant correlation between rim shape and age was obtained by Calce (2012)[24].

Considerably significant lower r coefficients were obtained for the auricular surface (Tables 5.67 and 5.68), compared with the acetabulum and pubic symphysis age-related criteria. Only 1.9% to 26.7% of the degenerative variance in both collections was significantly influenced by age. The highest significant r value obtained was for the Coimbra female composite score (r = 0.517). However, several morphological criteria did not share a significant correlation with age. Values from present study were lower than the ones obtained by other studies (*e.g.*, Bedford *et al.* 1993; Mulhern and Jones 2005; Rougé-Maillart *et al.* 2007), although conflicting results have been reported. Miranker (2015) stated an extreme low r coefficient of 0.04. Similar r coefficients were obtained between the Coimbra composite score (r = 0.37) and Rissech *et al.* (2012) (r = 0.37 and 0.39). Additionally, Falys *et al.* (2006), Campanacho (2010), Hens and Belcastro (2012) and Moraitis *et al.* (2014) presented lower r coefficients for transverse organization, dense bone, apical area, microporosity, and macroporosity.

For the pubic symphysis, the correlation coefficient ranged from low to high (Tables 5.75 and 5.76), with age affecting 5.6% to 31.8% of the degenerative variance in the Coimbra sample, and 2.3% to 60.0% in the Bass sample. Additionally, some of the morphological criteria lack significant correlation with

[24] For a detailed review of the r coefficient values between pelvic joints metamorphosis and age at death obtained in the literature see Mays (2015).

age, especially on the Bass collection. In the literature, diverse results among researchers have been reported, with r coefficient values ranging from 0.21 to 0.95 (Meindl *et al.* 1985; Katz and Suchey 1986; Bedford *et al.* 1993; Buckberry and Chamberlain 2002; Djurić *et al.* 2007; Martrille *et al.* 2007; Hens *et al.* 2008; Brown 2010; Campanacho 2010; Rissech *et al.* 2012; Merritt 2014b; Shirley and Montes 2015). For example, composite score r coefficients from the present study are comparable with other studies (*e.g.*, Meindl *et al.* 1985; Bedford *et al.* 1993; Rissech *et al.* 2012). Likewise, similar traits' correlation values were obtained between the present study and Campanacho (2010).

Inter- and intra-population variability in the correlation coefficient values between morphological criteria of the pelvic joints and age reported in the literature possibly results from the effect of confounding factors in bone ageing. Between 1.8% to 60.0% of the degenerative variance were caused by age, suggesting that confounding factors also affect pelvic joint metamorphosis. Wescott and Drew (2015) obtained a lower correlation (r coefficient ranging from 0.07 to 0.17) between estimated and chronological age for pubic symphysis and auricular surface degeneration in obese individuals from the Bass collection. However, for the present research, most morphological criteria showed similar r coefficients for Spearman's rank correlation and partial correlation controlling for body size proportions. Present results support the possibility that other confounding factors affect the metamorphosis of the pelvic joints. However, low significant correlation or non-significant correlation with age may also result from an insufficient number of individuals with trait presence. As an example, no significant correlation with age was obtained for dense bone since it was only recorded only in 10 Coimbra and 10 Bass individuals.

6.6. BODY SIZE INFLUENCE IN AGE-RELATED CRITERIA FROM THE PELVIC JOINTS

The main goal of Merritt (2014a) and Wescott and Drew (2015) were to evaluate how the results of applying an ageing method respond to the influence of body size. Evaluation of the accuracy of age estimation methods is an indirect approach to understanding skeletal ageing, since it does not determine the direct effect a confounding factor has on the degenerative process. Additionally, Merritt (2015)

and Wescott and Drew (2015) evaluated age estimation methods by applying Transitional Analysis to assess the possible body size effect on the age-at-transition between estimated phases, as explained in Chapter 3. The present study followed a direct approach, by determining the effects of body size variables on degenerative criteria at three levels of analysis (each trait, components and composite score), rather than using the age estimation methods' phases. This analysis not only informed which degenerative criterion was affected by body size, but also showed a different response to body size effect reflecting the level of independence among pelvic joints' age-related criteria. The effect different body size variables have on the acetabulum, auricular surface and pubic symphysis age-related criteria will be presented below.

6.6.1. Femoral proportions' influence on age-related criteria at the pelvic joints

6.6.1.1. Stature

Stature (evaluated through maximum femoral length) affects age-related criteria in the Coimbra and Bass pooled sex samples, especially when treating the predictor variable as continuous. However, stature did not influence pelvic joint ageing equally in both collections (Tables 5.95 and 5.97). A higher influence of stature on bone ageing in the Bass sample would be expected since specimens were significantly taller than Coimbra individuals. However, stature had an effect on age-related criteria for the Coimbra pubic symphysis, but none for the Bass sample. The inverse occurs for the auricular surface (more age-related criteria are affected by stature in the Bass collection). By treating stature as a categorical variable in the logistic regression model, resulted in slower ageing for shorter individuals on two acetabular age-related criteria, presenting an "older" median age of transition between scores.

Merritt (2014a, 2015) studied the effect of stature on ageing in 764 Bass individuals, although her results may not be directly comparable due to the employment of different methodological approaches. Merritt (2014a) investigated if cadaveric stature influenced age at death estimation methods using Lovejoy *et al.* (1985b), S-B system, Buckberry and Chamberlain (2002), and Rougé-Maillart *et al.*

(2009)[25]. Differences in age estimation results between stature groups were only obtained for males and individuals of European ancestry. Shorter individuals presented lower accuracy and were under-aged between 3 and 12 years compared with taller individuals. It was suggested that shorter individuals presented a decelerated ageing rate than taller individuals, which seems to be in agreement with the current study for two acetabular age-related criteria. Hence, Merritt (2014a: 244) stated, "there are few studies that consider stature in relation to skeletal aging except for those that identify short stature as an indicator of poor health, with the premise that short individuals have shorter life spans due to poor nutrition (…)". So far no correlation between pelvic joint metamorphosis and potential lifespan has been investigated. Even though shorter individuals may age slower, this may not be associated with lifespan, rather may result from biomechanical forces and bone remodelling processes in association with body size, which was also suggested by Merritt (2014a).

Merritt (2015) applied a Transitional Analysis (cumulative probit model) to the data collected for her dissertation (Merritt 2014a). Higher ages-at-transition for ageing methods' estimated phases were obtained for individuals with a longer femur length, thus taller specimens. However, Merritt misinterpreted the results, by concluding than an ageing acceleration took place for taller specimens. If taller individuals presented higher ages-at-transition between phases than shorter specimens, the result would indicate a decelerated ageing rate occurred instead. That is, the transition from a "younger" to an "older" phase occurred at older age for taller individuals than for shorter individuals[26]. Merritt (2014a) showed an accelerated ageing rate for taller individuals, but the inverse was obtained in her 2015 paper, possibly reflecting the employment of different statistical analyses. The evaluation of ageing methods in Merritt (2014a) is an indirect approach that may have brought the ageing methods' bias into the analysis, which may not occur with a Transition Analysis approach. Merritt (2015) also applied a one-way analysis of variance to test if score pattern differences between body size groups existed for five auricular surface features described by Buckberry and Chamberlain (2002). Significant differences were obtained for surface texture, apical activity and micro-

[25] Merritt (2014a) also applied age estimation methods that analyse the metamorphosis of the first and fourth rib end (*i.e.* İşcan *et al.* 1984, 1985; Kunos *et al.* 1999; DiGangi *et al.* 2009) and the auricular surface of the sacrum (Passalacqua 2009). However, only the results for the pubic symphysis, iliac auricular surface and acetabulum will be discussed in the present study.

[26] As an example of a correct interpretation of ages-at-transition between estimated phases for an ageing estimation method with Bayesian analysis see Wescott and Drew (2015).

and macroporosity between cadaveric stature groups, and for surface texture and apical activity for the maximum femur length data. The significant results Merritt (2015) found for the surface texture feature may be similar effect stature had on granularity features for the Bass collection in the present study.

6.6.1.2. Body mass

More pubic symphysis age-related criteria (n = 7) were affected by body mass (evaluated through femoral vertical head diameter) for the Coimbra pooled sex sample, than for the Bass pooled sex and male samples (n = 3: see Section 5.6.3.5). Additionally, an accelerated ageing rate for ligamentous outgrowths on the ventral bevelling (LOVBe) in heavier Bass individuals was observed; the median age of transition between scores occurred earlier for heavier individuals compared to lighter individuals. The pubic symphysis results for the Bass collection were in agreement with Wescott and Drew (2015), although different methodological approaches were followed. Wescott and Drew (2015) found no significant effect of obesity[27] on age estimation using the S-B system on the Bass collection. In addition, they found that only 0.6% of the pubic symphysis degenerative variance was caused by body mass index (BMI). Inaccuracy and bias were higher for obese individuals, except for specimens over 70 years old. Wescott and Drew (2015) applied a Transition Analysis, showing a distinct age-at-transition only from phase I/II to III between BMI groups. An earlier transition occurred for the obese group (18.39 years) than for the normal BMI group (30.24 years), suggesting an accelerated ageing rate in obese individuals for the initial phases of the S-B system, but not for older phases.

A greater effect of body mass at the auricular surface morphological criteria would be expected for both collections, since a greater loading stress occurs at the auricular surface compared with the pubic symphysis, however, the Bass collection showed more age-related criteria were affected than for the Coimbra collection (Table 5.99). Possibly the effect of body mass on the auricular surface is greater in significantly heavier individuals, as seen in the on average heavier Bass individuals compared with the on average lighted Coimbra individuals. The auricular surface results for the Bass collection were in agreement with Wescott and Drew (2015)

[27] Two groups of individuals with different body mass index (BMI) - normal BMI (18.5 to 24.9) and obese group (BMI >30) were compared. BMI categories were established according to the U.S. Center for Disease Control and Preservation parameters.

study. Wescott and Drew (2015) observed 7% of the auricular surface degenerative variance was explained by BMI. They also found significant inaccuracy and bias for the obese group except for specimens older than 70 years old by applying the Buckberry and Chamberlain method. Furthermore, earlier ages-at-transition between estimated phases were obtained, suggesting an accelerated ageing rate in obese individuals. For Merritt (2014a), body mass also had an influence when the age estimation methods of Lovejoy *et al.* (1985b), S-B system, and Buckberry and Chamberlain (2002) were used. A greater age estimation error was obtained for the lightest body mass group, and this group was under-aged between 3 and 8 years, suggesting a decelerated ageing rate compared to heavier individuals. However, when using Transitional Analysis Merritt (2015) achieved the opposite results[28]. Obese individuals (according to BMI data) and cadaveric body mass groups presented significantly higher scores for surface texture, porosity and apical activity (Merritt 2015). Furthermore, significant score differences for surface texture and apical activity were obtained for maximum femoral head diameter data (Merritt 2015). The significant results Merritt (2015) found for the surface texture feature may be similar effect body mass had on granularity features for the Bass collection in the present study.

Some of the age-related acetabular age-related criteria were significantly affected by body mass in both collections (Table 5.97). However, the affected age-related criteria in the Coimbra and Bass collections were different. The Coimbra lighter group showed a faster ageing rate for rim shape, and a decelerated ageing rate for the composite score, compared with the heavier group. A greater effect of body mass on the acetabular age-related criteria would be expected due to the weight and biomechanical loading the acetabulum withstands. However, present results possibly reflected different stress loading forces across the hip joint. The acetabular anterior and posterior horns suffer dissimilar degrees of stress transmission, with the anterior horn being more rigid, less mobile, and associated with a higher transmission of articular stress (Govsa *et al.* 2005). Furthermore, loading stress transfer occurs mainly along the anterior/superior acetabular edge (Dalstra and Huiskes 1995). Yet, depending on force direction, loading stress transference to the femur can also occur from a deeper area of the lunate surface (Dalstra and Huiskes 1995).

[28] Results for body mass data were also misinterpreted by Merritt (2015), as explained in Section 6.6.1.1.

6.6.1.3. Robusticity

Robusticity had the least effect on pelvic joint ageing in both study collections (Tables 5.97, 5.99 and 5.112), similar to Campanacho *et al.* (2012), although both studies employed different femoral robusticity formulae. Campanacho *et al.* (2012) applied Olivier and Demonlin (1984)[29] formula, while Wescott (2001, 2008) femoral robusticity formula was employed in the current study. Further, no age-related acetabular age-related criteria were affected by robusticity in the Coimbra sample. Application of external measurements to estimate robusticity provides information only regarding bone external morphological contour, and not its internal architecture, as cross-sectional methods offer (Ruff *et al.* 1983a). Possibly, lack of information regarding femoral internal architecture may have influenced the present results. Nevertheless, the employment of external dimensions to estimate robusticity can still provide an idea of biomechanical morphology, which has been shown to present a similar pattern to cross-sectional geometric properties (Jungers and Minns 1979; Bridges *et al.* 2000; Pearson 2000; Wescott 2001; Stock and Shaw 2007).

6.6.1.4. Osteological proxy for the estimation of femoral size variables

Body size analysis was performed using femoral measurements (*e.g.*, head diameter and maximum length) rather than biographical records of cadaveric stature and weight since those were not available for the Coimbra collection. Still, osteological indicators of size are not free of methodological and biological bias. Methodological biases are reported, for example, to the performance of external robusticity femoral measurements, as referred in Section 6.6.1.3. In turn, biological bias can refer to tissue plasticity in response to genetic and environmental factors, given higher variability exists for soft tissues than for bone.

Femoral head diameter and maximum length share a highly positive allometric association with lean body mass (Ruff *et al.* 1991; Lieberman *et al.* 2001; Pomeroy and Zackrzewshi 2009) and stature (Trotter and Glesser 1952; Jantz and Jantz 1999; Mendonça 2000). In the present study, preference was given to femoral head diameter to estimate body size instead of femur midshaft diameter, because the head diameter is less affected by physical activity mechanical loading than shaft cross-sectional dimensions (Ruff *et al.* 1991; Ruff 2002; Auerbach and Ruff 2004).

[29] Femoral robusticity = (midshaft perimeter/maximum length) x 100

Body mass is a complex variable with the tendency for not being uniform during adulthood, more so than stature. Ruff *et al.* (1991), while comparing the correlation between femoral measurements and body mass in two moments (the current body mass and self-reported weight at 18 years old), found firstly that shaft measurements have higher correlation with current weight than with weight at 18 years, and secondly that femoral head diameter correlates moderately with body mass in both periods of time, except for women (due to low correlation with weight at 18 years, possibly associated with self-reported data error). Even though it may be considered more reliable to use known weight and stature, these data are not free of bias. Cadaveric weight and stature does not reflect living body size fluctuations but corresponds to the last body proportions before death (Trotter and Glesser 1952, 1958). For the Bass collection, weight could be reported years before the body donation takes place, which have been found to be discrepant from cadaveric weight, possibly caused by ageing and diseases (Maijanen and Jeong 2015). Moreover, Merritt (2015) obtained similar results for the femoral maximum length and head diameter analysis compared with the log-age models for cadaveric stature weight for the Bass and Hamann collections, indicating that femoral measurements are valid body size proxies to understand age-related changes in the present study.

6.6.2. Joints surface area influence

The initial hypothesis of a slower ageing for individuals with larger surface joints was not possible to verify, since only one significant valid result was obtained for LOVBe when the predictor variable was treated as categorical. Additionally, the metamorphosis of LOVBe presented a faster ageing rate for Bass individuals with a larger pubic symphysis surface area, with median age of transition between scores at 42 years. Individuals with a smaller surface area had a median age of transition between scores at 76 years. Treating the predictor variable as continuous in the logistic regression resulted in more age-related criteria showing a significant effect from joint surface area for the Bass pooled sex sample (Tables 5.97, 5.99, 5.112). However, not all age-related criteria of the pelvic joints were affected, and its effect did not extend to all scores within a degenerative criterion, similar to the analysis of femoral proportions effect in bone ageing. Influence of pubic symphysis surface area extended to LOVBe, dorsal and ventral body of the pubic bone, although these traits are located on the pubic bone and not on the articular area (area measured). The

present results may result from a possible allometric relationship between pubic symphysis surface area and pubic bone size, since individuals with a larger joint surface area seem to present a more robust pubic bone than individuals with a smaller surface area.

The Coimbra collection showed no significant results, thus there was no effect of pelvic joint surface area in bone ageing for this sample. Different results between collections for the auricular surface and acetabulum may be due to the significantly bigger joint dimensions present in the Bass collection. Even though the pubic symphysis area is of similar size between collections[30], the joint surface area only had an effect on the Bass sample. It is possibly that an inverse effect of surface area and femoral proportions may exist for the pubic symphysis, since it is a non-weight bearing joint and experience less biomechanical loading (tension, compression and shearing) than auricular surface and acetabulum. For the Bass collection, pubic symphysis age-related criteria were only affected by surface area. Opposite results were obtained for the Coimbra collection, with stature and body mass affecting pubic symphysis age-related criteria, while joint surface area had no effect. However, for auricular surface and acetabulum an inverse relationship among body size variables may not be the case, since stature, body mass and joints surface area influenced age-related criteria for Bass collection, possibly reflecting the higher biomechanical loading at these joints.

6.6.3. Skeletal measurements correlation with age

For adult skeletons there has been reported an association between femoral measurements and age in the literature (*shaft breadth*[31]: Ruff *et al.* 1983b; Vance *et al.* 2010; Feik *et al.* 2000; *maximum length*: Trotter and Gleser 1951a; Kemkes-Grottenthaler 2005; *head diameter*: Vance *et al.* 2010). In the present study, few skeletal measurements showed significant correlation with age at death; the only exception was the Coimbra female sample (Table 5.27). However, the majority of

[30] Joint development is affected by gene expression, alongside the influence of mechanical loading, since joints have to be large enough to withstand and transfer stress loading forces (Plochocki 2004). Therefore, it would be expected for pubic symphysis surface area to be significantly greater for the American sample - with significantly bigger stature and body mass proportions - than for the Portuguese sample, as the auricular surface and the acetabulum did. However, the pubic symphysis surface area does not present significant differences between collections. The lack of significant size differences in the pubic symphysis surface area may suggest lack of a positive allometric relationship with body size (stature and body mass), possibly because it suffers less mechanical loading if compared with the auricular surface and the acetabulum.

[31] Femoral shaft breadth reports to anteroposterior and medial-lateral diameters.

these significant correlation coefficients were low, except for a few pelvic joints surface areas measurements which had significant moderate correlation with age. Similarly, Lottering *et al.* (2014) obtained a significant association between pubic symphysis surface area and age for an Australian sample. A significant correlation between pelvic joint surface area and age is possibly related to topographic changes at a joint with advancing age. For example, pubic symphyses of similar height and width may present distinct surface areas depending on billowing presence or absence. However, it is possible the association between joint surface area and age have no effect on the current results, since the logistic regression analysis was performed mainly with the pooled sex sample, where no significant correlation with age was found. However, except for the Bass pubic symphysis surface area and Coimbra female robusticity, these variables presented low correlation with age. Consequently, age at death effect on body size appeared to provide a minimum impact on the collections used in the present study.

6.6.4. Factors affecting body size variables: implications in skeletal ageing

Body size association with bone remodelling and mechanical loading may have an effect on bone ageing of the pelvic joints (Merritt 2014a, 2015; Wescott and Drew 2015). BMI and body mass influence on bone mineral density (BMD) have been reported (Morin *et al.* 2009) however, contradictory opinions regarding the effect of obesity on BMD have been stated. Obesity is possibly associated with a higher BMD, since an increase in bone formation may be stimulated by mechanical loading due to excess weight, and yet, the inverse has also been suggested, with obesity associated with a low BMD (Cao 2011). The increase in bone formation and consequently in BMD would be expected in association with a greater mechanical loading due to excessive weight, but with obesity the gene that controls bone formation mechanism tends to be downregulated (Merritt 2014a, 2015). Consequently, a low BMD can be associated with obesity, due to a decrease in osteoblastogenesis (bone formation) associated with an increase in bone resorption and adipogenesis (fat formation) (Cao 2011). Lower BMD has also been found in underweight older individuals suffering malnutrition (Coin *et al.* 2000). Hence, BMD is not only affected by body mass, but also by nutrition. In addition, hormones, such as leptin, also affect BMD (Merritt 2014a, 2015). Usually, the highest peak of BMD is reached around 25 to 30 years old (Goldfeder and Peddi

2009). Afterwards, bone mass declines with advancing age. However, the remodelling process in bone tissue, through bone resorption and bone formation, still occurs after the highest peak of BMD is reached. A higher bone mass decline increases the risk of osteoporosis, especially in women, due to a decrease in oestrogen, which is necessary for bone formation (Kaptoge *et al.* 2003). Therefore, a link between bone remodelling and age metamorphosis on the pelvic joints possibly exists (Merritt 2014a, 2015). A connection between reduction in bone mass after the highest peak of BMD with the metamorphosis of the pelvic changes occurring at 30 to 40 years, such as the emergence of auricular surface coarse granularity was suggested by Merritt (2014a, 2015). The present study support such a connection since body size affected age-related criteria changes were expressed through osteoblastogenesis (*e.g.*, emergence of bony projections on the ventral bevelling), and osteoclastic changes (*e.g.*, erosion of the symphyseal rim). It should be noted in the present study the majority of age-related criteria affected by body size were associated with bone formation. However, no systematic study has ever investigated a relationship between bone remodelling process and age-related changes in joints.

In addition to effect of bone turnover, mechanical loading and physical activity may influence age-related criteria of the pelvic joints in association with body size. An association between obesity and the development and progression of osteoarthritis has been observed, leading to a reduced physical function (greater stiffness of the joints) caused by stress overload damage to the cartilage of joints (Lievense *et al.* 2002; Ackerman and Osborne 2012). An association between BMD and physical activity has been suggested as weight bearing activities with high mechanical loading can lead to a greater BMD by inducing bone formation (Ducher *et al.* 2005). The lack of mechanical loading, caused for example by paralysis, can lead to greater bone reabsorption than bone formation, and consequently loss of BMD (Robling *et al.* 2006). It was suggested the lack of a significant effect of occupation and physical activities on pubic symphysis traits in Campanacho *et al.* (2012)[32] may result from smaller body size proportions in Portuguese males (Merritt 2014a: 251). However, in the present study stature and body mass influenced bone ageing in the Coimbra pubic symphysis sample, but not in the Bass sample with significantly bigger body size proportions. It is not entirely clear how physical activity influences age-related criteria in the pelvic joints. In the present study,

[32] Correction note: Campanacho *et al.* (2012)'s article was not faithfully described by Merritt (2014a: 251). A description of Campanacho *et al.* (2012) study is presented in Chapter 3 of the present study.

femoral robusticity did not affect bone ageing study which is supported by Campanacho *et al*. (2012), suggesting lack of influence from physical activity. Miranker (2015), however, found the accuracy of age estimation methods for the Bass collection was affected by occupation. An effect of robusticity on age-related criteria would be expected due to the association of robusticity with mechanical loading, reflecting bone strength in relation to shape and size (Stock and Shaw 2007). A more physically demanding activity may lead to bone deposition on the periosteal surface, especially in skeletal areas subjected to more stress, which increases second moment of area, torsional loading and bone resistance to decrease biomechanical stress and the risk of fracture (Robling *et al.* 2006). Such bone deposition from biomechanical loading may be conveyed through femoral robusticity; however, bone robusticity can also be affected by sex, genes, disease and diet (Ruff 1983b; Wescott 2001; Robling *et al.* 2006). Alternatively, lack of significant results for robusticity may reflect the application of external measurement formulae which may not reflect biomechanical bone changes accurately (as discussed in Section 6.6.1.3). Given these points, skeletal ageing may function in relation to bone remodelling, mechanical loading, nutrition and hormones in association with body size. For example, less mechanical stress and lesser level of bone formation in lighter individuals may be accountable for a slower ageing rate. However, this point requires further study.

6.7. AGEING VARIABILITY: IMPLICATIONS FOR AGE AT DEATH ESTIMATION

Stature, body mass and joint surface area all had an effect on age-related criteria of the pelvic joints in the Coimbra and Bass pooled sex samples. However, body size effect does not extend to all age-related criteria. Additionally, when the analysis was performed by sex, only one significant result for the Bass males was obtained, with body mass affecting the pubic symphysis composite score (stages 3 to 4). The results suggested the possibility that individuals with bigger skeletal proportions age faster than smaller individuals but it was only possible to analyse if there was a significant ageing rate difference for a few age-related criteria. Consequently, the assumption of faster ageing in pelvic joint criteria for individuals of bigger size proportions needs to be further investigated. Additionally, different patterns were obtained for both the Coimbra and Bass collections; the same body size variable affected different age-

related criteria. The only common denominator between collections was the minimum effect robusticity had on pelvic joint ageing. Since individuals from the Coimbra and Bass collections lived in different periods and countries (Coimbra individuals lived during late 19th century and early 20th century and Bass during 20th and 21st centuries), they possibly had different life histories and came from different socioeconomic conditions[33] that may be responsible for the significant differences in body size proportions. For example, stature has been associated with childhood living conditions (Silventoinen *et al.* 1999) and the Bass pooled sex sample presented significantly bigger body size proportions than the Coimbra pooled sex sample. Consequently, such differences may be responsible for the dissimilar impact body size had on pelvic joint bone ageing in the collections, suggesting lack of uniform effect of body size on age-related criteria. Consequently, the same

[33] From 1834 to 1938, Portugal suffered political changes associated with economic instability. The end of the Monarchy, in 1910, had been driven by popular support for a political change to a Republican State. However, the First Republic (1910 to 1926) did not see its liberal and stability ideals achieved. The immaturity of the Republican State political system, allied with power struggles and economic instability, led to several coups and a short period of civil war (Wheeler 1978). During this unstable and short period of time 45 governments were formed (Baiôa *et al.* 2003). The unstable Republic State was then overturned by the armed forces, establishing a military dictatorship (1926 to 1933). This period was marked by the ascension of António Salazar (appointed Minister of Finance in 1928), which subsequently led to the establishment of *Estado Novo* (1933 to 1974), the longest dictatorship regime in Europe. During this period, Portugal remained an isolated, traditional and underdeveloped society, with strong Catholic influence and patriarchal values, associated with high rates of illiteracy. The economy was associated with a fragile subsistence agriculture system and an insipid industry with a weak capitalistic system (Telo 1994). The social structure consisted mainly of a two class system: small elite at the top with land property and wealth, and a higher proportion of peasants with lower socioeconomic status (Cardoso 2005). The emergence of a middle class was timidly inserted into Portuguese society due to a late establishment of the industry sector in the country, and even so, these social changes occurred mainly in the two largest cities of Lisbon and Oporto and were partly controlled by the dictatorship. Social inequality was reflected in bad living conditions with inadequate nutrition and sanitation for poor and working masses. Despite poor individuals having free access to hospital services (Santos 2000), health conditions were among the poorest in Western Europe, reflected in high infant mortality rates and incidence of tuberculosis and other infectious diseases (Morais 2002). In the 19th century, Coimbra was a small city still associated with a rural life style, although a demographic increase lead to the development of urban areas (Roque 1982).

The American individuals lived between the years of 1904 and 2010, reflecting the East Tennessee demographics, which was mostly individuals of European ancestry (Jantz and Jantz 2008). Since the 20th century, the US established economic, technical, cultural and military power worldwide. Labour conditions in the US improved in the 20th century, associated with a rise in wages and a growth of fringe benefits, especially at the end of the century. Women emancipation during the 20th century also led to the increase in female participation in the labour market. Additionally, it has been pointed out that the improvement in work conditions was a result of technology, education and industrialization developments, associated with an increase in immigration, capital and government intervention (Bergeron *et al.* 1999). The health sector also suffered a development leading to increase in lifespan. However, between 1929 and the late 1930s the US suffered the Great Depression, originating from the fall in the New York Stock Market. During the Great Depression, people lost their savings; a rush to withdraw bank deposits took place, which had a major negative effect on the economy (Bergeron *et al.* 1999). The Great Depression was felt differently in each American state (Wallis 1989), but major consequences included laid-off workers, reduced wages, business bankruptcy, and increased number of homeless families. Additionally, in the 20th and 21st centuries the US have participated in several wars, which has also influenced US society and economy.

confounding factor may have varying effects on age-related criteria in different individuals and populations, contributing to ageing process variability. Differences between the Coimbra and Bass collections were also obtained regarding the correlation between degenerative criteria and age at death, sexual dimorphism and asymmetry results. Therefore, a non-uniform degenerative process can be pinpointed to a different behaviour of degenerative criteria in relation to sex, age and body size variables on the analysed collections. Additionally, auricular and acetabular features have shown moderate levels of degenerative independence among traits. However, the assumption of variability among age-related criteria to the same stimulus should be tested in other reference skeletal collections, as well as in "similar" samples from the same period and country (*e.g.*, Coimbra and Lisbon collections). If different degenerative patterns are obtained for skeletal collections whose individuals derived from the same country and period, it may suggest a high intra-population variation of the ageing process. Individual variation in bone ageing has rarely been approached but is of paramount importance (Jackes 2000; Kemkes-Grottenthaler 2002).

A distinct genetic makeup between Coimbra and Bass individuals possibly contributed to the present lack of uniform results between collections. The Bass individuals may present a more diverse gene pool than the Coimbra sample. In the early history of North America, gene admixture occurred between Native Americans, Africans and European settlers, which is still part of continuous gene admixture of present-day Americans (Bryc *et al.* 2015). It is possible that the Coimbra individuals closely resemble other Mediterranean populations (Branco and Mota-Vieira 2011).

The differences in individuals' age distribution between collections could also have contributed to the different results obtained (Usher 2002; Nawrocki 2010). The Coimbra collection pooled sex sample had a lower percentage of older individuals (≥50 years), and a higher percentage of younger individuals (≤ 39 years), compared to the Bass collection. Nonetheless, the age distribution for samples was not replicated by each age-related criterion (traits, components and composite score). Age distribution of each age-related criterion was not possible to control, since the stage of each trait was unknown, regardless of the age at death of an individual. Furthermore, *post-mortem* damage influenced traits and limited the data recorded; consequently, indirectly affecting the age distribution of each age-related criterion. Selecting the age distribution of a sample when the aim is to determine the

effect body size has on ageing estimation methods' accuracy and bias is easier than selecting a sample's age distribution for each age-related criterion as performed in the present study. Nonetheless, evaluating the validity of an ageing method according to body size does not provide a full understanding of the ageing process due to its indirect approach, as previously explained. By following a direct approach - analysing the effect of body size in each age-related criterion - a better understanding of the ageing process is allowed, even if some information is lost due to *post-mortem* destruction or the difficulty of having a similar age distribution by criterion. However, the application of logistic regression overcomes an uneven age distribution, the predictor variable's heteroscedasticity and non-normality (Cardoso *et al.* 2010). Invalid results were obtained for logistic regression analysis, non-significant Wald and p values, possibly arising from lack of high association between degenerative criteria and age at death, low number of individuals in some degenerative criteria scores and lower median and/or mean for "older" compared with "younger" stages (information provided in Appendices 4 and 6). The sample size in the present study, especially pertaining to the number of individual for each score/stage, may have led to erroneous insignificant results and only a larger sample could address this problem. However, assembling an even larger identified skeletal sample from the same historical period and country is not always feasible. It may not be advisable to combine skeletal specimens from different time periods and locations just to have a larger sample to work from. Secular trends and different life histories among individuals may or may not affect the results, since the same confounding factor may have a different effect on bone ageing in individuals from different time periods. Therefore, the investigation of significant differences in ageing rates among collections ought to be performed before combining skeletal samples.

The present results, concerning the effect of body size in pelvic joints ageing, suggest a different approach in future age estimation research should be followed. However, it may not be advisable at present to establish an age estimation method controlling only for body size. Given that age and body size are not the only factors influencing the degenerative variance of pelvic joints, there are strong suggestions that other confounding factors are involved. There has been a range of other factors that have been suggested as genetic (Deelen *et al.* 2013), hormonal (Sherman 1999; Mays 2015), dietary (Heaney 1999; Mays 2015), pathological (Weiner and Lipson 1999; Crews 2003; Rissech *et al.* 2003/2004; Cunningham *et al.* 2007; Mays 2015),

drug and alcohol abuse (Taylor 2000), sociocultural (Crews 2003), and biomechanical (Mays 2012, 2015; Miranker 2015). However, a greater emphasis should be placed on knowing more about the ageing process, especially regarding the effect of other confounding factors, presently poorly understood. Once this is better understood it would be possible to establish new age estimation methodologies, by incorporating or controlling for confounding factors, allied with appropriate statistical analysis such as Bayesian inference. Such procedures would lead to a new paradigm in the field of age estimation by involving the incorporation of more skeletal biological information per individual than just joint metamorphosis data. However, the assertion of improvement for new ageing methods following the inclusion of more biological information should subsequently be tested by evaluating their accuracy and bias. Furthermore, if future age methodologies include/control for body size, this implies skeletal measurements to estimate body proportions of unknown individuals will be necessary. Researchers rarely have access to living stature and body mass of unidentified skeletal remains, and therefore, these parameters are usually estimated through skeletal measurements (*e.g.*, femoral dimensions). Femur dimensions have shown an allometric association with body mass and stature, and thus, in the present study it was important to determine if femoral measurements influenced bone ageing.

CHAPTER 7
CONCLUSION

Estimating age at death for adult skeletons with accuracy is still one of the chief predicaments in bioanthropology. To improve the accuracy in ageing estimation a great emphasis has been placed on the methodological component, by re-arranging traits scores, the number of phases and even by applying different statistical tests. Yet revised methodologies do not seem to improve age estimation accuracy. It has been suggested that the methods' inaccuracy may result from the lack of a better understanding of the ageing process variability among populations and associated confounding factors. However, little is known about which, and to what extent, confounding factors affect adult skeletal ageing including for the pelvic joints metamorphosis. New research has mainly tested the possible effect a confounding factor has in inaccuracy and bias of ageing estimation methods. However, the evaluation of the effect of a confounding factor in ageing estimation methods is an indirect approach, since it does not measure the real effect the factor effectively has on joints degeneration by not providing detailed information by trait. Therefore, in the present study was investigated if body size (measured by stature, body mass, robusticity and articulation size) affects age-related morphological criteria (each trait, components (correlated traits), and composite score) of the pubic symphysis, auricular surface of the iliac and acetabulum.

7.1. SUMMARY OF PRINCIPAL FINDINGS

Stature, body mass and joint surface area affected age-related criteria on the pubic symphysis, auricular surface and acetabulum from the Coimbra and Bass pooled sex samples. However, robusticity does not affect the ageing of the pelvic joints, and the effect of body size did not however extended to all age-related criteria. Few age-related criteria exhibited significant sexual dimorphic differences, and only body mass significantly affected the pubic symphysis composite score (score 2 to 3) for Bass males.

The two study collections, Coimbra and Bass collections, showed a lack of a common pattern as to how the different age-related criteria were affected by the body size variables. A distinct body size effect on different types of joints was

obtained, which may be explained by the fact that the pubic symphysis is a secondary cartilaginous joint that experiences less biomechanical stress than the auricular surface (diarthrodial joint) and acetabulum (synovial multiaxial ball-and-socket joint). Joint surface area only influenced Bass pelvic joints ageing, not the Coimbra collection. The contradictory results between collections are possibly associated with a significant greater acetabulum and auricular surface area dimensions in the Bass collection. Even though pubic symphysis age-related criteria also displayed divergent results, there were no significant joint size differences between the collections. For pubic symphysis age-related criteria, only stature and body mass influenced the Coimbra collection, and only pubic symphysis surface area affected the Bass collection.

Stature and body mass did not influence Coimbra auricular surface, while in the Bass sample the auricular surface age-related criteria were affected by stature, body mass and joints surface area. This is possibly associated with the Bass individuals' significant bigger body size proportions than seen for the Coimbra individuals. Thus, it is possible that not all acetabular age-related criteria were affected by body size variables due to an unequal weight and biomechanical forces distribution in the lunate surface. Additional differences between collections were obtained for correlation coefficient values between degenerative criteria and age at death.

Significant differences among collections suggest a lack of a uniform effect due to body size on pelvic joint ageing, in view of the fact that the same confounding factor (body size variable) did not affect the same age-related criteria in both collections. Divergent results between Coimbra and Bass collections may be explained by significant body size differences which may result from Coimbra and Bass individuals lived in distinct historical periods with dissimilar socioeconomic and politic infrastructures. In addition, bone remodelling and mechanical loading in association with body size can possibly also influence pelvic joints bone ageing, however, further research is necessary to understand bone remodelling and mechanical loading possible effect in bone ageing. Distinct genetic makeups have contributed to the current lack of similar results between collections. The age distribution for pooled sex samples was possibly not replicated by each age-related criterion analysed since it is unknown *a priori* the stage a trait was at the time of death, regardless of individuals' age in records, and due to *post-mortem* damage encountered. However, potential differences in age-related criterion age distribution

were circumvented in the present study due to the application of logistic regression, which can overcome an uneven age distribution, but also predictor variable's heteroscedasticity and non-normality.

The results suggest the possibility of individuals of smaller skeletal proportions to age slower than larger individuals. The analysis to determine if a significant ageing rate differences existed was only possible to be tested for a few age-related criteria, due to the lack of valid logistic regression models explained by low correlation between degenerative criteria and age at death, and/or the presence of few individuals for some scores. However, significant results in the current study are in agreement with Merritt (2014) and Wescott and Drew (2015), which also suggested a decelerated ageing in individuals of smaller body size proportions. In summary, the present study is contributing to a better understanding of the ageing process in the pelvic joints, by informing the level of agreement between traits and how much they correlate with age. Besides providing information about the direct influence skeletal proportions have in pelvic joints age-related criteria.

7.2. SUGGESTIONS FOR FURTHER RESEARCH

For the present study, age at death and body size did not affect the degenerative criteria of all pelvic joints, which together with some level of degenerative independence between traits suggest other confounding factors may also be influence bone ageing. Therefore, further research is necessary to gain a better understanding of what other co-variables affect bone ageing alongside body size, such as genetic, dietary, pathological and biomechanical factors. Subsequently, knowing more about the ageing process could possibly lead to the establishment of improved age estimation methodologies, by incorporating or controlling for confounding factors, including for body size. Such procedure would result in a new ageing estimation paradigm by incorporating more skeletal data per individual than just joints metamorphosis scores. This assumption should be further explored firstly by understanding joints ageing process, to better conjecture which data possibly should be included in future ageing estimation methods.

An additional field of research should be to gain an understanding of how varied the effects of the confounding factors on joints' age-related criteria are at a population or individual level. A further understanding of ageing variability patterns

may also provide more information in the establishment of new ageing estimation methods. The assumption of no variability among age-related criteria to the same stimulus should be tested in different and similar reference skeletal collections according to period of time and geography. However, if different degenerative patterns are obtained for skeletal collections whose individuals derived from the same country and historical period, it may suggest the alternative hypothesis should be accepted of a high intra-population ageing variation.

Equally important is to further measure the correlation between degeneration criteria and age when confounding factors are controlled, and consequently ponder their inclusion in ageing estimation methods. Low correlation values between degenerative criteria and age at death, including when body size variables were controlled - as obtained for example for the auricular surface traits in the present study - leads to question their value as an age indicator. In light of the present results, elimination of traits poorly correlated with age could be considered as a possible solution. However, in the literature, low correlations were not found for the same degenerative criteria and, therefore, at present it is difficult to select which traits should be considered or eliminated. Therefore, it is suggested here that a greater focus should be placed instead on understanding bone ageing process and confounding factors, to allow for control of the effect of confounding factors, which may lead to higher correlation with age and help in deciding which traits should be included into an ageing estimation method.

For future research, it would be advisable to study not only other reference skeletal collections but also cadaveric and living individuals using imaging data (*e.g.*, computed tomography scan and/or magnetic radiographic imaging). The imaging analysis from cadaveric and living individuals would allow access to more biographical information than provided by identified skeletal collections, such as the different occupations an individual may held, although the investigation would have to be carried out without jeopardizing the subjects' identity. Consequently, a study involving larger samples with reference collections and imaging data may implicate an interdisciplinary research team involving bioanthropologists and clinicians.

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APPENDICES

APPENDIX 1 | DESCRIPTION OF THE BONE DEGENERATIVE TRAITS FROM THE PELVIC JOINTS

Acetabulum

Six morphological features were examined on the acetabulum with the following scoring system adapted from Rissech *et al.* (2006), and Calce and Rogers (2011):

Acetabular rim shape

In young individuals, the acetabular rim is usually rounded, dense and smooth to the touch, without osteophyte formation. With age partial narrowing of the acetabular rim occurs, where the internal part presents an upright form, but externally it remains rounded; or the narrowing occurs at the iliac part, although not the ischial section, but surface remains smooth to touch and without the formation of osteophyte excrescences. The acetabular rim becomes narrow and rough to touch and it is followed by osteophyte formation, which over time, may increase in size, leading to the creation of a crest that may extend over the whole acetabular rim, and may even lean towards the lunate surface. In older individuals, the acetabular rim bone can become fragile, spongy, and hollow and may appear bone breakdown. For the acetabular rim shape, the following scoring system was created (Figure 1):

Stage 1- Blunt-edged: acetabular rim is blunt-edged with a rounded, dense and smooth acetabular rim. It may also show a partially narrow acetabular rim. In some cases it may be rough to touch, however, no osteophytes are present at the acetabular rim

Stage 2 - Blunt-edged with localized osteophytes: acetabular rim is blunt-edged with a partially crested rim. The osteophyte formation forms a small chain with less than 1 mm in height, but do not cover the entire acetabular rim. However, a localized osteophyte larger than 1mm in height may also be present, which can be associated with the small crest

Stage 3- Crested acetabular rim: dense crest covering the entire acetabular rim, ranging from less than 1 mm in height to a partially higher crest, 2 to 4 mm in

height. A 4 mm crest may not present a dense appearance, rather a rounded spongy appearance, or may be thin and sharp

Stage 4- High crested acetabular rim: The acetabular rim presents a high crest with more than 4 mm, with or without bone destruction The large crest may be thin and sharp or it may be fragile, rounded and spongy extending to the lunate surface

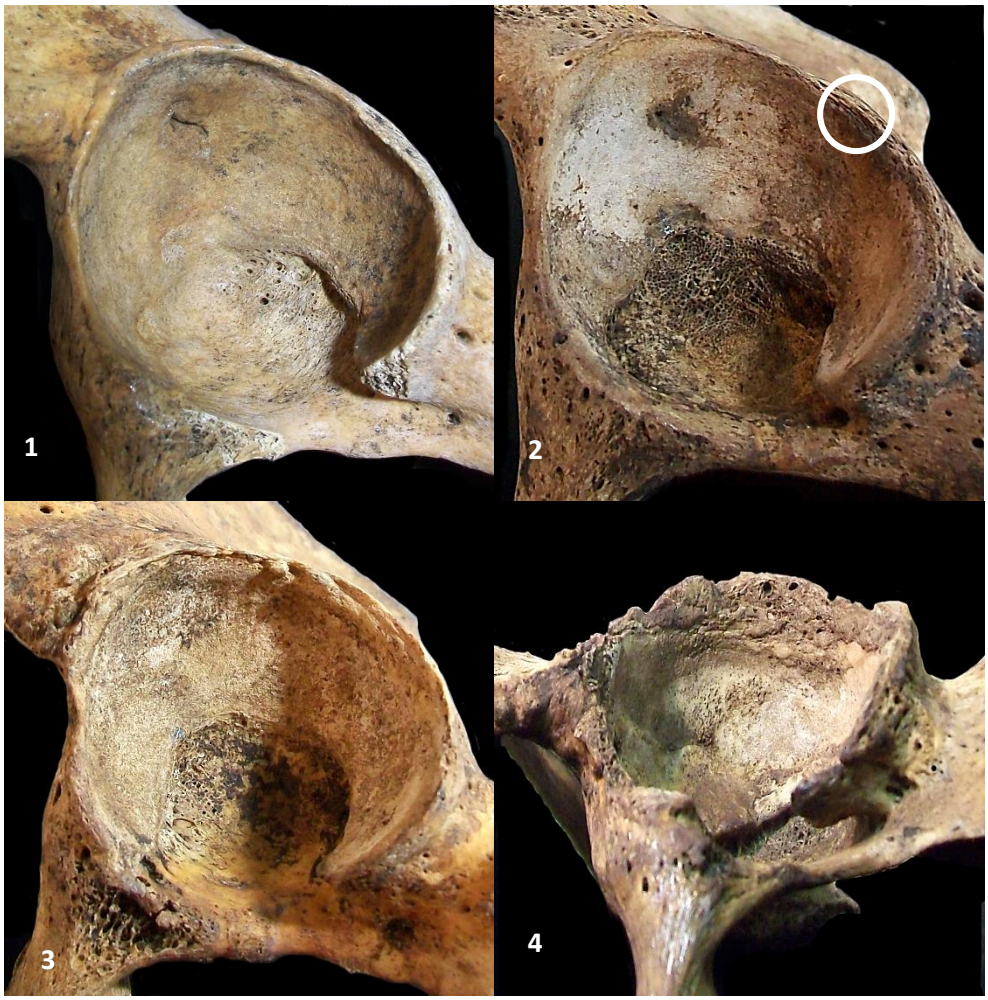

Figure 1. Acetabular rim shape metamorphosis representing the four stages: 1) blunt-edged; 2) blunt-edged with localized osteophytes; 3) crested acetabular rim; 4) high crested acetabular rim.

Acetabular rim porosity

With age, porosity may emerge at the acetabular rim (Figure 2). Younger individuals usually exhibit a round and smooth acetabular rim without porosities. Over time, microporosity may emerge, followed by the appearance of macroporosity. In older

individuals microporosity and macroporosity may increase, potentially leading to bone destruction, and it can even extend into the lunate surface. This criterion was evaluated with the following stages:

Stage 1 – Micro- and macroporosity are absent

Stage 2 - Microporosity (pores with regular borders and less than 1 mm in diameter) is present at the acetabular rim, even though, the acetabular rim is still round, dense and without bone destruction

Stage 3 - Rough acetabular rim with some macroporosity (pores with more than 1 mm in diameter and regular borders)

Stage 4 - Acetabular rim is very porous, with microporosity and macroporosity, with or without bone destruction, which can include the lunate surface

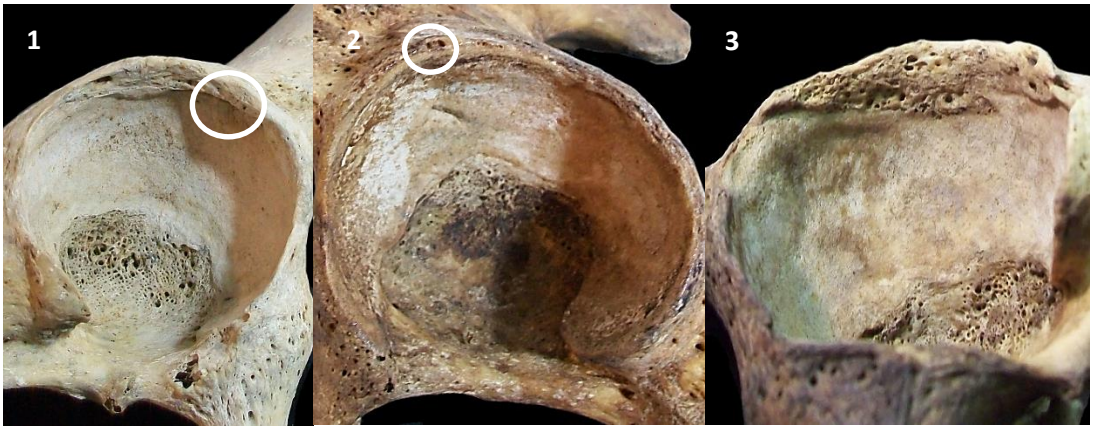

Figure 2. Acetabular rim porosity: 1) microporosity; 2) macroporosity; 3) porous acetabular rim.

Acetabular groove

An acetabular groove (Figure 3) can appear with age and occupy partial or entire acetabular rim. The groove creates discontinuity between the acetabular rim and lunate surface, since it appears below the internal margin of the acetabular rim. Usually, in younger individuals the acetabular groove is absent, however, with age a small and shallow groove may emerge, which might become more pronounced. Acetabular groove was analysed according to the following stages:

Stage 1 - Absent: no groove is present

Stage 2 - Slight groove: short or shallow groove surrounding part or almost the entire acetabular rim

Stage 3 - Pronounced groove: Prominent groove surrounding a large part or nearly all of the acetabular rim and tissue discontinuity between acetabular rim and lunate surface to a large bone formation

Figure 3. Acetabular groove: 1) small groove; 2) pronounced groove.

***Acetabulum* apex activity**

The acetabular apex is located on the posterior horn of the lunate surface and undergoes metamorphosis with age. Typically, in younger individuals the apex is rounded and smooth to the touch. With age, a small spicule can form which increase in size, and in some cases can even cover the whole horn of the lunate surface, or even fuse with the anterior horn of the lunate surface. The scoring system followed for the apex activity is (Figure 4):

Stage 1 – Smooth and round apex without an osteophyte

Stage 2 - Moderate apex activity: the apex presents a small osteophyte with ≤ 2 mm in size

Stage 3 - Pronounced apex activity: the osteophyte is larger than 2 mm

Figure 4. Acetabulum apex activity stages: 1) smooth and round apex; 2) moderate apex activity; 3) pronounced apex activity.

Activity on the outer edge of the acetabular fossa

The outer edge of the acetabular fossa is initially smooth to the touch without extra bone formation. With age, a small bone crest starts to develop towards the lunate surface. At this stage the increment of the bony crest is not visible, but it can be felt (it is more rough to the touch when moving the finger along the outer edge to the acetabular fossa). Bone activity on the outer edge can continue to increase, becoming more pronounced and visible and even cover part of the acetabular fossa. The development of the activity on the outer edge of the acetabular fossa was evaluated with the following stages (Figure 5):

Stage 1 - The outer edge is smooth (it is possible to move a finger smoothly on the outer edge towards the acetabular fossa)

Stage 2 - Minute bone growth can be felt on <1/4 of the outer edge

Stage 3 - Bone growth on >1/4 of the outer edge which can be felt

Stage 4 - Pronounced activity, with visible bone growth covering part of the fossa parallel to the outer edge

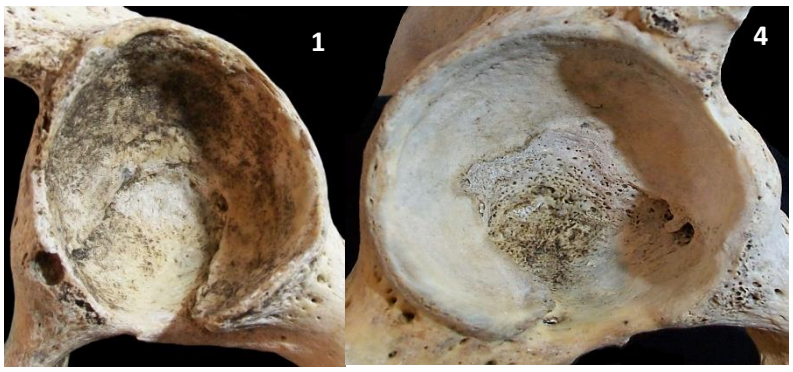

Figure 5. Visible stages (stage 1 - smooth and stage 4 – pronounced activity) for the outer edge of the acetabular fossa.

Activity and porosity of the acetabular fossa

The acetabular fossa also suffers changes with age, with the loss of its dense aspect due to bone destruction and proliferation. In young individuals, the acetabular fossa is composed of smooth and dense bone with some peripheral macroporosity, and is almost level with the lunate surface. Over time, the acetabular fossa changes to a more internal position, and microporosity appears. It can be followed by the emergence of macroporosity throughout the acetabular fossa. Bone formation can occur in older individuals, which may even obliterate the acetabular fossa. This criterion (Figure 6) was evaluated according to the following stages:

Stage 1 - Acetabular fossa is smooth, dense and with peripheral macroporosity. The acetabular fossa is almost level with the lunate surface

Stage 2 - Present of microporosity

Stage 3 - Present of a few macroporosity outside the peripheral area of the acetabular fossa

Stage 4 - Cortical bone destruction with more macroporosity

Stage 5 - Obliteration of the acetabular fossa due to pronounced bone proliferation

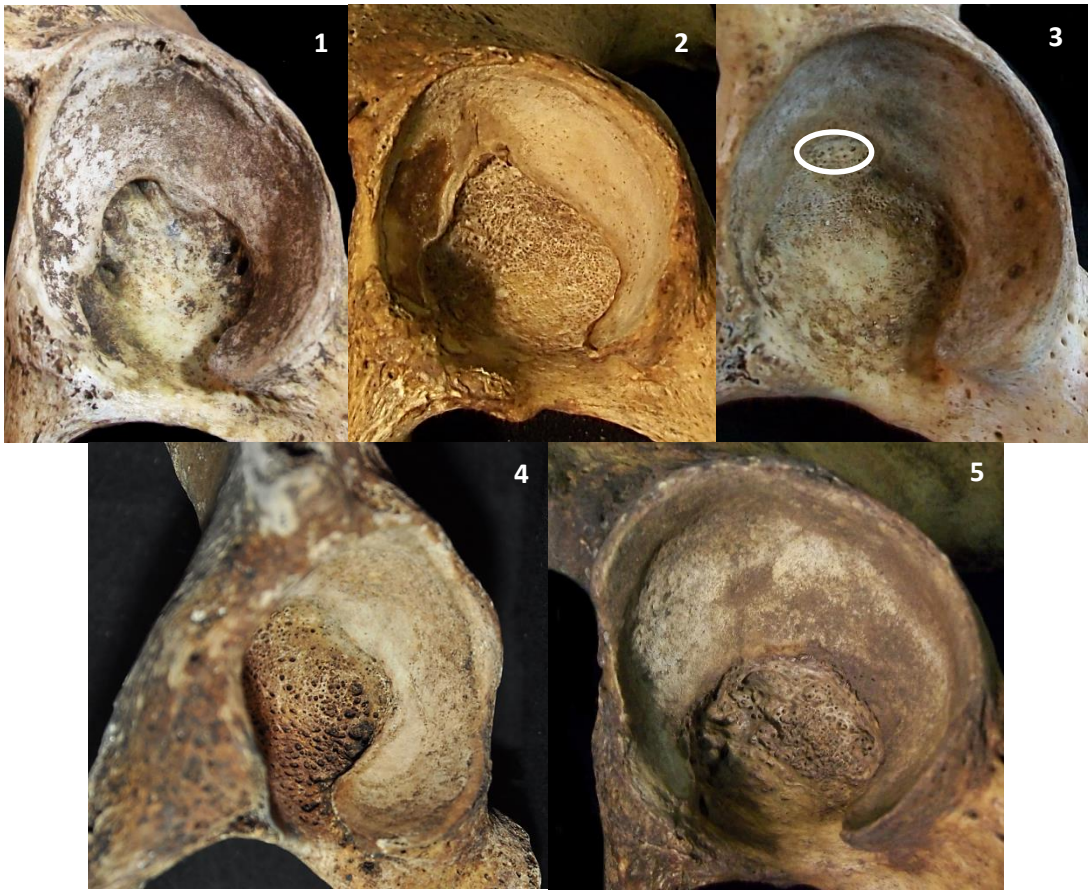

Figure 6. Representation of the five stages for the metamorphosis at the acetabular fossa: 1) smooth and dense; 2) presence of microporosity; 3) presence of few macroporosity pores; 4) cortical bone destruction 5) pronounced bone proliferation.

Iliac auricular surface

Eight morphological indicators of the auricular surface were analysed:

Transverse organization (billowing + striae)

Transverse organization (Figure 7) consists of billowing (ridges + furrows) and striae displayed medial-laterally across the auricular surface (Lovejoy *et al.* 1985b). Billowing is bigger than the striae, however smaller compared to the pubic symphysis billowing (Lovejoy *et al.* 1985b). Billowing emerges in younger individuals, but with time is substituted by striae, followed by the disappearance of both features leading to an amorphous auricular surface (Lovejoy *et al.* 1985b). Using the Buckberry and Chamberlain (2002) method it is difficult to make a distinction between billowing and striae, as they only consider this structure as transverse organization. The same principle was followed in the present study, with the following stages:

Stage 1- Transverse organization present in more than half of the auricular surface area

Stage 2- Transverse organization present in less than half of the auricular surface area

Stage 3- Transverse organization absent

Figure 7. Transverse organization at the iliac auricular surface.

Fine granularity

Fine granularity (Figure 8) entails the presence of grains with 0.5 mm in diameter spread on the auricular surface (Lovejoy *et al.* 1985b; Buckberry and Chamberlain 2002). Usually a more fine granularity texture it is associated with younger individuals, since with age it can be replaced by coarse granularity and then by dense bone. However, older individuals may retain fine granularity, although in smaller quantities compared to younger individuals (Lovejoy *et al.* 1985b; Buckberry and Chamberlain 2002). This criterion was evaluated with three stages:

Stage 1 - Fine granularity present in more than half of the auricular surface area, with or without coarse granularity and/or dense bone

Stage 2 - Fine granularity present in less than half of the surface area, with coarse granularity and/or dense bone

Stage 3 - Fine granularity is absent (presence of coarse granularity and/or dense bone)

Figure 8. Fine granularity at the iliac auricular surface.

Coarse granularity

Coarse granularity (Figure 9) provides a rough appearance to the auricular surface, with grains larger than 0.5 mm in diameter (Lovejoy *et al.* 1985b; Buckberry and Chamberlain 2002). Lovejoy *et al.* (1985b) compare a coarse granularity texture to fine grain sandpaper. The scoring system followed for the coarse granularity was:

Stage 1 - Absent with only fine granularity present

Stage 2 - Coarse granularity present in less than half of the surface area, with fine granularity and/or dense bone

Stage 3 - Coarse granularity present in more than half of the surface area, with or without fine granularity and/or dense bone

Figure 9. Coarse granularity at the iliac auricular surface.

Dense bone

Usually in older individuals, the texture changes in certain areas, with the

disappearance of granularity the bone surface becomes dense, smoother and compact (Lovejoy *et al.* 1985b; Buckberry and Chamberlain 2002). The development of dense bone (Figure 10) was evaluated with the following stages:

Stage 1- Absent with only fine and/or coarse granularity

Stage 2- Dense bone present in less than half of the surface area, with fine and/or coarse granularity

Stage 3- Dense bone present in more than half of the area, with or without fine and/or coarse granularity

Figure 10. Dense bone at the iliac auricular surface.

Microporosity

Surface area shows pores with < 1 mm diameter and with a regular border and cavity. Usually, micropores may be clustered in a smaller portion of the area or disperse across the entire surface (Buckberry and Chamberlain 2002). Microporosity must be distinguished from porosity resulting from a pathological condition, such as

hyperostosis (Lovejoy *et al.* 1985b), or from *post-mortem* destruction (holes with irregular border without bone formation and with visible trabecular bone (Buckberry and Chamberlain 2002). For this trait, it was evaluated using the following scoring system:

Stage 1 - Absent

Stage 2 - Microporosity present in one demiface

Stage 3 - Microporosity present in both demifaces

Macroporosity

Macroporosity (Figure 11) are bone perforations with > 1 mm in diameter (Lovejoy *et al.* 1985b). The macroporosity have a regular border and cavity, as seen in microporosity, opposing the irregular border without bone formation characteristic of *post-mortem* destruction (Buckberry and Chamberlain 2002; Campanacho 2010). Macroporosity should not be confused with cortical defects - areas without cortex bone formation – unrelated with age (Buckberry and Chamberlain 2002). Macroporosity can be circumscribed to an area or can be disperse along the surface (Buckberry and Chamberlain 2002). As in Campanacho (2010), macroporosity was recorded when one or more macroporous were present, if exhibiting regular margins and cavities, and thus that were distinct from cortical defects and *post-mortem* holes. Macroporosity was recorded according to the following stages:

Stage 1 - Macroporosity is absent

Stage 2 - Macroporosity present in one demiface

Stage 3 - Macroporosity present in both demifaces

Figure 11. Macroporosity at the auricular surface of the ilium.

Apical area

In Campanacho (2010), the apex was determined as the intersection between the termination of the *arc composé* at the auricular surface (Santos 1995) and posterior of the arcuate line (Lovejoy *et al.* 1985b). However, Campanacho (2010), by re-analysing 20 auricular surfaces at the Identified Skeletal Collection from the University of Coimbra, obtained a high intra-observer error (Cohen's Kappa = 0.23, indicating a fair agreement between both observations). The observation error may be due to the difficulty to determine the precise localization of the apex, since it is a small point, and the arcuate line seems to be divided into two posterior ends in a great number of cases. Thus, Campanacho (2010) suggested that the apical area should be analysed as the zone between the two posterior ends of the arcuate line. This suggestion is followed in the present investigation. Usually the apical zone (Figure 12) is distinct and regular in younger individuals, however, with age, it becomes irregular, and it may even present lipping (Lovejoy *et al.* 1985b). The scoring system followed for the apical area was:

Stage 1 - Apical area is distinct and regular

Stage 2 - Apical area is irregular with or without lipping

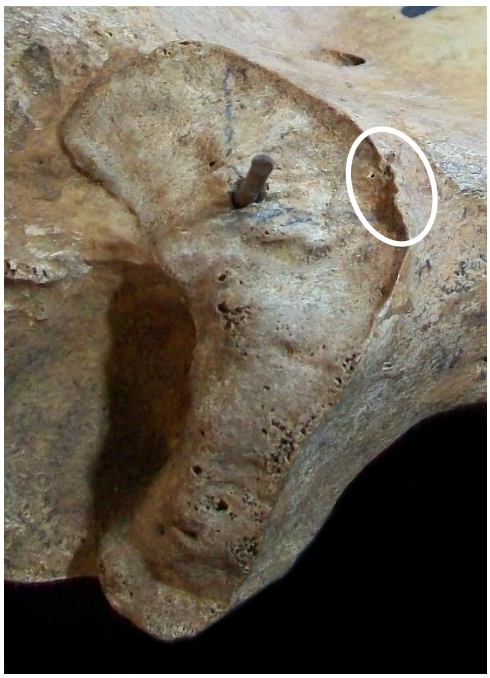

Figure 12. Irregular apical area at the iliac auricular surface.

Lipping

Lipping consists of bone extension from the auricular surface margin and usually appears in older individuals. This trait was recorded independently of expression degree, according to the following stages:

Stage 1 – Lipping is absent

Stage 2 – Lipping is present

Pubic symphysis

Sixteen degenerative characteristics associated with age were observed on the pubic bone:

Billowing on the pubic symphysis surface

Billowing (Figure 13) consists of transverse ridges and furrows on the pubic symphysis surface (Todd 1920, 1921a), characteristic of typical epiphysis plates (Meindl *et al.* 1985). This pattern can extend to the pubic tubercle area in younger individuals when the superior extremity is not formed (Brooks and Suchey 1990). In younger individuals the billowing (ridges and furrows) are exuberant and distinct (Todd 1920). Billowing fades with age, in size and area, due to bone deposition until its total disappearance in older individuals (Todd 1920, 1921a), although, vestiges of ridges and furrows may be retained in some individuals (Meindl *et al.* 1985). Mckern and Stewart (1957) state that a longitudinal groove or ridge divides the billowing patter in a dorsal and ventral demifaces. For this trait, the following scoring system was used:

Stage 1 - Billowing (ridges and furrows) present in more than half of the pubic symphysis surface area

Stage 2 - Billowing present in less than half of the pubic symphysis surface area

Stage 3 - Absence of billowing

Figure 13. Billowing at the pubic symphyses (left image: medial view; right image: dorsal view).

Inferior extremity of the pubic symphysis

Before the appearance of the inferior extremity, the symphyseal face limit is indistinguishable from the pubic ramus. However, with time bone deposition creates an inferior margin creating the inferior extremity of the pubic symphysis, with or without ossific nodules separating the face from the pubic ramus (Todd 1920, 1921a; Hanihara and Suzuki 1978; Brooks and Suchey 1990). With age the inferior extremity tends to enlarge (Hanihara and Suzuki 1978), a trait that is different between the sexes; in males it blends with the convexity of the pubic ramus and in females is accentuated by the concavity of the ramus (Meindl *et al.* 1985). The scoring system (Figure 14) followed for the inferior extremity was:

Stage 1 - Inferior extremity absent

Stage 2 - Inferior extremity present in less than half of the inferior margin

Stage 3 - Inferior extremity present in more than half of the inferior margin

Figure 14. Complete inferior extremity at the pubic symphysis.

Superior extremity of the pubic symphysis

Initially the superior extremity of the symphyseal face is absent on younger individuals, with age bone deposition in the superior margin leads to the formation of the superior extremity (Todd 1920, 1921a). The superior extremity is presented at the Figure 15. Ossific nodules can also delimitate the superior border (Todd 1921b). The development of the superior extremity was scored with the following stages:

Stage 1 - Absent

Stage 2 - Superior extremity present in less than half of the superior border

Stage 3 - Superior extremity present in more than half of the superior border

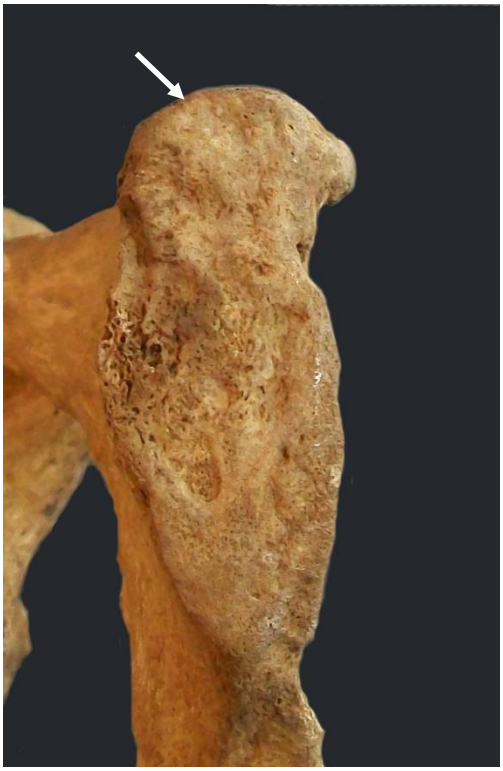

Figure 15. Superior extremity at the pubic symphysis.

Dorsal plateau of the pubic symphysis

In younger adults, the dorsal plateau (Figure 16) is non-existent, though, with time billowing breaks down and bone deposits on the dorsal border leading to the

formation of this trait (Todd 1920, 1921a; Mckern and Stewart 1957). For the dorsal plateau a three stage scoring system was used:

Stage 1 – Dorsal plateau is absent

Stage 2 - Dorsal plateau present in less than half of the dorsal border

Stage 3 - Dorsal plateau present in more than half of the dorsal border

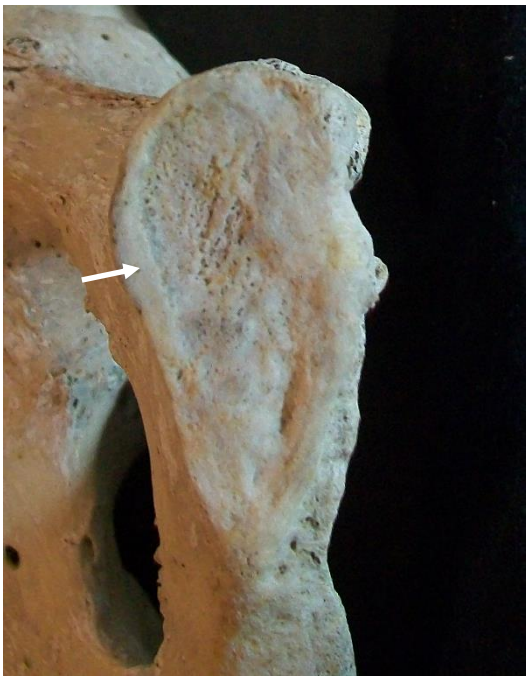

Figure 16. Dorsal plateau at the pubic symphysis.

Ventral rampart of the pubic symphysis

Bone deposition on ventral border leads to the ventral rampart formation (Figure 17), and there can be ossific nodules forming on the ventral rampart (Todd 1920, 1921a; Brooks and Suchey 1990). For the ventral rampart of the symphyseal face, the following scoring system was created:

Stage 1 - Absent

Stage 2 - Ventral rampart present in less than half of the ventral border

Stage 3 - Ventral rampart present in more than half of the ventral border

Figure 17. Ventral rampart at the pubic symphysis.

Symphyseal rim

The symphyseal rim formation (Figure 18) consists of the complete delineation of the pubic symphysis face, due to bone deposition in superior, inferior, dorsal and ventral margins (Todd 1920, 1921a). Symphyseal rim development was recorded according to four stages:

Stage 1 - Absent

Stage 2 - Margin present in less than half of the area but is not complete

Stage 3 - Margin present in more than half of the area, but is not complete

Stage 4 - Symphyseal rim margin complete. In case of presence of erosion, it was considered that the symphyseal rim was complete and suffered destruction (Campanacho 2010)

Figure 18. Symphyseal rim stages: 1) absent; 2) present in <50% of the area; 3) present > 50% of the area, but not complete; 4) complete symphyseal rim.

Symphyseal face shape

The shape of the symphyseal face changes over time. In younger adults, it is convex due to the presence of a billowing system (Brooks and Suchey 1990). With age, the billowing system disappears, due to bone deposition, leading to the flattening of the symphyseal face (Todd 1920, 1921a; Brooks and Suchey 1990). This is followed by the depression of the face, and usually tends to occur in older individuals (Brooks and Suchey 1990). However, depression of the symphyseal face should not be mistaken with smaller concavities (Figure 19) that may occur on the articulation surface, since they are just morphological variations not associated with age (Campanacho 2010). For the symphyseal face the following scoring system was used (Figure 20):

Stage 1 - Symphyseal face is convex due to the presence of exuberant and distinct ridges and furrows

Stage 2 - Symphyseal face is convex and flattened (the face is not totally flattened due to the presence of a few ridges and furrows)

Stage 3 - Symphyseal face is flattened, without face depression

Stage 4 - Symphyseal face with mild depression

Stage 5 - Symphyseal face with marked depression

Figure 19. Concavity distinct from symphyseal face depression at pubic symphysis (adapted from Campanacho 2010).

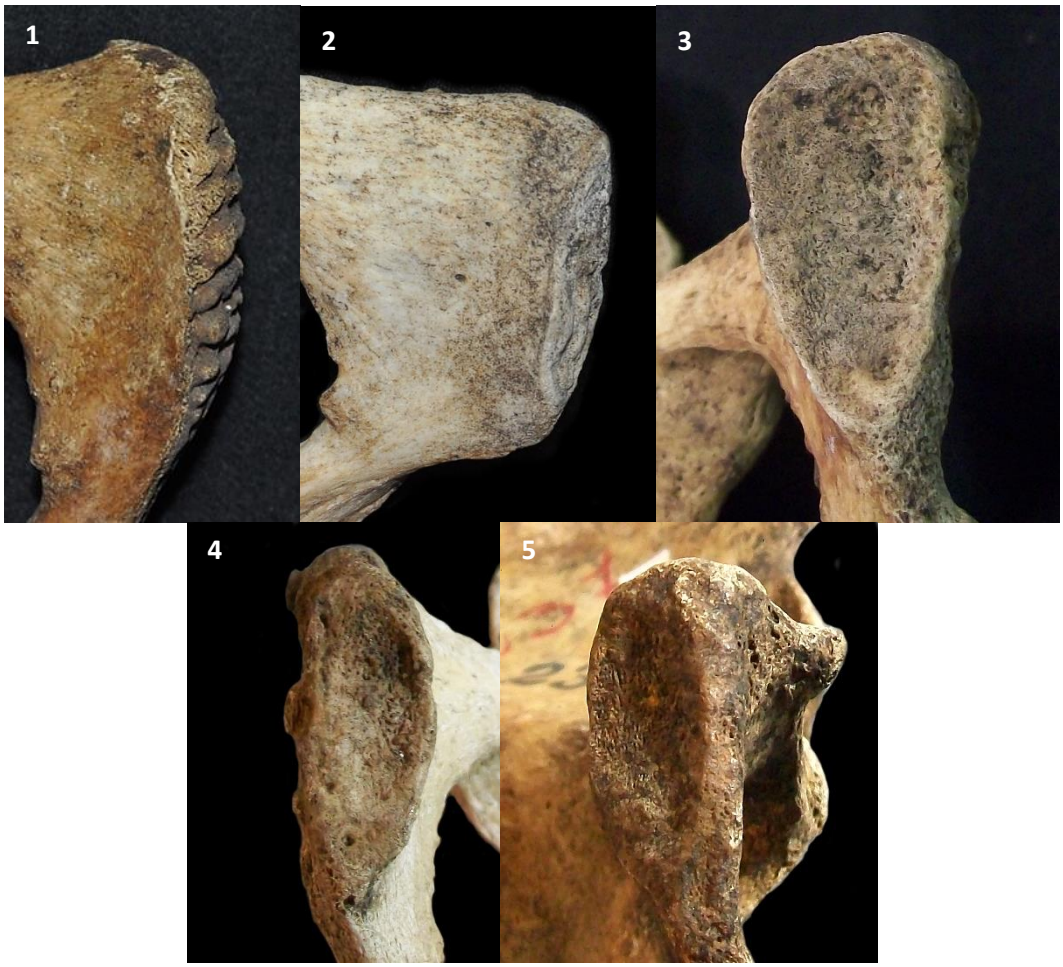

Figure 20. Symphyseal face depression stages: 1) Convex face; 2) Convex and flat face; 3) Flat face; 4) Face with mild depression; 5) Face with marked depression.

Erosion of the symphyseal face

Erosion (Figure 21) consists of the partial or total absence of subchondral bone, without bone formation, creating surface breakdown. Usually, the lack of subchondral bone starts on the inferior area (Meindl *et al.* 1985). Normally, the erosion of the symphyseal face occurs in older individuals (Meindl *et al.* 1985) and according to Berg (2008) it is possible that bone breakdown in women may be associated with osteopenia and osteoporosis. However, erosion of the symphyseal face must be distinguished from osteolytic lesions, which are less diffuse and occupy a smaller area (Campanacho 2010). Osteolytic lesions can be of three types, active, moderately active and slowly active or inactive (Ortner and Putschar 1985). According to Ortner and Putschar (1985) an active lesion will present a higher destruction, without bone formation, since trabecular bone will be visible on the lytic cavity. The boundary in a very active lesion is not sharply defined and it decays faster. A moderate active osteolytic lesion will be less destructive and slower compare with a more active one and it may have some bone formation. In a moderate lesion, the boundary is sharply defined. A slower active lesion or inactive lesion corresponds respectively, to a slower destruction or to the stop of the destruction activity after an acute phase. A slower or inactive lytic lesion exhibits dense bone formation without trabecular bone visible. Erosion of the symphyseal face was recorded according to three stages:

Stage 1 - Absent

Stage 2 - Erosion of the symphyseal face present in less than half of the articulation area

Stage 3 - Erosion of the symphyseal face present in more than half of the articulation area

Figure 21. Erosion of the symphyseal face at pubic symphysis.

Erosion of the symphyseal rim

As in erosion of the symphyseal face, erosion of the rim (Figure 22) corresponds to the symphyseal breakdown, due to wear between both symphysis surfaces, and usually appears in older individuals (Todd 1920). It should not be mistaken with osteolytic lesions (Campanacho 2010). For this morphological indicator the following stages were established:

Stage 1 - Absent

Stage 2 - Erosion present in less than half of the symphyseal rim

Stage 3 - Erosion present in more than half of the symphyseal rim

Figure 22. Erosion of the symphyseal rim at pubic symphysis.

Dorsal body of the pubic bone

Hartnett (2007, 2010) reports alterations with age on the dorsal body surface of the pubic bone. In younger individuals, the dorsal body tend to be dense, firm and smooth, with age it became porous, followed by surface roughening; in older individuals it can became coarse and irregular. For the dorsal body of the pubic bone was created the following scoring system (Figure 23):

Stage 1 - Firm, heavy, dense and smooth

Stage 2 - Firm, heavy, dense and smooth, with little porosity

Stage 3 - Roughened and becoming coarse

Stage 4 - Coarse and irregular with some bony projections

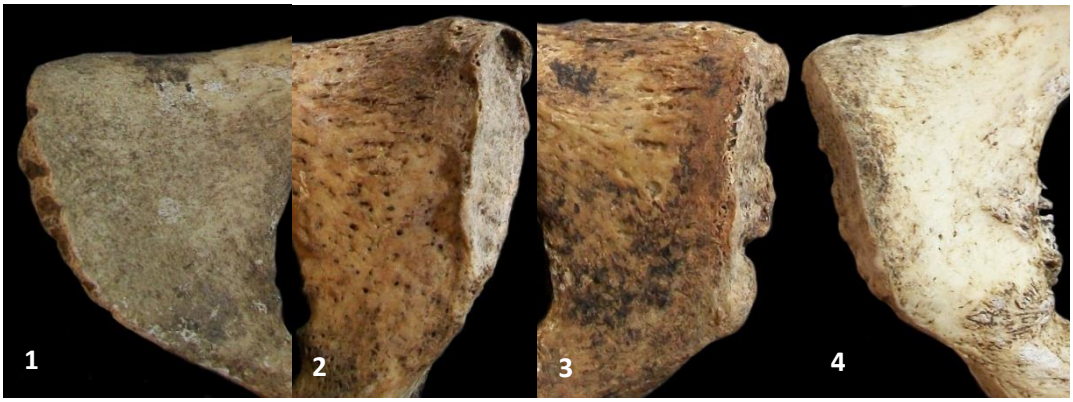

Figure 23. *Dorsal body of the pubic bone* metamorphosis stages: 1) Firm, heavy, dense and smooth; 2) Firm, heavy, dense and smooth, with little porosity; 3) Roughened and becoming coarse; 4) Coarse and irregular with some bony projections.

Ventral body of the pubic bone

With age the ventral body surface of the pubic bone becomes more elaborated (Hartnett 2007, 2010). Similar to the dorsal body, it is firm, dense and smooth in younger individuals, with time little porosity appears (Hartnett 2007, 2010). Posteriorly the surface becomes roughened and coarse and followed by the formation of bony projections (Hartnett 2007, 2010). The ventral body scoring system followed Hartnett (2007, 2010) (Figure 24):

Stage 1 - Firm, heavy, dense and smooth

Stage 2 - Firm, heavy, dense and smooth, with little porosity

Stage 3 - Roughened and becoming coarse

Stage 4 - Roughened and irregular with some bony excrescences

Stage 5 - Roughened and elaborate, with more bony excrescences

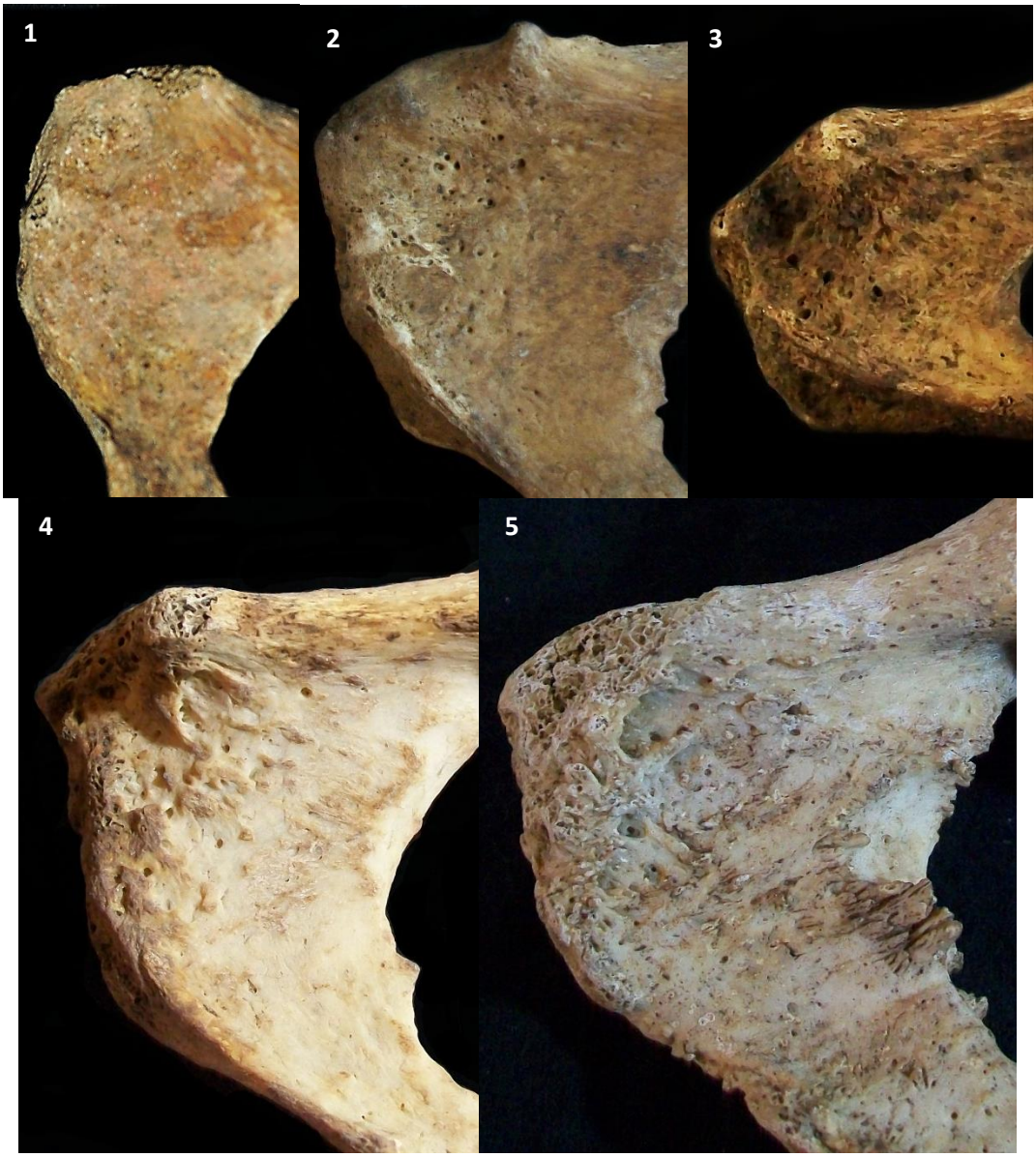

Figure 24. *Ventral body of the pubic bone* metamorphosis five stages: 1) Firm, heavy, dense and smooth; 2) Firm, heavy, dense and smooth, with little porosity; 3) Roughened and becoming coarse; 4) Roughened and irregular with some bony excrescences; 5) Roughened and elaborate, with more bony excrescences.

Ventral bevelling of the pubic symphysis

Ventral bevelling (Figure 25) is represented as a slope close to the ventral rampart. Usually it forms from the inferior area to the superior area, although, in most individuals, the ventral bevelling is not completely form on the superior part (Meindl *et al.* 1985). This trait starts to form in younger individuals, even before the appearance of the ventral rampart (Todd 1921b). For the ventral bevelling was only

recorded the trait's absence or presence, with the following scoring system:

Stage 1 - Ventral bevelling is absent

Stage 2 - Ventral bevelling is present

Figure 25. Ventral bevelling at pubic symphysis.

Ligamentous outgrowths on the ventral bevelling

In older individuals, there may appear ligamentous outgrowths (bony projections) on the ventral bevelling (Figure 26; Todd 1920; Brooks and Suchey 1990). Ligamentous outgrowths on the ventral bevelling were recorded as absence or present:

Stage 1 - Absent

Stage 2 - Present (independently of the degree of activity)

Figure 26. Ligamentous outgrowths on the ventral bevelling.

Pubic tubercle

In younger individuals, the pubic tubercle is attached to the symphyseal face, since the superior extremity is not formed or it is partially present (Brook and Suchey 1990). With the completion of the superior extremity, the pubic tubercle becomes separated from the symphyseal face (Brook and Suchey 1990). This morphological trait was evaluated by the phases (Figure 27):

Stage 1 - The pubic tubercle is attached to the symphyseal face (the superior extremity is absent)

Stage 2 - The pubic tubercle is partially separated from the symphyseal face (the superior extremity is present but it is incomplete)

Stage 3 - The pubic tubercle is separated from the symphyseal face (the superior extremity is complete)

Figure 27. The three stages recorded for the trait pubic tubercle: 1) attached to the symphyseal face; 2) partially separated from the symphyseal face; 3) separated from the symphyseal face.

Medial aspect of the obturator foramen

Hartnett (2007, 2010) evaluated the age modifications that occur on the medial aspect of the *obturator foramen* but only the medial section was analysed. Bony outgrowth (Figure 28) starts on the medial aspect of the *obturator foramen* and become more elaborated with age (Hartnett 2007, 2010). Even though the author had access to the complete *os coxae* only the medial aspect of the *obturator foramen* were analysed according to the stages:

Stage 1 - Absence of bony projections at the medial aspect of the *obturator foramen*

Stage 2 - Small bony projections at the medial aspect of the *obturator foramen*

Stage 3 - Bigger bony projections are present at the medial aspect of the *obturator foramen*

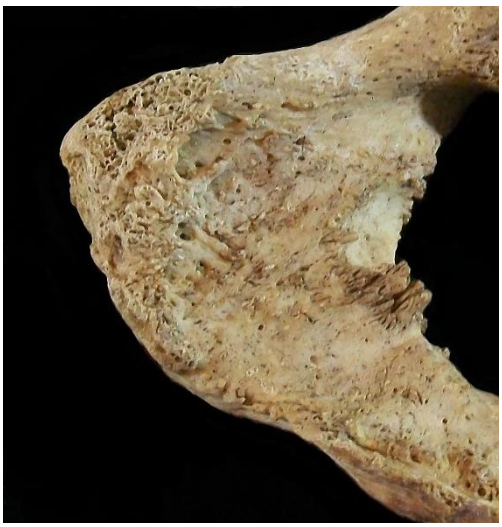

Figure 28. Bony outgrowth (stage 3) on the medial aspect of the *obturator foramen*.

APPENDIX 2 | ALTERATION OF THE SCORING SYSTEM FOR THE DEGENERATIVE TRAITS SCORES

In the present appendix, it is presented the alterations made to the original scoring system used in the current analysis during the direct record of the traits in each of the pelvic joints (as explained in section 2.2.1.1.).

Acetabulum

Trait	Original scoring system	New scoring system
Acetabular groove	1 - Absent 2 - Short and shallow 3 - Pronounced	1 - Absent 2 - Present
Acetabular rim porosity	1 - Absent 2 - Smooth with microporosity 3 - Rough rim with macroporosity 4 - Destructed acetabular rim	1 - Absent 2 - Smooth with microporosity to rough rim with macroporosity 3 - Destructed acetabular rim
Acetabular fossa	1 - No activity 2 - Microporosity is present 3 - Macroporosity is present 4 - Cortical bone destruction 5 - Bone proliferation	1 - No activity 2 - Microporosity and macroporosity are present 3 - Cortical bone destruction 4 - Bone proliferation

Iliac auricular surface

Trait	Original scoring system	New scoring system
Transverse organization	1 - Present in >50% 2 - Present in <50% 3 - Absent	1 - Present 2 - Absent
Macroporosity	1 - Absent 2 - Present on one demiface 3 - Present on both demifaces	1 - Absent 2 - Present
Microporosity*	1 - Absent 2 - Present in one demiface 3 - Present in both demifaces	1 - Absent 2 - Present

* The scores were changed to diminish the intra-observer error

Pubic symphysis

Trait	Original scoring system	New scoring system
Billowing	1 - Present >50% 2 - Present <50% 3 - Absent	1 - Present 2 - Absent
Inferior extremity	1 - Absent 2 - Present <50% 3 - Present >50%	1 - Absent 2 - Present
Dorsal plateau	1 - Absent 2 - Present <50% 3 - Present >50%	1 - Absent 2 - Present
Dorsal body of the pubic bone	1 - Firm, heavy, dense and smooth 2 - Firm, heavy, dense, smooth and little porosity 3 - Roughened and becoming coarse 4 - Coarse and irregular	1 - Firm, heavy, dense and smooth 2 - Firm, heavy, dense, smooth and little porosity 3 - Roughened and becoming coarse to already coarse and irregular
Ventral body	1 - Firm, heavy, dense and smooth 2 - Firm, heavy, dense, smooth and little porosity 3 - Roughened and becoming coarse 4 - Roughened, irregular with some bone excrements 5 - Roughened and elaborate	1 - Firm, heavy, dense and smooth 2 - Firm, heavy, dense, smooth and little porosity 3 - Roughened and becoming coarse 4 - Roughened, irregular with some bone excrements and/or elaborate
Pubic tubercle	1 - Attached to the face 2 - Partially separated from the face 3 - Separated from the face	1 - Attached to partially attached to the face 2 - Separated from the face
Erosion on the symphyseal face	1 - Absent 2 - Present <50% 3 - Present >50%	1 - Absent 2 - Present
Erosion on the symphyseal rim	1 - Absent 2 - Present <50% 3 - Present >50%	1 - Absent 2 - Present
Symphyseal face shape	1 - Convex 2 - Convex and flat 3 - Flat 4 - Mild depression 5 - Marked depression	1 - convex, but may show signs of becoming flat in some area 2 - Flat 3 - Depressed

APPENDIX 3 | DESCRIPTIVE STATISTICS FOR THE COIMBRA COLLECTION

Age descriptive statistics, in years, for the acetabulum, iliac auricular surface and pubic symphyseal traits: number of individuals (N), minimum (min), maximum (max), mean, median, standard deviation (SD) age and 95% confidence interval for the mean (95% CI). Cases were highlighted in bold when a more advanced stage showed a lower age mean and/or median when compared with the previous stage.

Acetabulum

Total sample (without group division): age descriptive statistics for the acetabular traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	147	18	88	34	32	13.3	32-37
	2	150	19	84	49	50	15.1	46-51
Acetabular rim shape	1	27	18	41	26	24	6.7	23-29
	2	73	19	63	37	36	11.4	34-39
	3	67	25	88	50	49	14.9	47-54
	4	40	38	87	59	58	11.2	56-63
Acetabular rim porosity	1	134	18	75	39	38	14.5	37-42
	2	21	28	77	55	56	11.7	50-61
	3	17	39	88	62	66	16.1	54-70
Apex activity	1	91	18	70	31	28	11.3	29-34
	2	77	20	88	48	48	16.5	45-52
	3	26	26	75	59	58	10.3	55-63
Outer edge of the acetabular fossa	1	25	18	62	34	33	11.2	29-38
	2	76	18	77	40	38	15.2	37-44
	3	135	19	88	42	39	16.5	39-44
	4	38	20	87	48	46	17.0	43-54
Acetabular fossa	1	11	21	77	37	35	16.9	26-48
	2	99	18	84	40	38	15.9	36-43
	3	83	19	75	40	37	15.1	36-43
	4	61	19	88	46	45	17.5	41-50

Shorter height group: age descriptive statistics for the acetabular traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	57	19	88	37	34	14.4	33-40
	2	71	19	77	48	47	15.8	44-51
Acetabular rim shape	1	14	19	41	27	24	7.2	23-31
	2	33	19	60	36	36	10.6	33-40
	3	39	26	88	51	47	14.8	46-55
	4	14	39	77	59	58	12.4	52-66
Acetabular rim porosity	1	65	19	75	39	38	13.8	36-42
	2	10	37	77	58	60	13.0	49-67
	3	7	39	88	61	60	17.6	45-77
Apex activity	1	48	19	70	35	34	12.2	32-39
	2	34	20	88	48	46	16.4	42-54
	3	5	54	75	63	60	8.8	—
Outer edge of the acetabular fossa	1	11	21	62	37	34	12.2	29-45
	2	40	19	77	41	38	15.4	36-46
	3	58	19	88	43	40	17.1	38-47
	4	12	26	68	47	46	13.7	39-56
Acetabular fossa	1	4	21	77	39	28	26.3	—
	2	39	20	77	40	38	13.4	35-44
	3	38	19	75	41	39	16.2	35-46
	4	26	19	88	44	43	18.1	37-52

Taller height group: age descriptive statistics for the acetabular traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	62	19	75	35	32	12.3	32-38
	2	57	21	84	49	50	15.1	45-53
Acetabular rim shape	1	9	19	39	27	26	6.3	22-32
	2	32	20	62	36	35	11.1	32-40
	3	23	25	75	49	49	16.7	42-57
	4	15	40	73	59	57	9.7	53-64
Acetabular rim porosity	1	53	19	75	40	36	15.4	35-44
	2	7	28	57	48	53	10.3	—
	3	7	40	73	58	67	16.0	43-73
Apex activity	1	26	19	42	27	26	6.2	25-30
	2	32	21	75	47	48	15.5	42-53
	3	16	26	73	57	57	11.6	51-63
Outer edge of the acetabular fossa	1	13	21	55	32	30	9.6	26-38
	2	23	20	67	41	40	14.1	35-47
	3	51	19	84	42	38	15.5	37-46
	4	19	20	75	47	40	19.3	38-57
Acetabular fossa	1	6	21	55	36	37	12.3	23-49
	2	38	20	84	42	38	17.0	36-47
	3	31	23	72	**39**	**33**	12.9	34-43
	4	25	19	75	47	53	16.5	40-54

Lighter group: age descriptive statistics for the acetabular traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	66	18	88	36	34	14.5	32-39
	2	70	19	77	47	49	14.4	44-51
Acetabular rim shape	1	16	19	41	26	25	7.0	23-30
	2	32	19	63	36	34	10.8	32-40
	3	43	26	88	51	50	13.9	47-55
	4	14	41	87	60	57	12.6	53-68
Acetabular rim porosity	1	72	19	75	39	38	13.9	36-42
	2	10	46	77	58	58	9.9	51-65
	3	6	41	88	69	70	17.9	50-88
Apex activity	1	47	19	64	32	30	10.8	29-36
	2	37	20	88	51	50	17.6	45-56
	3	9	50	73	61	58	8.1	54-67
Outer edge of the acetabular fossa	1	15	21	62	37	34	12.3	30-44
	2	38	19	77	41	39	14.0	36-45
	3	62	19	88	41	40	16.3	37-45
	4	14	26	87	56	54	18.2	45-66
Acetabular fossa	1	5	21	55	34	34	13.9	—
	2	47	18	77	39	38	14.7	35-43
	3	34	19	70	43	41	14.8	38-48
	4	27	19	88	44	40	20.8	35-52

Heavier group: age descriptive statistics for the acetabular traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	57	19	66	35	33	11.0	32-38
	2	56	21	77	50	51	14.9	46-54
Acetabular rim shape	1	6	21	39	30	30	6.1	23-36
	2	37	20	62	36	36	11.4	33-40
	3	20	25	77	49	44	17.0	41-57
	4	18	38	75	58	57	11.9	52-64
Acetabular rim porosity	1	51	20	74	40	38	14.6	36-44
	2	9	28	72	50	53	13.1	40-60
	3	10	39	75	58	66	15.2	47-69
Apex activity	1	27	19	70	33	30	12.2	28-37
	2	33	21	74	44	41	14.3	39-50
	3	12	26	75	57	57	13.2	49-65
Outer edge of the acetabular fossa	1	7	21	41	32	30	7.7	25-39
	2	27	20	77	42	38	16.7	35-48
	3	48	19	75	44	43	15.1	39-48
	4	16	20	74	43	**40**	15.5	34-51
Acetabular fossa	1	6	21	77	39	37	20.1	—
	2	33	19	74	41	37	16.4	35-47
	3	32	25	75	40	**35**	14.4	35-45
	4	26	20	74	48	49	13.5	42-53

Gracile group: age descriptive statistics for the acetabular traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	47	19	75	34	29	12.7	30-37
	2	46	19	77	46	43	16.3	42-51
Acetabular rim shape	1	9	19	39	25	21	7.1	19-30
	2	29	20	58	36	36	10.1	32-40
	3	20	25	77	49	43	16.9	41-57
	4	11	39	75	60	57	10.9	53-68
Acetabular rim porosity	1	49	19	75	39	38	15.1	35-43
	2	7	28	72	48	46	14.2	35-61
	3	6	39	75	60	67	16.0	—
Apex activity	1	29	19	59	30	28	9.5	27-34
	2	27	20	75	43	40	15.5	37-49
	3	5	53	75	65	67	9.7	—
Outer edge of the acetabular fossa	1	10	21	39	29	28	6.4	24-34
	2	22	20	77	43	41	17.0	35-51
	3	43	19	75	**38**	**36**	15.8	34-43
	4	11	20	75	41	39	16.9	30-53
Acetabular fossa	1	4	21	77	**43**	**37**	24.0	—
	2	32	20	71	36	32	14.4	31-41
	3	23	25	75	41	36	16.0	34-48
	4	22	19	75	42	40	17.1	34-50

Robust group: age descriptive statistics for the acetabular traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	53	19	88	37	37	13.1	33-40
	2	59	21	77	50	50	13.8	46-54
Acetabular rim shape	1	10	19	41	29	28	7.0	24-34
	2	29	21	62	37	33	11.4	32-41
	3	32	26	88	52	51	14.5	47-58
	4	14	40	77	56	56	11.6	50-63
Acetabular rim porosity	1	56	19	74	40	39	13.9	37-44
	2	9	46	77	58	57	10.5	50-66
	3	7	40	88	59	58	18.9	42-77
Apex activity	1	33	19	64	34	31	11.6	30-38
	2	28	21	88	50	49	15.4	44-56
	3	13	26	73	56	56	12.2	48-63
Outer edge of the acetabular fossa	1	11	21	62	40	35	12.3	32-49
	2	32	19	77	42	41	14.2	36-47
	3	45	21	88	45	43	15.0	40-49
	4	13	26	74	52	54	18.2	41-63
Acetabular fossa	1	5	21	55	35	34	13.7	—
	2	32	24	77	44	41	15.0	39-50
	3	34	19	69	**40**	**39**	13.2	36-45
	4	19	23	88	49	48	17.8	41-58

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	27	18	88	33	32	13.4	27-38
	2	27	19	74	42	40	14.6	36-48
Acetabular rim shape	1	11	19	38	26	24	6.5	22-31
	2	15	19	43	33	35	7.2	29-37
	3	17	34	88	50	48	14.5	43-58
	4	4	41	69	55	55	11.8	36-74
Acetabular rim porosity	1	39	19	74	37	37	13.1	32-41
	2	1	—	—	—	—	—	—
	3	2	41	88	65	65	33.2	—
Apex activity	1	25	19	64	32	34	11.0	28-37
	2	15	20	88	46	42	18.8	36-57
	3	1	—	—	—	—	—	—
Outer edge of the acetabular fossa	1	9	21	62	37	34	12.7	27-47
	2	14	23	53	37	38	9.1	32-42
	3	27	19	88	40	37	18.4	32-47
	4	3	26	50	40	43	12.3	—
Acetabular fossa	1	2	21	34	28	28	9.2	—
	2	24	18	74	39	38	13.4	33-44
	3	14	19	69	40	38	15.2	31-48
	4	11	19	88	**35**	**29**	20.3	21-48

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	33	19	60	32	29	11.4	28-36
	2	25	21	77	46	49	14.0	41-52
Acetabular rim shape	1	7	19	41	28	26	7.7	20-35
	2	28	20	60	37	37	11.9	33-42
	3	11	25	77	47	45	17.7	35-59
	4	5	49	60	56	57	4.1	—
Acetabular rim porosity	1	37	19	74	37	36	13.0	33-41
	2	6	28	60	46	47	11.9	33-58
	3	1	—	—	—	—	—	—
Apex activity	1	26	19	60	31	27	10.1	27-35
	2	18	21	74	46	49	13.6	39-53
	3	2	26	57	**42**	**42**	21.9	—
Outer edge of the acetabular fossa	1	4	21	49	33	30	12.0	—
	2	15	20	77	40	41	15.3	31-48
	3	25	19	60	**36**	**33**	12.5	31-41
	4	8	20	74	41	39	18.2	26-57
Acetabular fossa	1	2	21	77	**49**	**49**	39.6	—
	2	25	20	74	36	33	15.1	30-43
	3	16	23	57	36	33	9.6	31-41
	4	11	21	60	40	49	15.9	—

Iliac auricular surface

Total sample (without group division): age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	217	18	84	41	38	14.9	39-43
	2	19	21	69	45	47	13.7	38-51
Fine granularity	1	246	18	84	40	38	14.6	39-42
	2	13	20	72	46	47	15.4	37-55
Coarse granularity	1	5	20	46	30	23	11.5	—
	2	217	18	76	41	39	14.1	39-43
	3	13	20	72	46	47	15.4	37-55
Dense bone	1	121	19	75	42	39	13.5	39-44
	2	10	20	74	**39**	**34**	16.2	27-50
Microporosity	1	94	19	75	41	39	13.2	38-44
	2	14	29	74	47	40	15.3	38-55
Macroporosity	1	91	19	75	41	38	13.3	38-43
	2	24	29	77	50	48	13.9	44-56
Apical area	1	199	18	88	41	38	15.6	39-43
	2	46	26	77	50	51	13.7	46-54
Lipping	1	84	19	75	42	40	14.9	39-46
	2	21	20	77	55	56	17.7	46-63

Total sample (without group division): age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	117	18	88	43	40	16.8	40-46
	2	11	26	77	54	53	15.7	43-64
Male	1	82	19	72	39	37	13.4	36-42
	2	35	27	75	49	50	13.1	44-53

Shorter height group: age descriptive statistics for the auricular surface trait for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	92	19	76	41	39	14.5	38-44
	2	11	21	60	44	47	12.6	36-53
Fine granularity	1	101	19	76	41	39	14.1	38-43
	2	6	20	64	47	50	16.1	30-64
Coarse granularity	1	4	20	46	32	30	12.6	—
	2	89	20	76	42	40	14.1	39-45
	3	6	20	64	47	50	16.1	30-64
Dense bone	1	58	20	75	42	40	13.4	38-46
	2	5	20	74	**40**	**38**	20.4	—
Microporosity	1	46	20	75	42	40	13.6	38-46
	2	7	29	55	**40**	**37**	8.2	32-48
Macroporosity	1	43	20	75	40	38	13.4	36-44
	2	13	36	77	49	45	12.5	42-57
Apical area	1	104	19	88	42	39	16.0	39-45
	2	13	29	77	50	46	13.8	41-58
Lipping	1	44	20	75	42	40	14.6	38-47
	2	9	20	77	54	55	19.4	39-68

Shorter height group: age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	48	19	88	44	39	17.4	39-49
	2	6	38	70	51	51	11.8	39-64
Male	1	39	20	60	40	38	11.0	36-43
	2	15	28	67	46	42	11.1	39-52

Taller height group: age descriptive statistics for the auricular surface traits for pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	91	19	84	41	38	15.8	38-44
	2	6	28	57	39	33	13.7	—
Fine granularity	1	104	19	84	41	38	15.2	38-44
	2	7	28	72	46	41	16.1	31-60
Coarse granularity	1	1	—	—	—	—	—	—
	2	94	20	75	41	38	14.2	38-44
	3	7	28	72	46	41	16.1	31-60
Dense bone	1	47	21	75	41	38	14.7	37-45
	2	4	24	49	**33**	**30**	11.0	—
Microporosity	1	36	21	75	39	36	13.0	35-44
	2	6	30	74	55	58	19.1	—
Macroporosity	1	35	21	75	40	36	13.9	35-45
	2	10	29	74	50	49	16.8	38-62
Apical area	1	67	19	74	40	37	14.3	36-43
	2	25	27	75	50	55	14.7	44-56
Lipping	1	31	20	75	41	37	14.8	36-47
	2	9	25	74	56	56	17.7	42-70

Taller height group: age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	52	19	75	41	40	16.2	37-46
	2	2	74	77	76	76	2.1	—
Male	1	32	19	72	38	33	15.3	32-43
	2	15	27	75	50	56	15.8	42-59

Lighter group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	97	18	75	40	38	14.5	37-43
	2	12	21	69	49	51	12.9	40-57
Fine granularity	1	110	18	75	40	39	14.3	38-43
	2	6	20	64	47	50	16.1	30-64
Coarse granularity	1	4	20	46	32	30	12.6	—
	2	96	18	75	42	40	14.0	39-45
	3	6	20	64	47	50	16.1	30-64
Dense bone	1	59	20	75	43	40	13.9	39-46
	2	5	20	53	**36**	**38**	12.3	21-51
Microporosity	1	48	20	75	42	40	13.5	38-46
	2	7	29	74	47	45	14.5	34-61
Macroporosity	1	44	20	75	41	39	13.5	37-45
	2	13	38	74	51	49	10.8	45-58
Apical area	1	107	18	88	41	39	15.7	38-44
	2	15	26	75	50	51	12.8	43-57
Lipping	1	48	20	75	43	42	14.5	39-47
	2	10	20	74	49	53	17.9	36-62

Lighter group: age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	70	18	88	40	37	16.5	36-44
	2	7	26	70	48	46	14.4	34-61
Male	1	32	19	56	40	43	10.8	36-44
	2	12	29	75	48	47	12.1	40-56

Heavier group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	85	20	75	42	40	14.8	39-46
	2	6	28	57	**39**	**33**	13.7	—
Fine granularity	1	97	20	75	41	39	14.5	38-44
	2	6	28	72	49	47	15.4	32-65
Coarse granularity	1	0	—	—	—	—	—	—
	2	90	20	75	41	39	14.2	38-44
	3	6	28	72	49	47	15.4	32-65
Dense bone	1	51	21	75	41	39	13.5	38-45
	2	4	24	49	**33**	**30**	11.0	—
Microporosity	1	38	21	75	40	38	12.5	36-44
	2	6	30	74	47	38	18.5	—
Macroporosity	1	38	21	75	41	38	13.2	36-45
	2	11	29	77	48	44	17.3	36-60
Apical area	1	61	20	75	42	39	14.9	38-46
	2	26	27	77	50	53	14.8	44-56
Lipping	1	27	20	75	41	39	16.7	35-47
	2	8	32	77	61	64	16.3	47-74

Heavier group: age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	32	22	77	49	50	15.8	43-54
	2	3	53	77	68	74	13.1	—
Male	1	34	20	72	39	36	15.0	34-45
	2	19	27	67	49	55	13.9	42-56

Gracile group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	71	19	75	39	37	15.5	35-43
	2	6	21	58	39	**35**	15.5	22-55
Fine granularity	1	77	19	75	38	36	15.3	35-42
	2	5	20	57	40	40	15.8	—
Coarse granularity	1	2	20	38	29	29	12.7	—
	2	66	20	75	40	38	15.1	36-43
	3	5	20	57	40	40	15.8	—
Dense bone	1	39	20	75	40	38	14.3	35-44
	2	3	20	49	**33**	**30**	14.7	—
Microporosity	1	28	20	75	40	37	15.1	34-46
	2	4	30	67	43	37	16.6	—
Macroporosity	1	27	20	75	40	36	16.0	33-46
	2	9	35	77	49	44	13.6	38-59
Apical area	1	73	19	75	39	36	15.7	35-43
	2	13	28	77	54	56	15.0	44-63
Lipping	1	28	20	75	40	34	16.5	33-46
	2	7	20	77	50	56	22.1	30-71

Gracile group: age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	47	19	75	40	38	16.6	35-45
	2	3	70	77	74	74	3.5	—
Male	1	35	19	72	38	35	14.3	33-43
	2	12	28	75	52	54	13.9	43-60

Robust group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	82	20	74	43	41	14.5	39-46
	2	7	37	58	45	47	8.3	38-53
Fine granularity	1	94	20	74	42	40	13.2	39-45
	2	3	52	72	63	64	10.1	—
Coarse granularity	1	2	22	46	34	34	17.0	—
	2	87	20	74	42	41	13.0	40-45
	3	3	52	72	63	64	10.1	—
Dense bone	1	50	21	74	43	41	14.3	39-47
	2	4	24	40	**33**	**34**	7.4	—
Microporosity	1	41	21	72	41	39	12.9	37-45
	2	9	29	74	49	45	15.9	37-61
Macroporosity	1	39	21	72	40	39	12.5	36-45
	2	12	29	74	53	50	14.4	44-62
Apical area	1	73	19	88	44	42	14.9	40-47
	2	16	27	74	48	45	14.9	40-56
Lipping	1	37	21	70	44	46	12.5	39-48
	2	7	41	74	61	58	12.9	49-73

Robust group: age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	39	19	88	45	43	16.9	40-51
	2	3	42	58	49	46	8.3	—
Male	1	25	20	60	42	43	11.1	38-47
	2	11	27	66	44	**41**	13.5	35-53

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	37	19	74	36	35	12.6	32-41
	2	4	21	69	47	48	21.3	—
Fine granularity	1	41	19	74	37	37	13.7	33-42
	2	0	—	—	—	—	—	—
Coarse granularity	1	3	20	38	27	22	9.9	—
	2	37	19	74	38	37	13.8	34-43
	3	0	—	—	—	—	—	—
Dense bone	1	28	19	74	37	36	13.7	31-42
	2	2	23	69	38	**34**	15.0	—
Microporosity	1	21	19	58	35	37	11.7	30-41
	2	5	29	74	45	41	18.4	—
Macroporosity	1	22	19	58	34	34	11.4	29-39
	2	4	41	74	52	46	15.2	—
Apical area	1	35	19	74	37	37	13.6	32-42
	2	4	26	60	45	46	15.4	—
Lipping	1	18	19	54	33	32	10.5	28-39
	2	5	25	74	54	60	20.4	28-79

Smaller joint surface area group: age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	23	19	74	36	34	15.2	30-43
	2	2	26	54	40	40	19.8	—
Male	1	12	23	59	39	42	10.9	32-46
	2	2	38	60	49	49	15.6	—

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	34	20	72	38	36	12.5	33-42
	2	4	28	49	39	39	8.7	—
Fine granularity	1	35	20	67	37	36	10.7	33-40
	2	3	28	72	51	53	22.1	—
Coarse granularity	1	1	—	—	—	—	—	—
	2	34	20	67	37	37	10.5	33-41
	3	3	28	72	51	53	22.1	—
Dense bone	1	27	21	72	40	37	12.3	35-45
	2	1	—	—	—	—	—	—
Microporosity	1	25	21	72	40	38	12.7	35-45
	2	2	36	37	**37**	37	0.7	—
Macroporosity	1	24	21	72	39	37	12.7	34-45
	2	5	36	77	50	44	16.2	—
Apical area	1	31	21	72	40	40	11.8	36-45
	2	3	27	77	44	**28**	28.6	—
Lipping	1	20	20	67	38	39	12.6	32-44
	2	3	32	77	60	72	24.7	—

Larger joint surface area group: age descriptive statistics for the apical area for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	20	24	72	42	40	12.4	37-48
	2	1	—	—	—	—	—	—
Male	1	11	21	53	37	37	9.5	30-43
	2	2	27	28	**28**	**28**	0.7	—

Pubic symphysis

Total sample (without group division): age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	119	18	88	42	39	15.5	39-45
	2	100	20	75	49	49	13.9	46-52
Superior extremity	1	1	—	—	—	—	—	—
	2	8	25	74	46	42	18.1	31-61
	3	138	20	87	47	46	14.1	44-49
Inferior extremity	1	10	19	26	21	21	2.4	20-23
	2	192	23	88	47	46	14.5	45-49
Dorsal plateau	1	16	18	40	26	25	6.2	22-29
	2	182	23	88	48	46	14.3	46-50
Ventral rampart	1	12	19	74	36	31	18.1	24-47
	2	23	23	87	41	37	16.6	34-48
	3	141	25	88	49	48	13.8	47-51
Dorsal body of the pubic bone	1	143	18	77	38	36	14.6	36-41
	2	102	21	88	47	46	15.2	44-50
	3	7	26	75	54	58	20.5	35-73
Ventral body of the pubic bone	1	39	18	68	29	26	10.4	25-32
	2	67	18	77	36	32	14.8	33-40
	3	101	24	88	51	50	13.5	48-53
	4	28	26	74	51	53	12.2	46-55
Medial aspect of the obturator foramen	1	24	18	38	24	21	6.7	21-27
	2	229	19	88	43	40	15.6	41-45
	3	13	23	67	**42**	**36**	14.7	33-51
Symphyseal rim	1	0	—	—	—	—	—	—
	2	21	20	60	33	30	10.6	28-38
	3	62	23	87	48	47	14.5	45-52
	4	45	25	75	48	46	12.2	44-51
Pubic tubercle	1	21	20	74	39	35	15.5	32-46
	2	117	23	87	48	46	13.5	45-50
Ventral bevelling	1	22	18	87	30	24	16.7	23-38
	2	220	23	88	47	45	14.6	45-49
Erosion of the symphyseal face	1	75	18	74	46	44	13.3	43-49
	2	20	32	66	49	50	10.2	44-54
Erosion of the symphyseal rim	1	48	25	75	44	41	13.9	40-48
	2	11	31	75	54	53	14.5	44-63
Symphyseal face shape	1	73	18	87	38	34	16.1	34-42
	2	121	26	76	48	46	13.9	46-51
	3	34	28	88	48	49	14.0	44-53
Ligamentous outgrowths on the ventral bevelling	1	65	25	76	47	46	13.3	43-50
	2	25	31	75	53	55	11.1	48-57

Shorter height group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	49	19	88	43	39	16.0	38-47
	2	44	26	74	49	48	13.0	45-53
Superior extremity	1	1	—	—	—	—	—	—
	2	6	25	74	46	38	21.2	—
	3	52	24	76	47	46	13.4	43-51
Inferior extremity	1	1	—	—	—	—	—	—
	2	84	24	88	48	46	14.9	45-51
Dorsal plateau	1	6	19	35	27	27	6.3	21-34
	2	83	26	88	48	45	14.2	45-51
Ventral rampart	1	7	22	74	41	33	18.5	23-58
	2	12	24	70	42	39	14.5	33-51
	3	57	26	88	49	47	14.1	45-53
Dorsal body of the pubic bone	1	72	19	77	41	39	14.8	37-44
	2	38	21	88	45	42	16.3	40-51
	3	6	34	75	58	64	18.0	—
Ventral body of the pubic bone	1	19	19	68	31	27	12.6	25-37
	2	34	20	77	38	34	15.4	33-44
	3	47	24	88	50	49	14.9	46-54
	4	11	31	62	**46**	**43**	9.9	39-53
Medial aspect of the obturator foramen	1	10	19	38	27	28	7.3	22-33
	2	103	19	88	44	41	16.1	41-47
	3	3	31	34	**33**	**34**	1.7	—
Symphyseal rim	1	0	—	—	—	—	—	—
	2	9	24	37	30	30	4.4	27-34
	3	25	28	74	52	51	13.8	46-57
	4	16	26	58	**42**	**42**	8.7	37-46
Pubic tubercle	1	13	24	74	40	35	16.9	30-51
	2	43	26	76	47	45	12.6	43-51
Ventral bevelling	1	5	19	37	27	28	7.0	—
	2	96	24	88	48	46	14.8	45-51
Erosion of the symphyseal face	1	32	26	74	46	42	12.7	42-51
	2	8	33	60	49	50	8.8	42-56
Erosion of the symphyseal rim	1	19	25	74	40	37	12.7	34-46
	2	7	31	75	50	47	15.8	35-65
Symphyseal face shape	1	29	19	74	39	35	16.1	33-45
	2	56	26	76	47	43	13.8	44-51
	3	14	28	88	49	49	16.2	39-58
Ligamentous outgrowths on the ventral bevelling	1	27	25	76	47	48	10.9	43-51
	2	6	31	75	54	56	14.6	39-70

Taller height group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	47	20	74	39	35	13.7	35-43
	2	45	28	75	50	51	14.1	46-55
Superior extremity	1	0	—	—	—	—	—	—
	2	2	44	53	**49**	**49**	6.4	—
	3	67	20	75	45	42	14.4	42-49
Inferior extremity	1	7	19	26	22	21	2.7	19-24
	2	83	23	84	46	43	14.3	43-49
Dorsal plateau	1	6	21	30	25	25	3.4	21-28
	2	75	23	84	47	46	14.5	43-50
Ventral rampart	1	4	20	59	32	24	18.5	—
	2	8	23	46	33	31	8.6	25-40
	3	67	25	84	48	49	14.0	45-52
Dorsal body of the pubic bone	1	43	20	74	38	35	13.4	33-42
	2	54	23	75	47	49	14.9	43-51
	3	1	—	—	—	—	—	—
Ventral body of the pubic bone	1	9	20	38	28	29	6.3	23-33
	2	22	20	66	35	31	12.9	29-41
	3	42	28	75	50	49	13.0	46-54
	4	12	26	74	52	56	14.2	43-61
Medial aspect of the obturator foramen	1	5	21	38	26	23	7.1	—
	2	93	19	84	42	40	15.1	39-46
	3	10	23	67	45	40	15.9	33-56
Symphyseal rim	1	0	—	—	—	—	—	—
	2	9	20	59	32	28	12.5	22-42
	3	28	23	74	44	40	13.2	39-49
	4	26	25	75	50	54	12.7	45-55
Pubic tubercle	1	8	20	59	38	36	13.8	26-49
	2	57	23	75	47	46	13.6	43-51
Ventral bevelling	1	8	20	38	26	24	7.3	20-32
	2	98	23	84	45	43	14.8	42-48
Erosion of the symphyseal face	1	38	25	74	46	45	13.1	42-51
	2	9	32	66	48	53	12.4	39-58
Erosion of the symphyseal rim	1	27	25	75	47	44	14.2	41-52
	2	4	49	72	60	60	10.8	—
Symphyseal face shape	1	29	20	69	36	32	14.3	31-42
	2	46	28	75	49	46	14.3	44-53
	3	19	29	73	49	50	13.0	42-55
Ligamentous outgrowths on the ventral bevelling	1	34	25	75	46	41	14.9	41-51
	2	17	37	67	52	55	9.4	47-57

Lighter group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	57	18	88	41	39	16.0	37-45
	2	43	27	75	50	48	13.2	46-54
Superior extremity	1	1	—	—	—	—	—	—
	2	4	25	40	32	32	6.6	—
	3	55	23	87	47	46	13.7	43-51
Inferior extremity	1	3	19	25	22	22	3.0	—
	2	81	23	88	48	48	14.6	45-51
Dorsal plateau	1	9	18	35	26	25	5.8	21-30
	2	81	23	88	48	46	13.9	45-51
Ventral rampart	1	6	22	58	35	33	12.2	22-48
	2	15	23	87	45	42	18.8	35-56
	3	54	27	88	49	48	12.7	45-52
Dorsal body of the pubic bone	1	75	18	70	39	38	13.7	36-42
	2	37	21	88	47	46	16.2	42-52
	3	4	34	70	50	49	16.7	—
Ventral body of the pubic bone	1	19	19	68	32	27	12.6	26-38
	2	40	18	65	33	30	12.4	29-37
	3	48	24	88	50	49	14.0	46-54
	4	11	35	62	49	52	9.1	43-55
Medial aspect of the obturator foramen	1	13	18	38	26	26	7.2	22-30
	2	104	19	88	43	41	15.5	40-46
	3	4	23	55	**37**	**34**	13.4	—
Symphyseal rim	1	0	—	—	—	—	—	—
	2	10	24	37	30	30	4.5	27-33
	3	26	23	87	50	49	14.4	44-55
	4	14	29	75	**48**	**46**	11.7	41-54
Pubic tubercle	1	12	24	42	32	33	6.6	28-37
	2	46	23	87	48	48	13.4	44-52
Ventral bevelling	1	8	18	87	33	25	22.9	—
	2	98	23	88	47	47	14.0	45-50
Erosion of the symphyseal face	1	30	18	70	44	42	11.9	39-48
	2	10	33	60	48	49	8.9	41-54
Erosion of the symphyseal rim	1	20	25	75	41	39	13.6	35-48
	2	5	33	59	47	47	9.3	35-58
Symphyseal face shape	1	42	18	87	40	35	17.4	35-45
	2	51	26	75	47	43	13.1	43-51
	3	15	28	88	48	48	15.0	40-57
Ligamentous outgrowths on the ventral bevelling	1	24	25	75	48	49	13.8	42-54
	2	7	37	69	52	49	10.0	42-61

Heavier group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	44	20	74	42	40	14.5	38-47
	2	45	20	73	48	46	14.1	44-52
Superior extremity	1	0	—	—	—	—	—	—
	2	4	44	74	**60**	**62**	14.2	—
	3	65	20	74	45	42	13.9	42-49
Inferior extremity	1	6	20	26	21	21	2.3	—
	2	86	24	75	46	43	13.7	43-49
Dorsal plateau	1	5	21	40	26	24	7.9	—
	2	79	25	77	47	46	13.9	44-50
Ventral rampart	1	5	20	74	40	26	24.9	—
	2	7	24	46	33	33	7.6	26-40
	3	68	19	77	48	46	13.5	44-51
Dorsal body of the pubic bone	1	43	20	77	39	38	14.8	35-44
	2	49	24	73	46	46	13.7	42-50
	3	3	26	75	58	74	28.0	—
Ventral body of the pubic bone	1	12	20	38	28	29	6.7	24-32
	2	16	20	77	41	39	15.8	33-50
	3	41	28	75	52	51	12.9	47-56
	4	14	26	74	**50**	**48**	14.6	41-58
Medial aspect of the obturator foramen	1	3	21	27	23	21	3.5	—
	2	91	20	77	43	40	14.8	40-46
	3	8	26	67	45	40	16.1	32-59
Symphyseal rim	1	0	—	—	—	—	—	—
	2	8	20	59	34	29	13.2	23-45
	3	29	27	74	47	40	14.6	41-52
	4	27	25	72	47	46	12.5	42-52
Pubic tubercle	1	9	20	74	**49**	**53**	19.0	34-64
	2	55	25	74	46	45	13.1	43-50
Ventral bevelling	1	12	19	50	27	24	9.6	21-33
	2	93	24	77	46	43	14.4	43-49
Erosion of the symphyseal face	1	37	26	74	48	46	14.1	43-53
	2	9	32	66	50	53	12.2	41-60
Erosion of the symphyseal rim	1	27	26	74	46	44	14.0	41-52
	2	5	31	72	56	60	15.9	—
Symphyseal face shape	1	22	20	74	38	37	15.5	31-45
	2	50	26	75	48	46	13.5	44-51
	3	18	29	73	49	52	14.0	42-56
Ligamentous outgrowths on the ventral bevelling	1	34	26	74	45	42	12.2	41-49
	2	16	31	75	53	56	11.7	47-60

Gracile group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	38	19	74	38	37	13.2	33-42
	2	35	26	75	50	51	14.1	45-55
Superior extremity	1	0	—	—	—	—	—	—
	2	5	25	74	**47**	**44**	18.1	25-70
	3	51	20	75	44	40	14.4	40-48
Inferior extremity	1	6	19	26	22	21	2.9	19-25
	2	63	24	75	46	43	14.5	42-49
Dorsal plateau	1	5	19	26	23	25	3.0	—
	2	63	25	77	46	42	14.2	42-50
Ventral rampart	1	7	20	74	42	33	21.7	21-62
	2	9	24	65	**39**	**38**	13.0	29-49
	3	45	25	75	46	44	13.8	42-51
Dorsal body of the pubic bone	1	46	19	77	37	34	14.6	32-41
	2	37	25	75	47	46	14.6	42-52
	3	3	26	75	58	74	28.0	—
Ventral body of the pubic bone	1	14	19	38	27	27	5.9	24-31
	2	24	20	77	36	32	15.1	30-43
	3	35	28	75	52	53	13.8	47-57
	4	8	26	67	**46**	**42**	13.7	35-57
Medial aspect of the obturator foramen	1	5	19	29	23	21	4.5	—
	2	79	19	77	42	39	16.0	38-45
	3	7	26	67	44	39	16.3	29-59
Symphyseal rim	1	0	—	—	—	—	—	—
	2	9	20	59	30	26	11.5	21-39
	3	19	28	74	45	40	13.2	39-51
	4	21	25	75	46	46	14.0	40-53
Pubic tubercle	1	13	20	74	38	33	16.2	28-48
	2	41	25	75	46	46	13.4	42-50
Ventral bevelling	1	8	19	38	25	24	6.4	20-30
	2	71	24	77	45	42	15.1	42-49
Erosion of the symphyseal face	1	31	25	74	46	44	13.4	41-51
	2	6	33	59	51	55	10.4	40-61
Erosion of the symphyseal rim	1	26	25	75	46	47	15.3	40-52
	2	3	33	59	48	53	13.6	—
Symphyseal face shape	1	23	19	74	37	35	15.6	30-44
	2	37	26	75	48	43	14.3	43-52
	3	14	28	73	**45**	**42**	14.2	37-53
Ligamentous outgrowths on the ventral bevelling	1	26	25	75	44	40	13.6	38-49
	2	8	38	75	58	56	11.6	48-68

Robust group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	44	19	88	42	40	15.2	37-46
	2	40	27	74	49	48	12.8	45-53
Superior extremity	1	1	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	52	23	74	46	46	12.3	43-50
Inferior extremity	1	2	21	22	22	22	0.7	—
	2	77	23	88	47	46	13.9	44-50
Dorsal plateau	1	5	21	33	26	24	5.1	—
	2	69	23	88	47	46	13.3	44-50
Ventral rampart	1	3	22	33	28	29	5.6	—
	2	9	23	46	33	33	8.0	27-39
	3	56	27	88	50	49	12.5	46-53
Dorsal body of the pubic bone	1	51	19	74	43	41	14.0	39-47
	2	37	21	88	46	45	15.6	41-51
	3	3	34	58	**44**	**39**	12.7	—
Ventral body of the pubic bone	1	13	19	68	33	27	14.6	24-42
	2	24	21	66	38	34	12.6	32-43
	3	39	24	88	49	48	13.1	45-54
	4	12	31	74	50	53	12.7	42-58
Medial aspect of the obturator foramen	1	7	20	38	27	26	6.9	21-33
	2	83	19	88	44	43	14.6	41-48
	3	5	23	57	**40**	**34**	15.2	21-59
Symphyseal rim	1	0	—	—	—	—	—	—
	2	7	24	46	32	30	7.2	26-39
	3	28	23	74	46	45	13.2	41-51
	4	16	31	72	47	45	10.2	41-52
Pubic tubercle	1	6	29	60	38	35	11.5	—
	2	45	23	74	46	46	11.9	43-50
Ventral bevelling	1	4	21	37	27	26	7.4	—
	2	89	23	88	47	46	13.9	44-50
Erosion of the symphyseal face	1	26	30	74	47	44	11.3	42-51
	2	11	32	66	48	49	11.0	40-55
Erosion of the symphyseal rim	1	18	27	74	41	38	12.2	35-47
	2	6	31	72	54	55	15.1	38-70
Symphyseal face shape	1	28	19	70	39	34	15.1	33-44
	2	45	26	74	47	43	12.6	43-50
	3	16	31	88	52	50	14.5	44-60
Ligamentous outgrowths on the ventral bevelling	1	26	32	74	50	49	11.7	45-54
	2	11	31	60	**47**	**47**	9.4	41-54

Smaller joint surface area group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	15	24	60	45	49	10.7	39-51
	2	17	29	72	44	**43**	11.1	38-50
Superior extremity	1	0	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	24	24	72	45	44	11.9	40-50
Inferior extremity	1	0	—	—	—	—	—	—
	2	30	24	72	44	44	11.0	40-49
Dorsal plateau	1	0	—	—	—	—	—	—
	2	29	29	72	45	43	10.4	41-49
Ventral rampart	1	1	—	—	—	—	—	—
	2	4	24	51	37	36	12.1	—
	3	25	29	72	45	43	10.4	40-49
Dorsal body of the pubic bone	1	20	24	62	40	40	9.3	36-45
	2	11	37	72	52	49	10.0	45-58
	3	0	—	—	—	—	—	—
Ventral body of the pubic bone	1	4	24	52	38	38	13.0	—
	2	10	29	46	38	40	5.9	34-42
	3	11	37	72	51	49	10.4	44-58
	4	5	41	60	51	54	8.3	—
Medial aspect of the obturator foramen	1	2*	—	—	—	—	—	—
	2	28	24	72	44	43	11.3	40-49
	3	0	—	—	—	—	—	—
Symphyseal rim	1	0	—	—	—	—	—	—
	2	3	24	59	38	30	18.7	—
	3	10	30	62	44	44	9.5	37-51
	4	9	29	72	48	45	12.9	38-58
Pubic tubercle	1	6	24	59	40	41	12.1	27-53
	2	20	29	72	46	46	11.1	41-51
Ventral bevelling	1	0	—	—	—	—	—	—
	2	32	24	72	44	43	10.7	40-48
Erosion of the symphyseal face	1	17	30	72	47	46	10.0	42-52
	2	6	32	60	48	47	10.5	37-59
Erosion of the symphyseal rim	1	12	29	60	44	43	11.0	37-51
	2	3	45	72	55	49	14.6	—
Symphyseal face shape	1	10	24	60	46	49	12.0	37-54
	2	15	30	52	**41**	**41**	5.9	38-44
	3	7	29	72	49	48	15.6	35-63
Ligamentous outgrowths on the ventral bevelling	1	14	30	72	45	44	11.1	38-51
	2	2	49	56	53	53	4.9	—

*Both individuals were 38 years old

Larger joint surface area group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	18	19	76	37	33	18.4	28-47
	2	9	36	67	48	45	10.7	40-56
Superior extremity	1	0	—	—	—	—	—	—
	2	2	25	29	27	27	2.8	—
	3	22	20	76	45	39	16.6	37-52
Inferior extremity	1	4	19	25	21	21	2.6	—
	2	23	25	76	44	39	15.9	38-51
Dorsal plateau	1	6	19	29	24	25	3.6	20-28
	2	20	25	76	47	41	15.3	40-54
Ventral rampart	1	5	19	29	23	21	4.3	—
	2	5	25	70	39	33	17.6	—
	3	15	25	76	47	42	14.6	39-55
Dorsal body of the pubic bone	1	13	19	74	41	36	18.2	30-52
	2	10	25	76	42	38	14.5	32-52
	3	2	26	70	48	48	32.1	—
Ventral body of the pubic bone	1	1	—	—	—	—	—	—
	2	8	19	76	39	31	19.6	22-55
	3	9	33	70	48	45	14.6	37-60
	4	6	26	74	**43**	**38**	16.4	—
Medial aspect of the obturator foramen	1	3	19	29	23	21	5.3	—
	2	19	25	74	44	39	15.4	37-52
	3	3	26	39	**34**	**36**	6.8	—
Symphyseal rim	1	0	—	—	—	—	—	—
	2	7	20	37	28	26	5.5	23-33
	3	10	33	74	52	51	15.0	41-63
	4	6	25	56	**40**	**40**	10.3	30-51
Pubic tubercle	1	5	20	37	27	25	6.3	—
	2	19	25	76	47	42	16.0	40-55
Ventral bevelling	1	5	19	37	25	21	7.7	—
	2	22	25	76	45	39	16.4	37-52
Erosion of the symphyseal face	1	14	25	74	46	41	15.9	37-55
	2	1	—	—	—	—	—	—
Erosion of the symphyseal rim	1	11	25	74	39	33	15.4	29-49
	2	1	—	—	—	—	—	—
Symphyseal face shape	1	10	19	70	32	26	16.5	20-44
	2	12	33	76	48	39	16.3	38-59
	3	4	36	56	**46**	46	8.7	—
Ligamentous outgrowths on the ventral bevelling	1	17	25	70	45	39	16.1	37-53
	2	1	—	—	—	—	—	—

Age descriptive statistics for the superior extremity, for female individuals

Sample	Score	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	1	1	—	—	—	—	—	—
	2	6	25	74	43	38	18.2	—
	3	49	25	87	49	47	14.9	45-54
Shorter group	1	1	—	—	—	—	—	—
	2	3	29	40	35	35	5.5	—
	3	22	28	74	47	46	14.3	41-53
Taller	1	0	—	—	—	—	—	—
	2	3	25	74	51	**53**	24.6	—
	3	19	25	75	50	49	14.7	43-57
Lighter	1	1	—	—	—	—	—	—
	2	4	25	40	32	32	6.6	—
	3	25	25	87	49	47	15.2	43-55
Heavier	1	0	—	—	—	—	—	—
	2	2	53	74	**64**	**64**	14.8	—
	3	18	28	74	46	42	14.0	39-53
Gracile	1	0	—	—	—	—	—	—
	2	4	25	74	**48**	**47**	20.8	—
	3	17	25	74	46	40	16.6	37-54
Robust	1	1	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	17	30	64	47	47	10.0	42-52
Smaller area	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	7	29	54	40	39	9.4	32-49
Larger area	1	0	—	—	—	—	—	—
	2	2	25	29	27	27	2.8	—
	3	5	25	74	62	70	20.6	—

Age descriptive statistics for the superior extremity, for male individuals

Sample	Score	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	1	0	—	—	—	—	—	—
	2	2	44	70	**57**	**57**	18.4	—
	3	89	20	76	45	43	13.5	43-48
Shorter	1	0	—	—	—	—	—	—
	2	2	44	70	**57**	**57**	18.4	—
	3	41	23	76	43	42	12.6	39-47
Taller	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	37	20	75	47	49	14.7	42-52
Lighter	1	0	—	—	—	—	—	—
	2	2	44	70	**57**	**57**	18.4	—
	3	37	23	75	44	45	12.1	40-48
Heavier	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	40	20	72	46	41	14.2	41-50
Gracile	1	0	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	38	20	75	45	44	15.0	40-50
Robust	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	31	23	66	43	42	11.3	39-48
Smaller area	1	0	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	18	24	62	44	44	11.0	39-50
Larger area	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	16	20	76	42	39	14.3	35-50

APPENDIX 4 | DESCRIPTIVE STATISTICS FOR THE BASS COLLECTION

Age descriptive statistics, in years, for the acetabulum, iliac auricular surface and pubic symphyseal traits: number of individuals (N), minimum (min), maximum (max), mean, median, standard deviation (SD) age and 95% confidence interval for the mean (95% CI). Cases were highlighted in bold when a more advanced stage showed a lower age mean and/or median when compared with the previous stage.

Acetabulum

Total sample (without group division): age descriptive statistics for the acetabulum traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	44	19	90	50	46	15.9	45-54
	2	190	25	92	60	60	15.1	58-62
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	31	19	82	43	41	14.4	38-48
	3	118	25	92	57	55	14.6	54-59
	4	76	43	90	67	69	12.3	64-70
Acetabular rim porosity	1	137	19	92	54	54	15.2	52-57
	2	35	29	86	60	60	15.5	55-65
	3	27	47	90	70	68	12.3	65-74
Apex activity	1	23	19	62	41	43	10.9	37-46
	2	135	26	92	57	56	15.7	55-60
	3	61	43	90	65	64	11.8	62-68
Outer edge of the acetabular fossa	1	14	33	90	61	60	15.9	52-70
	2	45	19	90	58	58	16.8	53-63
	3	49	25	86	**55**	**51**	16.7	50-60
	4	100	29	92	58	59	14.6	56-61
Acetabular fossa	1	11	19	60	44	44	12.6	36-53
	2	64	29	90	59	58	15.1	55-63
	3	39	29	92	**50**	**47**	15.7	44-55
	4	91	26	88	61	61	14.3	58-64

Shorter height group: age descriptive statistics for the acetabulum traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	14	29	78	48	46	11.7	41-55
	2	51	25	82	57	58	13.5	53-61
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	8	29	60	44	44	11.4	34-53
	3	37	25	82	54	52	13.4	49-58
	4	17	44	78	63	64	11.2	57-69
Acetabular rim porosity	1	42	25	82	53	52	13.5	49-57
	2	9	29	73	52	52	13.7	41-62
	3	7	61	76	70	68	5.3	65-75
Apex activity	1	9	25	51	40	43	8.5	34-47
	2	36	29	77	54	54	12.8	50-58
	3	19	49	82	62	60	10.0	58-67
Outer edge of the acetabular fossa	1	6	33	74	54	58	15.3	37-70
	2	17	43	78	60	58	10.8	54-65
	3	15	25	71	**49**	**45**	13.3	41-56
	4	22	29	78	**55**	**55**	13.8	49-61
Acetabular fossa	1	7	38	60	49	50	8.6	41-57
	2	21	29	76	51	49	12.4	45-57
	3	13	29	78	54	52	13.6	46-63
	4	15	31	82	62	66	13.6	55-70

Taller height group: age descriptive statistics for the acetabulum traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	13	19	72	40	36	14.2	32-49
	2	51	31	92	56	55	14.4	52-60
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	14	19	72	39	37	13.9	31-47
	3	28	31	92	53	52	14.7	47-58
	4	20	50	81	64	63	9.9	59-68
Acetabular rim porosity	1	42	19	92	51	49	16.2	46-56
	2	7	39	77	55	51	12.6	44-67
	3	6	51	65	60	62	5.0	—
Apex activity	1	6	19	57	36	33	13.8	21-50
	2	38	31	92	52	51	14.9	47-57
	3	15	47	81	61	62	10.7	56-67
Outer edge of the acetabular fossa	1	2	51	55	53	53	2.8	—
	2	11	19	70	**48**	**47**	16.4	37-59
	3	16	31	83	**50**	**50**	16.8	41-59
	4	28	32	92	56	56	14.7	50-61
Acetabular fossa	1	2	19	39	29	29	14.1	—
	2	10	44	81	59	59	11.9	50-67
	3	16	31	92	**44**	**38**	17.1	35-54
	4	31	26	83	**55**	**55**	12.7	51-60

Lighter group: age descriptive statistics for the acetabulum traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	12	32	78	47	45	12.0	39-54
	2	51	25	82	58	60	13.4	54-62
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	7	29	60	42	42	10.5	33-52
	3	36	25	82	55	54	13.5	50-59
	4	18	44	78	63	62	11.3	58-69
Acetabular rim porosity	1	44	25	82	53	53	13.6	49-57
	2	8	44	77	58	54	13.7	46-69
	3	6	51	76	68	71	9.3	—
Apex activity	1	8	25	51	41	44	9.0	33-48
	2	34	31	77	54	55	13.1	50-59
	3	20	49	82	62	60	10.5	58-67
Outer edge of the acetabular fossa	1	6	33	74	53	56	15.3	37-69
	2	17	43	78	59	58	11.2	53-65
	3	16	25	71	**47**	**45**	13.1	40-54
	4	18	31	78	57	60	13.6	51-64
Acetabular fossa	1	5	39	60	49	50	8.2	39-60
	2	23	29	76	51	49	12.1	46-56
	3	9	32	78	53	52	15.2	41-65
	4	17	31	82	63	66	12.3	56-69

Heavier group: age descriptive statistics for the acetabulum traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	16	19	86	45	42	17.6	36-55
	2	51	31	92	55	55	14.4	51-59
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	15	19	72	40	37	14.2	32-48
	3	30	31	92	53	52	15.5	47-59
	4	19	46	81	63	63	9.7	59-68
Acetabular rim porosity	1	40	19	92	51	49	16.2	45-56
	2	9	29	86	53	51	16.1	41-65
	3	7	59	68	63	63	3.0	60-66
Apex activity	1	7	19	57	36	33	12.6	24-48
	2	41	29	92	53	52	15.3	48-57
	3	14	47	81	61	62	10.0	56-67
Outer edge of the acetabular fossa	1	3	55	86	**66**	**56**	17.6	—
	2	11	19	70	49	51	16.5	38-60
	3	15	31	83	52	51	16.8	43-61
	4	32	29	92	54	54	14.6	49-59
Acetabular fossa	1	4	19	56	38	39	15.1	—
	2	9	44	86	**63**	**61**	14.0	53-74
	3	20	29	92	47	42	16.7	39-55
	4	29	26	83	55	55	13.2	50-60

Gracile group: age descriptive statistics for the acetabulum traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	13	19	72	40	36	13.7	31-48
	2	45	25	92	57	58	15.7	52-62
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	12	19	72	38	36	14.1	29-47
	3	28	25	92	53	55	16.1	47-59
	4	14	46	80	67	68	8.6	62-72
Acetabular rim porosity	1	39	19	92	51	52	17.2	46-57
	2	3	29	62	51	61	18.8	—
	3	6	63	76	69	68	5.4	63-74
Apex activity	1	10	19	57	38	39	12.3	29-74
	2	32	29	92	53	55	16.5	47-59
	3	11	56	82	66	63	8.5	60-71
Outer edge of the acetabular fossa	1	3	33	56	48	55	13.0	—
	2	10	19	74	51	56	18.1	38-64
	3	14	25	83	**49**	**45**	17.2	39-59
	4	23	29	92	55	57	16.5	48-62
Acetabular fossa	1	4	19	56	38	39	15.1	—
	2	14	33	76	53	55	11.3	47-60
	3	12	29	92	**46**	**37**	19.3	34-59
	4	21	26	83	59	62	16.4	52-67

Robust group: age descriptive statistics for the acetabulum traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	14	32	78	49	46	11.6	42-56
	2	57	29	81	56	56	12.4	53-60
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	10	29	64	44	43	11.1	36-52
	3	37	31	78	54	52	12.1	50-58
	4	23	44	81	61	60	10.8	56-66
Acetabular rim porosity	1	45	29	81	52	52	12.7	49-56
	2	13	39	77	54	51	12.1	47-61
	3	7	51	74	62	61	7.1	56-69
Apex activity	1	5	29	46	39	43	7.9	—
	2	42	31	75	53	52	11.7	49-57
	3	23	47	81	60	60	10.7	56-65
Outer edge of the acetabular fossa	1	5	38	74	57	**60**	13.3	40-73
	2	18	43	78	57	55	11.4	52-63
	3	17	29	71	**50**	**50**	13.3	43-57
	4	27	31	81	**55**	55	12.2	51-60
Acetabular fossa	1	5	39	60	49	50	8.2	39-60
	2	17	29	81	54	51	13.9	47-61
	3	17	32	78	**51**	**48**	14.0	43-58
	4	25	31	74	56	55	10.2	52-61

Smaller joint surface group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	15	26	50	42	44	6.7	38-46
	2	60	26	90	57	58	14.8	53-61
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	13	26	60	40	39	10.1	34-46
	3	46	31	81	54	52	12.5	50-58
	4	15	44	90	67	66	14.1	59-75
Acetabular rim porosity	1	55	26	90	52	50	14.2	48-56
	2	10	38	80	55	49	14.6	44-65
	3	5	47	88	68	74	16.2	48-88
Apex activity	1	10	26	62	43	44	9.2	36-49
	2	54	26	90	54	52	15.2	50-59
	3	10	49	75	62	62	9.7	55-69
Outer edge of the acetabular fossa	1	4	38	66	55	57	12.0	—
	2	25	26	90	57	58	18.1	50-65
	3	17	31	80	**51**	**46**	15.0	43-59
	4	28	31	80	**53**	**52**	12.3	49-58
Acetabular fossa	1	6	31	57	46	47	9.8	36-56
	2	25	38	78	54	49	11.8	49-59
	3	13	32	80	**48**	**39**	15.2	38-57
	4	28	26	88	58	59	15.8	51-64

Larger joint surface group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Acetabular groove	1	34	19	90	47	46	15.5	42-53
	2	109	26	92	57	57	14.2	55-60
Acetabular rim shape	1	0	—	—	—	—	—	—
	2	25	19	72	41	41	12.7	36-46
	3	79	31	92	55	54	14.1	52-59
	4	38	44	90	63	64	12.1	59-67
Acetabular rim porosity	1	95	19	92	53	51	14.6	50-56
	2	22	29	86	56	52	15.7	49-62
	3	16	47	88	65	64	11.6	59-71
Apex activity	1	17	19	62	41	43	10.4	36-47
	2	95	26	92	55	54	15.2	52-58
	3	26	47	88	62	62	10.7	58-66
Outer edge of the acetabular fossa	1	9	38	90	**63**	**60**	16.2	50-75
	2	35	19	90	57	58	18.4	51-64
	3	30	31	80	**53**	**51**	14.9	47-58
	4	64	29	92	**55**	**54**	12.7	51-58
Acetabular fossa	1	9	19	57	43	44	12.7	33-53
	2	39	38	90	57	52	13.5	52-61
	3	31	29	92	**48**	**44**	16.0	43-54
	4	60	26	88	58	55	13.8	54-61

Iliac auricular surface

Total sample (without group division): age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	185	19	92	56	55	15.2	54-58
	2	32	33	90	62	61	15.0	56-67
Fine granularity	1	171	26	92	58	57	15.6	55-60
	2	49	19	90	**56**	**55**	14.8	52-60
Coarse granularity	1	6	31	56	42	42	9.5	32-51
	2	162	26	92	58	57	15.4	56-61
	3	48	19	90	**56**	**55**	14.9	52-61
Dense bone	1	178	19	92	56	54	14.8	53-58
	2	10	29	82	57	59	18.0	45-70
Microporosity	1	149	26	92	55	52	15.6	53-58
	2	31	19	71	55	55	11.3	51-59
Macroporosity	1	126	19	92	54	52	15.5	51-57
	2	63	31	88	60	60	13.3	56-63
Apical area	1	135	19	90	55	54	15.6	53-58
	2	86	32	92	61	61	14.7	58-64
Lipping	1	108	19	92	54	52	15.2	51-57
	2	66	29	90	64	65	15.2	61-68

Total sample (without group division): age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	88	31	90	59	58	13.3	56-61
	2	4	29	82	55	54	23.8	—
Male	1	90	19	92	53	50	15.7	49-56
	2	6	36	80	59	59	15.4	43-75

Shorter height group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	56	29	78	54	54	12.4	51-58
	2	6	33	82	63	64	16.8	45-80
Fine granularity	1	54	29	82	55	55	13.2	52-59
	2	9	33	67	54	**52**	10.3	46-62
Coarse granularity	1	2	31	56	44	44	17.7	—
	2	51	29	82	55	54	13.1	52-59
	3	9	33	67	54	**52**	10.3	46-62
Dense bone	1	53	29	78	54	54	12.3	51-57
	2	4	29	82	57	59	22.5	—
Microporosity	1	44	29	82	52	52	13.4	48-56
	2	11	46	71	59	56	8.6	54-65
Macroporosity	1	38	29	82	52	52	13.3	48-56
	2	19	31	76	58	60	11.5	53-64
Apical area	1	44	29	78	54	54	13.1	50-58
	2	18	38	77	58	59	11.9	52-64
Lipping	1	32	29	78	52	52	12.4	47-56
	2	21	29	77	57	60	12.7	51-63

Shorter height group: age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	20	31	76	54	53	12.0	48-59
	2	2	66	82	74	74	11.3	—
Male	1	30	19	92	51	51	17.3	45-57
	2	1	—	—	—	—	—	—

Taller height group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	53	19	92	52	51	16.4	48-57
	2	9	43	62	53	51	6.7	48-58
Fine granularity	1	41	26	92	51	50	16.2	46-56
	2	20	19	73	54	57	13.7	48-61
Coarse granularity	1	3	32	47	39	39	7.5	—
	2	38	26	92	52	51	16.3	46-57
	3	19	19	73	55	59	14.0	48-61
Dense bone	1	50	19	92	50	50	14.5	46-54
	2	5	36	80	61	63	16.7	—
Microporosity	1	46	26	92	51	51	15.1	47-56
	2	6	19	65	**46**	**47**	16.4	28-63
Macroporosity	1	35	19	92	48	48	15.3	43-54
	2	19	31	81	55	58	13.6	49-62
Apical area	1	38	19	81	49	49	14.4	45-54
	2	24	32	92	58	61	16.2	51-65
Lipping	1	32	19	92	49	48	16.3	43-55
	2	14	32	81	60	61	13.1	52-67

Taller height group: age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	25	34	78	56	52	11.4	51-60
	2	1	—	—	—	—	—	—
Male	1	28	31	70	48	48	11.0	44-53
	2	5	36	80	61	63	16.7	—

Lighter group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	52	29	78	55	53	12.6	51-58
	2	7	33	82	62	61	15.6	47-76
Fine granularity	1	50	29	82	55	54	13.4	52-59
	2	10	33	67	55	57	9.9	48-62
Coarse granularity	1	2	31	32	32	32	0.7	—
	2	46	29	82	56	54	12.9	52-60
	3	10	33	67	55	57	9.9	48-62
Dense bone	1	50	31	78	54	52	12.3	51-57
	2	3	29	82	59	66	27.2	—
Microporosity	1	45	29	82	53	51	13.1	49-57
	2	6	46	71	60	61	11.0	—
Macroporosity	1	37	29	82	52	51	13.2	48-57
	2	17	31	76	59	60	11.9	53-65
Apical area	1	42	29	78	54	53	12.7	50-58
	2	18	32	77	58	60	13.7	51-65
Lipping	1	27	31	78	52	51	12.4	47-57
	2	23	29	77	56	57	13.9	50-62

Lighter group: age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	28	31	76	55	55	11.1	51-60
	2	1	—	—	—	—	—	—
Male	1	40	19	92	50	47	17.0	44-55
	2	0	—	—	—	—	—	—

Heavier group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	58	19	92	53	54	16.5	48-57
	2	8	43	62	53	**51**	7.1	47-59
Fine granularity	1	45	26	92	51	51	15.8	46-56
	2	20	19	86	56	57	15.4	48-63
Coarse granularity	1	3	39	56	47	47	8.5	—
	2	43	26	92	51	51	16.0	46-56
	3	19	19	86	56	59	15.7	48-64
Dense bone	1	54	19	92	51	51	15.1	47-55
	2	6	36	80	59	59	15.4	43-75
Microporosity	1	46	26	92	51	51	16.0	47-56
	2	11	19	68	51	56	13.8	42-61
Macroporosity	1	37	19	92	49	48	16.2	44-54
	2	21	31	81	55	56	13.2	49-61
Apical area	1	40	19	81	49	49	14.4	44-53
	2	25	33	92	59	61	15.9	52-65
Lipping	1	37	19	92	49	48	15.8	44-54
	2	13	43	86	64	61	11.4	57-71

Heavier group: age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	17	34	78	54	51	12.5	47-60
	2	2	66	82	74	74	11.3	—
Male	1	19	31	70	52	55	10.5	47-57
	2	6	36	80	59	59	15.4	43-75

Gracile group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	50	19	92	52	54	16.5	48-57
	2	6	33	82	62	64	17.0	44-80
Fine granularity	1	40	26	92	53	53	17.2	47-58
	2	16	19	73	55	59	15.3	47-63
Coarse granularity	1	2	39	56	48	48	12.0	—
	2	37	26	92	53	51	17.6	47-59
	3	16	19	73	55	59	15.3	47-63
Dense bone	1	44	19	92	51	52	15.8	46-55
	2	7	36	82	64	66	15.8	50-79
Microporosity	1	39	26	92	52	51	17.0	46-57
	2	8	19	68	53	56	15.6	40-66
Macroporosity	1	34	19	92	50	49	17.4	44-56
	2	15	31	76	58	60	13.6	51-66
Apical area	1	36	19	80	49	48	15.7	43-54
	2	19	33	92	61	61	14.9	54-68
Lipping	1	31	19	92	49	46	16.8	43-55
	2	11	39	77	62	61	10.7	55-69

Gracile group: age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	20	39	77	56	53	11.5	50-61
	2	2	66	82	74	74	11.3	—
Male	1	26	19	73	46	45	14.5	40-52
	2	5	36	80	61	63	16.7	—

Robust group: age descriptive statistics for the auricular surface traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	59	29	81	54	52	12.6	51-57
	2	9	43	62	53	51	6.9	48-59
Fine granularity	1	55	29	81	54	52	12.6	50-57
	2	13	41	67	53	52	8.7	48-59
Coarse granularity	1	3	31	47	37	32	9.0	—
	2	52	29	81	55	53	12.1	51-58
	3	12	41	67	54	54	8.9	48-60
Dense bone	1	59	31	81	53	51	11.6	50-56
	2	2	29	52	**41**	**41**	16.3	—
Microporosity	1	51	29	81	52	51	11.8	48-55
	2	9	37	71	56	54	11.7	47-65
Macroporosity	1	39	29	78	51	50	11.2	47-54
	2	23	31	81	56	58	12.1	51-61
Apical area	1	46	29	81	54	52	11.9	50-57
	2	23	32	77	56	59	13.8	50-61
Lipping	1	35	20	77	42	39	18.0	36-48
	2	44	21	74	46	48	14.0	42-51

Robust group: age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	25	31	78	54	52	11.8	49-59
	2	1	—	—	—	—	—	—
Male	1	32	26	92	52	51	14.3	47-58
	2	1	—	—	—	—	—	—

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	45	29	81	54	51	12.4	50-54
	2	7	46	82	65	66	12.4	54-77
Fine granularity	1	40	29	88	57	55	14.6	52-62
	2	13	43	73	**54**	54	9.7	48-60
Coarse granularity	1	1	—	—	—	—	—	—
	2	38	29	82	57	55	13.7	52-61
	3	13	43	73	**54**	**54**	9.7	48-60
Dense bone	1	49	29	82	55	54	12.6	51-58
	2	0	—	—	—	—	—	—
Microporosity	1	42	29	82	54	53	12.9	50-58
	2	7	46	71	57	54	11.2	47-67
Macroporosity	1	38	29	82	53	50	12.4	49-57
	2	11	43	81	61	60	12.0	53-69
Apical area	1	36	29	88	57	55	14.4	52-62
	2	16	39	80	56	55	11.8	50-62
Lipping	1	28	29	82	52	47	13.0	47-57
	2	20	39	88	61	60	13.1	55-67

Smaller joint surface area group: age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	28	38	78	54	53	10.5	50-58
	2	0	—	—	—	—	—	—
Male	1	56	19	92	52	49	14.1	48-56
	2	1	—	—	—	—	—	—

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Transverse organization	1	51	19	92	50	50	15.2	46-54
	2	6	41	90	57	53	18.3	—
Fine granularity	1	39	31	92	50	50	14.8	45-55
	2	18	19	90	52	52	17.4	44-61
Coarse granularity	1	1	—	—	—	—	—	—
	2	39	31	92	50	50	14.8	45-55
	3	17	19	90	53	52	17.9	43-62
Dense bone	1	54	19	92	51	50	15.8	47-55
	2	3	36	54	**47**	52	9.9	—
Microporosity	1	43	31	92	51	49	16.8	46-56
	2	12	19	65	50	53	12.4	42-58
Macroporosity	1	43	19	92	51	49	17.1	45-56
	2	13	31	65	51	52	9.9	45-57
Apical area	1	35	19	77	46	49	11.6	42-50
	2	22	33	92	58	56	18.5	50-66
Lipping	1	33	19	92	50	50	16.0	44-56
	2	9	34	86	58	61	16.9	45-71

Larger joint surface area group: age descriptive statistics for the dense bone for both sexes

Sex	Score	N	Min	Max	Mean	Median	SD	95% CI
Female	1	50	31	82	55	53	11.7	51-58
	2	0	—	—	—	—	—	—
Male	1	103	19	92	53	51	14.4	50-56
	2	3	36	54	**47**	52	9.9	—

Pubic symphysis

Total sample (without group division): age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	80	19	82	53	52	15.4	50-57
	2	146	31	92	61	60	14.8	59-64
Superior extremity	1	2	19	71	45	45	36.8	—
	2	3	31	56	47	54	13.9	—
	3	208	26	92	58	58	15.2	56-60
Inferior extremity	1	1	—	—	—	—	—	—
	2	221	26	92	58	57	15.2	56-60
Dorsal plateau	1	1	—	—	—	—	—	—
	2	220	26	92	58	58	15.2	56-60
Ventral rampart	1	2	19	54	37	37	24.7	—
	2	9	32	60	48	49	10.5	40-56
	3	211	26	92	59	58	15.4	57-61
Dorsal body of the pubic bone	1	55	26	80	51	50	12.3	48-55
	2	83	26	90	53	51	14.3	50-56
	3	85	29	92	68	71	13.4	65-71
Ventral body of the pubic bone	1	2	19	43	31	31	17.0	—
	2	6	31	60	50	51	10.7	39-61
	3	134	26	92	57	56	15.2	54-60
	4	81	26	90	60	59	15.1	57-64
Medial aspect of the obturator foramen	1	3	44	65	57	**61**	11.2	—
	2	215	19	92	58	58	15.7	56-60
	3	9	47	73	59	**56**	9.9	51-67
Symphyseal rim	1	1	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	26	26	90	53	54	15.3	47-60
	4	131	26	92	57	55	14.8	54-59
Pubic tubercle	1	8	19	71	48	55	16.6	34-62
	2	196	26	92	58	58	15.3	56-60
Ventral bevelling	1	0	—	—	—	—	—	—
	2	231	19	92	58	58	15.5	56-60
Erosion of the symphyseal face	1	128	19	92	56	54	15.5	53-58
	2	38	34	90	65	64	13.1	61-69
Erosion of the symphyseal rim	1	135	19	92	55	54	15.6	53-58
	2	15	42	88	61	60	13.1	53-68
Symphyseal face shape	1	25	19	78	49	46	16.1	43-56
	2	156	31	92	60	60	14.3	58-63
	3	46	26	88	**57**	**58**	17.5	52-62
Ligamentous outgrowths on the ventral bevelling	1	97	19	90	53	52	14.6	50-56
	2	108	33	92	63	62	14.6	60-66

Shorter height group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	26	29	82	53	53	14.2	47-58
	2	35	38	78	59	60	11.5	55-63
Superior extremity	1	0	—	—	—	—	—	—
	2	2	54	56	55	55	1.4	—
	3	59	29	82	56	56	13.2	53-59
Inferior extremity	1	0	—	—	—	—	—	—
	2	63	29	82	56	56	12.7	52-59
Dorsal plateau	1	0	—	—	—	—	—	—
	2	64	29	82	56	56	12.8	53-59
Ventral rampart	1	1	—	—	—	—	—	—
	2	4	34	58	46	46	10.2	—
	3	56	29	82	57	57	12.8	54-61
Dorsal body of the pubic bone	1	15	29	73	47	45	13.6	40-55
	2	24	38	82	56	54	11.1	51-60
	3	22	29	78	62	61	11.9	56-67
Ventral body of the pubic bone	1	1	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	41	29	82	55	56	14.4	50-59
	4	20	44	76	59	58	9.0	55-63
Medial aspect of the obturator foramen	1	1	—	—	—	—	—	—
	2	58	29	82	56	56	13.1	52-59
	3	4	49	56	**53**	**53**	3.0	—
Symphyseal rim	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	14	34	73	53	55	11.6	46-60
	4	33	29	82	56	54	13.3	52-61
Pubic tubercle	1	5	42	57	53	56	6.2	45-61
	2	52	29	82	56	55	13.5	52-60
Ventral bevelling	1	0	—	—	—	—	—	—
	2	64	29	82	56	56	12.8	53-59
Erosion of the symphyseal face	1	39	29	78	56	56	11.2	52-59
	2	10	34	78	59	60	13.3	49-68
Erosion of the symphyseal rim	1	39	29	82	55	54	12.7	51-59
	2	5	42	78	59	60	16.4	39-80
Symphyseal face shape	1	10	31	78	50	48	14.7	39-60
	2	41	38	82	58	56	11.6	54-62
	3	11	29	78	**54**	60	14.7	44-64
Ligamentous outgrowths on the ventral bevelling	1	29	29	82	53	52	12.9	48-57
	2	24	38	78	60	60	12.0	55-65

Taller height group: age descriptive statistics for the pubic symphysis traits for the pooled sex

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	21	19	74	47	46	15.4	40-54
	2	43	31	92	56	57	14.9	52-61
Superior extremity	1	1	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	59	26	92	53	51	15.1	50-57
Inferior extremity	1	1	—	—	—	—	—	—
	2	60	26	92	53	53	15.0	49-57
Dorsal plateau	1	1	—	—	—	—	—	—
	2	62	26	92	53	53	15.2	50-57
Ventral rampart	1	1	—	—	—	—	—	—
	2	4	32	60	51	**55**	13.0	—
	3	58	26	92	53	53	15.2	49-57
Dorsal body of the pubic bone	1	12	26	80	50	49	15.0	40-60
	2	34	31	70	49	49	12.1	44-53
	3	16	35	92	67	68	14.4	59-74
Ventral body of the pubic bone	1	1	—	—	—	—	—	—
	2	2	31	60	46	46	20.5	—
	3	32	31	92	52	51	14.7	47-58
	4	27	26	83	55	57	15.7	49-61
Medial aspect of the obturator foramen	1	0	—	—	—	—	—	—
	2	61	19	92	52	51	15.6	48-56
	3	3	58	73	67	70	7.9	—
Symphyseal rim	1	1	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	6	31	66	50	**54**	14.8	34-65
	4	48	26	92	53	51	15.3	48-57
Pubic tubercle	1	2	19	31	25	25	8.5	—
	2	59	26	92	53	51	15.1	50-57
Ventral bevelling	1	0	—	—	—	—	—	—
	2	64	19	92	53	53	15.6	49-57
Erosion of the symphyseal face	1	37	19	92	49	48	16.6	44-55
	2	13	43	83	64	63	10.9	58-71
Erosion of the symphyseal rim	1	44	19	92	50	48	16.9	45-55
	2	7	44	65	58	60	7.5	51-65
Symphyseal face shape	1	5	19	74	45	39	22.6	—
	2	46	31	92	55	55	14.0	51-59
	3	13	26	83	**48**	**46**	17.3	37-58
Ligamentous outgrowths on the ventral bevelling	1	28	19	63	44	45	11.8	40-49
	2	35	33	92	59	61	15.0	54-65

Lighter group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	23	29	82	53	52	14.6	46-59
	2	36	38	78	59	60	11.5	56-63
Superior extremity	1	0	—	—	—	—	—	—
	2	1	45	60	53	53	10.6	—
	3	57	29	82	57	58	13.4	53-60
Inferior extremity	1	0	—	—	—	—	—	—
	2	61	29	82	56	56	12.8	53-60
Dorsal plateau	1	0	—	—	—	—	—	—
	2	62	29	82	57	57	12.9	53-60
Ventral rampart	1	1	—	—	—	—	—	—
	2	5	34	60	49	49	10.9	—
	3	53	29	82	58	58	13.0	54-61
Dorsal body of the pubic bone	1	14	31	73	49	47	12.8	42-57
	2	25	32	82	55	54	11.8	50-60
	3	20	29	78	64	65	12.4	58-69
Ventral body of the pubic bone	1	1	—	—	—	—	—	—
	2	2	52	60	56	56	5.7	—
	3	38	29	82	56	57	14.0	51-61
	4	20	32	77	58	56	11.9	53-64
Medial aspect of the obturator foramen	1	1	—	—	—	—	—	—
	2	57	29	82	56	57	13.2	53-60
	3	3	49	56	**53**	**54**	3.6	—
Symphyseal rim	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	14	34	73	54	55	12.2	47-61
	4	29	29	82	58	58	13.9	52-63
Pubic tubercle	1	4	42	57	52	55	6.9	—
	2	50	29	82	57	58	13.7	53-61
Ventral bevelling	1	0	—	—	—	—	—	—
	2	62	29	82	57	57	13.0	53-60
Erosion of the symphyseal face	1	35	32	78	57	56	11.7	53-61
	2	10	34	78	59	60	13.1	50-69
Erosion of the symphyseal rim	1	33	29	82	56	54	13.8	51-61
	2	6	42	78	60	60	14.6	44-75
Symphyseal face shape	1	10	31	78	50	48	14.7	39-60
	2	40	38	82	59	60	11.6	56-63
	3	10	29	78	**54**	59	14.8	43-65
Ligamentous outgrowths on the ventral bevelling	1	30	29	82	53	52	12.0	48-57
	2	21	38	78	62	61	12.8	57-68

Heavier group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	24	19	74	47	51	15.0	41-54
	2	43	31	92	56	56	15.4	51-61
Superior extremity	1	1	—	—	—	—	—	—
	2	2	31	56	44	44	17.7	—
	3	62	26	92	53	53	15.2	50-57
Inferior extremity	1	1	—	—	—	—	—	—
	2	63	26	92	53	54	15.2	49-57
Dorsal plateau	1	1	—	—	—	—	—	—
	2	65	26	92	53	54	15.4	50-57
Ventral rampart	1	1	—	—	—	—	—	—
	2	3	32	59	47	51	13.9	—
	3	62	26	92	53	54	15.2	50-57
Dorsal body of the pubic bone	1	13	26	80	47	44	15.7	38-57
	2	34	31	86	50	50	13.4	46-55
	3	18	35	92	64	62	14.1	57-71
Ventral body of the pubic bone	1	1	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	35	29	92	51	49	14.8	46-56
	4	28	26	86	57	58	15.2	51-62
Medial aspect of the obturator foramen	1	0	—	—	—	—	—	—
	2	63	19	92	52	52	15.8	48-56
	3	4	52	73	63	64	9.9	—
Symphyseal rim	1	1	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	6	31	58	48	**54**	12.6	34-61
	4	53	26	92	53	52	15.3	49-57
Pubic tubercle	1	3	19	56	35	31	18.9	—
	2	62	26	92	53	53	15.2	50-57
Ventral bevelling	1	0	—	—	—	—	—	—
	2	67	19	92	53	54	15.7	49-57
Erosion of the symphyseal face	1	42	19	92	50	50	16.4	45-55
	2	13	43	83	54	63	11.4	57-71
Erosion of the symphyseal rim	1	51	19	92	51	50	16.4	46-55
	2	6	44	65	57	60	8.2	—
Symphyseal face shape	1	5	19	74	45	39	22.6	—
	2	48	31	92	55	55	14.5	51-59
	3	14	26	83	**48**	**46**	17.3	38-58
Ligamentous outgrowths on the ventral bevelling	1	27	19	68	44	43	12.4	39-49
	2	39	33	92	59	58	14.7	54-64

Gracile group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	22	19	82	48	53	16.3	41-56
	2	34	31	92	58	58	15.8	52-63
Superior extremity	1	1	—	—	—	—	—	—
	2	2	31	56	44	44	17.7	—
	3	50	26	92	55	57	16.2	50-60
Inferior extremity	1	1	—	—	—	—	—	—
	2	54	26	92	54	56	15.9	50-59
Dorsal plateau	1	1	—	—	—	—	—	—
	2	54	26	92	55	56	16.0	50-59
Ventral rampart	1	1	—	—	—	—	—	—
	2	5	32	60	50	**58**	12.6	35-66
	3	49	26	92	55	56	16.2	51-60
Dorsal body of the pubic bone	1	12	26	80	46	43	15.1	36-55
	2	26	31	82	53	56	15.1	47-59
	3	15	35	92	65	64	14.3	57-73
Ventral body of the pubic bone	1	1	—	—	—	—	—	—
	2	2	31	60	46	46	20.5	—
	3	31	29	92	53	52	16.0	47-59
	4	21	26	83	58	58	16.0	50-65
Medial aspect of the obturator foramen	1	0	—	—	—	—	—	—
	2	54	19	92	53	55	16.2	49-58
	3	1	—	—	—	—	—	—
Symphyseal rim	1	1	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	10	31	68	50	**57**	12.9	41-59
	4	38	26	92	54	54	16.8	49-60
Pubic tubercle	1	5	19	57	41	42	16.3	—
	2	48	26	92	55	57	16.5	51-60
Ventral bevelling	1	0	—	—	—	—	—	—
	2	56	19	92	54	56	16.4	50-58
Erosion of the symphyseal face	1	39	19	92	51	52	16.2	46-56
	2	9	61	83	70	68	7.8	64-76
Erosion of the symphyseal rim	1	42	19	92	52	53	17.6	47-58
	2	2	44	61	53	53	12.0	—
Symphyseal face shape	1	7	19	63	41	39	14.8	28-55
	2	40	31	92	58	58	14.9	53-62
	3	9	26	83	**48**	**46**	19.1	33-62
Ligamentous outgrowths on the ventral bevelling	1	31	19	82	48	49	15.0	42-53
	2	23	35	92	61	62	15.8	54-68

Robust group: age descriptive statistics for the pubic symphysis traits for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	25	29	78	51	51	13.7	45-57
	2	44	33	81	57	60	11.5	54-61
Superior extremity	1	0	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	68	29	81	55	52	12.6	51-58
Inferior extremity	1	0	—	—	—	—	—	—
	2	69	29	81	54	54	12.2	52-57
Dorsal plateau	1	0	—	—	—	—	—	—
	2	72	29	81	55	54	12.4	52-58
Ventral rampart	1	1	—	—	—	—	—	—
	2	3	34	51	45	49	9.3	—
	3	65	29	81	55	54	12.5	52-58
Dorsal body of the pubic bone	1	15	31	73	51	50	13.2	43-58
	2	32	32	70	51	51	9.2	47-54
	3	23	29	81	63	62	12.5	58-69
Ventral body of the pubic bone	1	1	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	42	29	81	54	51	13.5	50-58
	4	26	32	77	56	55	10.8	51-60
Medial aspect of the obturator foramen	1	1	—	—	—	—	—	—
	2	65	29	81	55	52	12.9	51-58
	3	6	49	70	57	55	7.3	49-64
Symphyseal rim	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	10	34	73	54	53	12.1	45-62
	4	43	29	81	54	52	12.5	50-58
Pubic tubercle	1	2	54	56	55	**55**	1.4	—
	2	63	29	81	54	52	12.6	51-57
Ventral bevelling	1	0	—	—	—	—	—	—
	2	72	29	81	55	54	12.4	52-58
Erosion of the symphyseal face	1	37	32	81	54	52	12.0	50-58
	2	14	34	78	57	59	11.6	50-63
Erosion of the symphyseal rim	1	41	29	81	52	51	12.5	49-56
	2	10	42	78	60	60	11.5	51-68
Symphyseal face shape	1	8	31	78	54	53	17.5	40-69
	2	47	37	81	56	54	11.0	53-59
	3	15	29	78	**53**	58	14.6	44-61
Ligamentous outgrowths on the ventral bevelling	1	26	29	71	49	50	10.2	45-53
	2	36	33	81	59	60	12.4	55-63

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	36	26	82	51	50	15.1	46-56
	2	53	31	90	57	58	13.8	53-61
Superior extremity	1	0	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	86	26	90	55	52	14.6	51-58
Inferior extremity	1	0	—	—	—	—	—	—
	2	89	26	90	54	52	14.6	51-57
Dorsal plateau	1	0	—	—	—	—	—	—
	2	89	26	90	54	52	14.6	51-57
Ventral rampart	1	0	—	—	—	—	—	—
	2	4	34	58	46	46	10.2	—
	3	84	26	90	55	54	14.7	52-58
Dorsal body of the pubic bone	1	28	26	71	49	50	11.7	44-53
	2	30	31	90	51	49	14.8	46-57
	3	28	35	88	63	63	14.1	57-68
Ventral body of the pubic bone	1	1	—	—	—	—	—	—
	2	2	31	50	41	41	13.4	—
	3	61	29	82	55	54	13.6	51-58
	4	23	26	90	54	**52**	16.6	47-61
Medial aspect of the obturator foramen	1	1	—	—	—	—	—	—
	2	85	26	90	54	52	14.9	51-58
	3	2	49	56	53	53	24.5	—
Symphyseal rim	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	12	31	90	55	**54**	16.5	44-65
	4	65	26	88	55	52	14.6	51-58
Pubic tubercle	1	3	31	56	43	42	12.5	—
	2	82	26	90	55	52	14.7	52-58
Ventral bevelling	1	0	—	—	—	—	—	—
	2	89	26	90	54	52	14.6	51-57
Erosion of the symphyseal face	1	61	26	84	51	49	13.1	48-54
	2	18	34	88	63	63	12.8	57-70
Erosion of the symphyseal rim	1	70	26	90	54	52	15.2	50-58
	2	3	52	78	63	60	13.3	—
Symphyseal face shape	1	13	34	78	51	50	12.2	44-59
	2	57	31	90	56	54	14.5	52-60
	3	19	26	82	**51**	55	16.0	43-59
Ligamentous outgrowths on the ventral bevelling	1	52	26	90	52	51	14.9	48-56
	2	26	35	88	60	61	14.1	54-66

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Billowing	1	30	26	81	55	54	13.7	50-60
	2	46	33	92	61	61	16.0	57-66
Superior extremity	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	75	26	92	59	58	15.5	55-62
Inferior extremity	1	0	—	—	—	—	—	—
	2	74	26	92	59	58	15.4	55-62
Dorsal plateau	1	0	—	—	—	—	—	—
	2	76	26	92	59	58	15.4	55-62
Ventral rampart	1	0	—	—	—	—	—	—
	2	2	32	51	42	42	13.4	—
	3	74	26	92	59	59	15.3	56-63
Dorsal body of the pubic bone	1	14	39	80	53	51	11.1	46-59
	2	33	26	86	52	52	13.9	47-57
	3	29	29	92	69	71	13.5	64-74
Ventral body of the pubic bone	1	0	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	36	26	92	55	52	16.0	50-61
	4	38	32	88	62	61	14.6	57-66
Medial aspect of the obturator foramen	1	0	—	—	—	—	—	—
	2	70	26	92	59	59	15.8	55-62
	3	5	52	73	62	58	9.8	—
Symphyseal rim	1	0	—	—	—	—	—	—
	2	0	—	—	—	—	—	—
	3	4	26	58	42	42	15.2	—
	4	58	29	92	59	58	15.0	55-63
Pubic tubercle	1	0	—	—	—	—	—	—
	2	72	26	92	58	58	15.5	55-62
Ventral bevelling	1	0	—	—	—	—	—	—
	2	76	26	92	59	58	15.4	55-62
Erosion of the symphyseal face	1	43	26	92	56	54	15.3	52-61
	2	17	29	85	56	57	15.7	48-64
Erosion of the symphyseal rim	1	53	26	92	57	55	16.1	52-61
	2	8	44	88	63	63	13.2	52-74
Symphyseal face shape	1	5	26	71	45	39	18.6	—
	2	54	38	92	61	61	13.9	57-65
	3	17	29	88	**55**	**51**	17.3	47-64
Ligamentous outgrowths on the ventral bevelling	1	18	26	63	46	47	10.6	41-51
	2	56	33	92	62	61	14.7	58-66

Age descriptive statistics for superior extremity and dorsal plateau for female individuals

Group	Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	Superior extremity	1	0	—	—	—	—	—	—
		2	107	29	90	60	60	13.9	57-62
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	103	29	90	60	60	13.8	57-62
Shorter	Superior extremity	1	0	—	—	—	—	—	—
		2	27	31	82	58	58	13.1	53-63
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	27	31	82	58	58	13.1	53-63
Taller	Superior extremity	1	0	—	—	—	—	—	—
		2	29	29	78	56	54	12.5	51-61
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	29	29	78	56	54	12.5	51-61
Lighter	Superior extremity	1	0	—	—	—	—	—	—
		2	35	29	78	57	58	12.3	52-61
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	35	29	78	57	58	12.3	52-61
Heavier	Superior extremity	1	0	—	—	—	—	—	—
		2	21	34	82	57	54	13.8	51-63
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	21	34	82	57	54	13.8	51-63
Gracile	Superior extremity	1	0	—	—	—	—	—	—
		2	24	39	82	58	56	12.1	53-63
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	24	39	82	58	56	12.1	53-63
Robust	Superior extremity	1	0	—	—	—	—	—	—
		2	32	29	78	56	58	13.4	51-61
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	32	29	78	56	58	13.4	51-61
Smaller area	Superior extremity	1	0	—	—	—	—	—	—
		2	37	39	88	58	58	12.1	54-62
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	37	39	88	58	58	12.1	54-62
Larger area	Superior extremity	1	0	—	—	—	—	—	—
		2	32	29	90	60	59	14.7	55-65
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	32	29	90	60	59	14.7	55-65

Age descriptive statistics for superior extremity and dorsal plateau for male individuals

Group	Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	Superior extremity	1	1	—	—	—	—	—	—
		2	114	26	92	56	55	16.3	53-59
	Dorsal plateau	1	1	—	—	—	—	—	—
		2	117	26	92	57	55	16.4	54-60
Shorter	Superior extremity	1	1	—	—	—	—	—	—
		2	35	26	92	54	54	16.2	49-60
	Dorsal plateau	1	1	—	—	—	—	—	—
		2	37	26	92	55	56	16.4	50-61
Taller	Superior extremity	1	0	—	—	—	—	—	—
		2	32	31	80	50	51	12.3	46-55
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	33	31	80	50	51	12.6	46-55
Lighter	Superior extremity	1	1	—	—	—	—	—	—
		2	40	26	92	52	52	16.4	47-57
	Dorsal plateau	1	1	—	—	—	—	—	—
		2	43	26	92	53	52	16.5	48-58
Heavier	Superior extremity	1	0	—	—	—	—	—	—
		2	28	31	83	54	55	12.9	49-59
	Dorsal plateau	1	1	—	—	—	—	—	—
		2	28	31	83	55	55	13.3	49-60
Gracile	Superior extremity	1	1	—	—	—	—	—	—
		2	31	29	80	50	54	14.7	45-56
	Dorsal plateau	1	1	—	—	—	—	—	—
		2	31	29	80	51	54	15.1	45-56
Robust	Superior extremity	1	0	—	—	—	—	—	—
		2	36	26	92	54	53	14.3	49-59
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	39	26	92	55	54	14.6	50-60
Smaller area	Superior extremity	1	0	—	—	—	—	—	—
		2	47	26	92	52	49	16.8	47-57
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	48	26	92	52	50	16.9	47-57
Larger area	Superior extremity	1	0	—	—	—	—	—	—
		2	47	26	88	57	55	14.8	53-62
	Dorsal plateau	1	0	—	—	—	—	—	—
		2	48	26	88	57	55	14.9	53-61

APPENDIX 5 | ASSEMBLED STAGES FOR THE COMPONENTS AND COMPOSITE SCORE FOR THE POOLED SEX SAMPLE

COMPONENTS

Acetabulum

Component lunate surface

Sum	N Coimbra	N Bass	Stage
4	15	0	
5	18	6	1
6	22	12	
7	20	33	
8	15	48	2
9	5	43	
10	12	17	
11	8	23	3
12	5	11	

Component Acetabular fossa

Sum	N Coimbra	N Bass	Stage
2	5	1	
3	14	8	1
4	35	18	
5	69	28	
6	60	58	
7	35	29	2
8	20	48	

Iliac auricular surface

Component granularity

Sum	N Coimbra	N Bass	Stage
2	5	5	1
3	217	163	
4	0	0	2
5	13	48	

Component porosity + lipping

Sum	N Coimbra	Stage
3	39	1
4	11	2
5	3	
6	3	

Component osteophytic changes

Sum	N Bass	Stage
2	70	It was not established
3	64	
4	34	

Component Porosity

Sum	N Bass	Stage
2	112	1
3	51	2
4	16	

Pubic symphysis

Component erosion

Sum	N Coimbra	N Bass	Stage
2	25	92	1
3	8	26	2
4	7	10	

Component face topography

Sum	N Coimbra	N Bass	Stage
2	66	24	It was not established
3	46	41	
4	80	129	
5	24	31	

Component margin changes Coimbra

Sum	N Coimbra	Stage
5	0	1
6	1	
7	2	
8	1	
9	4	
10	2	
11	7	
12	12	
13	28	2
14	45	

Component margin changes Bass

Sum	N Bass	Stage
4	1	1
5	0	
6	0	
7	1	
8	0	
9	3	
10	7	
11	12	
12	131	2

311

Component dorsal body + LOVBe (Ligamentous outgrowths on the ventral bevelling)

Sum	N Coimbra	Stage
2	29	
3	34	1
4	17	
5	2	2

COMPOSITE SCORE

Acetabulum

Sum	N Coimbra	N Bass	Stage
6	1	0	
7	1	0	
8	4	1	1
9	9	2	
10	12	4	
11	12	12	
12	12	16	
13	15	20	2
14	12	17	
15	7	26	
16	7	27	
17	3	17	
18	3	14	3
19	1	8	
20	1	0	

Iliac auricular surface

Composite score without lipping

Sum	N Coimbra	N Bass	Stage
7	4	1	
8	51	44	1
9	25	57	
10	12	31	
11	3	29	
12	2	10	2
13	0	2	
14	0	0	
15	0	0	

Bass: composite score total (with lipping)

Sum	N Bass	Stage
8	1	
9	27	1
10	36	
11	39	2
12	20	
13	14	
14	3	
15	1	3
16	0	
17	0	

Pubic symphysis

Composite score without erosion of the symphyseal face, erosion of the symphyseal rim and ligamentous outgrowth on the ventral bevelling

Sum	N Coimbra	N Bass	Stage
12	0	0	
13	0	0	
14	0	0	
15	0	0	
16	2	0	
17	1	0	
18	0	0	1
19	1	0	
20	1	0	
21	1	0	
22	4	1	
23	3	1	
24	8	1	
25	9	1	
26	6	8	2
27	12	12	
28	15	31	
29	15	33	
30	8	39	
31	3	12	3
32	1	7	
33	0	1	

Bass: Composite score (with erosion of the symphyseal face, erosion of the symphyseal rim and ligamentous outgrowth on the ventral bevelling)

Sum	N Bass	Stage
15	0	
16	0	
17	0	
18	0	
19	0	
20	0	
21	0	
22	0	1
23	0	
24	0	
25	0	
26	0	
27	1	
28	2	
29	3	
30	6	
31	15	
32	21	2
33	23	
34	20	
35	9	
36	3	3
37	5	
38	1	
39	1	

APPENDIX 6 | DESCRIPTIVE STATISTICS FOR THE COIMBRA COLLECTION: COMPONENTS AND COMPOSITE SCORE

Age descriptive statistics, in years, for the acetabulum, iliac auricular surface and pubic symphyseal components and composite score: number of individuals (N), minimum (min), maximum (max), mean, median, standard deviation (SD) age and 95% confidence interval for the mean (95% CI). Cases were highlighted in bold when a more advanced stage showed a lower age mean and/or median when compared with the previous stage.

Acetabulum

Total sample (without group division): age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	55	18	60	31	29	10.7	29-34
	2	40	21	88	50	48	16.1	45-55
	3	25	39	77	59	58	10.8	54-63
Component fossa	1	123	18	84	39	37	15.2	36-41
	2	115	19	88	43	40	16.8	40-46
Composite score	1	27	18	43	28	26	7.8	25-31
	2	58	19	77	44	43	15.8	39-48
	3	15	39	88	59	58	14.2	51-67

Shorter height group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	28	19	60	32	31	10.4	28-36
	2	20	26	88	49	46	15.3	42-56
	3	10	39	77	58	58	13.1	49-67
Component fossa	1	56	19	77	38	36	14.6	34-42
	2	48	19	88	45	43	16.9	40-50
Composite score	1	13	19	43	31	33	7.7	26-35
	2	31	19	77	43	41	14.9	38-49
	3	6	39	88	61	58	18.3	41-80

Taller height group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	19	19	55	30	27	9.1	26-35
	2	18	21	75	50	50	18.0	41-59
	3	11	40	73	57	56	10.4	50-64
Component fossa	1	46	20	84	40	38	15.1	36-45
	2	46	19	75	42	39	16.2	37-47
Composite score	1	9	21	42	28	26	7.5	23-34
	2	22	19	75	42	39	17.9	34-50
	3	8	40	73	58	57	12.3	47-68

Lighter group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	29	19	51	30	29	8.7	27-34
	2	20	26	88	52	49	15.9	45-60
	3	10	41	77	60	58	11.1	52-67
Component fossa	1	59	19	77	38	37	13.9	34-41
	2	49	19	88	45	43	17.9	40-50
Composite score	1	14	19	43	31	34	8.0	27-36
	2	32	19	77	43	42	16.1	38-49
	3	4	58	88	69	66	14.4	—

Heavier group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	18	20	60	33	30	11.6	27-39
	2	19	21	74	46	45	15.4	39-54
	3	13	39	75	57	56	11.6	50-64
Component fossa	1	41	19	77	40	37	16.0	35-45
	2	46	20	75	43	40	14.7	38-47
Composite score	1	7	21	39	27	26	6.1	21-33
	2	20	20	74	42	39	14.5	35-48
	3	10	39	75	55	55	13.0	45-64

Gracile group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	22	19	55	31	29	9.2	27-35
	2	15	25	75	47	44	16.0	38-56
	3	7	39	75	60	56	12.4	48-71
Component fossa	1	39	20	77	38	35	15.7	33-43
	2	37	19	75	39	38	15.6	34-45
Composite score	1	10	21	43	31	29	8.3	25-37
	2	22	19	75	37	37	14.0	31-43
	3	6	39	75	60	62	13.4	46-74

Robust group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	20	19	60	33	32	10.9	28-38
	2	19	21	88	51	48	16.6	43-59
	3	13	40	77	56	55	11.7	49-63
Component fossa	1	43	19	77	41	38	14.2	37-45
	2	41	21	88	46	45	16.2	41-51
Composite score	1	10	19	38	28	28	6.5	23-33
	2	24	21	77	48	49	14.9	42-54
	3	8	40	88	58	58	16.2	44-71

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	19	19	43	29	29	8.2	25-33
	2	11	34	88	52	48	17.0	41-63
	3	2	41	58	**50**	50	12.0	—
Component fossa	1	28	21	74	38	38	12.1	33-43
	2	21	19	88	39	36	18.7	31-48
Composite score	1	12	19	43	30	32	7.9	25-35
	2	16	19	74	40	40	15.6	32-48
	3	2	58	88	73	73	21.2	—

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	20	19	60	33	31	11.9	27-39
	2	11	21	74	45	45	16.0	34-55
	3	2	49	56	53	53	4.9	—
Component fossa	1	29	20	77	37	33	14.4	31-42
	2	22	19	74	37	35	13.6	31-43
Composite score	1	8	20	42	27	25	7.5	20-33
	2	21	19	74	40	38	14.9	33-47
	3	1	—	—	—	—	—	—

Iliac auricular surface

Total sample (without group division): age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	222	18	76	41	39	14.2	39-43
	2	13	20	72	46	47	15.4	37-55
Component porosity + lipping	1	39	19	75	41	40	15.0	37-46
	2	17	29	74	51	51	16.1	43-59
Composite score	1	80	19	75	40	39	12.8	37-43
	2	17	28	74	50	47	16.0	42-58

Shorter height group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	93	20	76	42	39	14.1	39-44
	2	6	20	64	47	50	16.1	30-64
Component fossa	1	22	20	75	41	40	14.4	34-47
	2	7	29	68	47	47	12.7	35-59
Composite score	1	43	20	75	41	39	13.5	37-45
	2	8	29	64	45	43	11.6	35-54

Taller height group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	95	20	75	40	37	14.2	38-43
	2	7	28	72	46	41	16.1	31-60
Component porosity + lipping	1	13	21	75	42	37	15.8	33-52
	2	10	29	74	53	54	18.3	40-66
Composite score	1	29	21	75	39	36	12.3	34-43
	2	8	28	74	55	60	19.9	38-71

Lighter group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	101	18	75	41	40	14.0	39-44
	2	6	20	64	47	50	16.1	30-64
Component porosity + lipping	1	21	20	75	41	39	14.6	34-47
	2	10	29	74	50	50	13.4	41-60
Composite score	1	44	20	75	41	39	13.6	37-45
	2	8	38	74	53	50	12.3	42-63

Heavier group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	90	20	75	41	39	14.2	38-44
	2	6	28	72	49	47	15.4	32-65
Component porosity + lipping	1	15	21	75	44	42	14.1	36-51
	2	7	29	74	51	56	20.6	32-70
Composite score	1	32	21	75	40	38	11.5	36-44
	2	8	28	74	50	47	19.1	34-66

Gracile group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	68	20	75	39	38	15.0	36-43
	2	5	20	57	40	40	15.8	—
Component porosity + lipping	1	14	20	75	42	34	19.3	31-53
	2	3	30	67	51	56	19.0	—
Composite score	1	27	20	75	39	36	14.7	33-45
	2	5	28	67	48	53	16.0	—

Robust group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	89	20	74	42	41	13.0	39-45
	2	3	52	72	63	64	10.1	—
Component porosity + lipping	1	16	21	62	40	40	10.7	35-46
	2	12	29	74	53	52	16.0	43-64
Composite score	1	37	21	68	41	39	11.8	37-45
	2	8	29	74	56	56	17.4	41-70

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	40	19	74	38	37	13.8	33-42
	2	0	—	—	—	—	—	—
Component porosity + lipping	1	10	19	54	33	34	11.4	25-41
	2	5	29	74	45	41	18.4	—
Composite score	1	23	19	58	35	35	11.3	30-40
	2	2	41	74	58	58	23.3	—

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	35	20	67	37	36	10.7	33-40
	2	3	28	72	51	53	22.1	—
Component porosity + lipping	1	12	21	67	40	39	13.5	31-48
	2	3	32	72	52	52	20.0	—
Composite score	1	20	21	67	40	38	11.2	34-45
	2	4	28	72	47	45	19.5	—

Age descriptive statistics for the composite score for the female individuals

Group	Score	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	1	46	19	75	41	39	13.8	37-45
	2	8	38	74	60	61	13.4	49-71
Shorter	1	22	22	68	41	39	12.8	35-47
	2	3	38	64	50	47	13.2	—
Taller	1	19	20	75	40	38	15.2	33-48
	2	4	58	74	70	73	7.7	—
Lighter	1	39	20	68	40	38	13.2	36-44
	2	6	38	74	56	56	12.7	42-69
Heavier	1	4	38	75	54	51	15.4	—
	2	2	72	74	73	73	1.4	—
Gracile	1	19	20	75	37	38	14.6	30-44
	2	3	58	74	68	72	8.7	
Robust	1	17	22	68	45	46	13.3	38-52
	2	3	47	74	62	64	13.7	—
Smaller Joint	1	19	19	58	35	35	12.1	29-41
	2	1	—	—	—	—	—	—
Larger Joint	1	10	29	67	44	45	12.0	35-52
	2	1	—	—	—	—	—	—

Age descriptive statistics, in years, for the auricular surface criteria for male individuals

Group	Score	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	1	34	21	75	39	38	11.4	35-43
	2	9	28	67	41	41	12.8	31-51
Shorter	1	17	27	51	39	38	7.4	35-43
	2	5	28	45	**36**	**36**	7.4	—
Taller	1	14	21	75	39	34	16.2	30-48
	2	4	29	67	48	47	16.3	—
Lighter	1	5	37	75	51	48	14.5	—
	2	2	41	45	**43**	**43**	2.8	—
Heavier	1	28	21	57	38	37	9.6	34-42
	2	6	28	67	42	39	15.1	—
Gracile	1	12	26	75	39	36	14.2	30-48
	2	4	28	67	46	46	17.5	—
Robust	1	16	21	51	38	39	9.0	34-43
	2	3	29	45	38	41	8.3	—
Smaller Joint	1	4	27	43	34	34	7.2	23-46
	2	1	—	—	—	—	—	—
Larger Joint	1	10	21	48	35	37	8.9	29-42
	2	3	28	53	39	36	12.8	—

Pubic symphysis

Total sample (without group): age descriptive statistics for the pubic symphysis criteria for the pooled sexes

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	29	23	87	44	38	16.8	37-50
	2	73	25	75	48	46	12.5	45-51
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	63	25	76	47	46	12.9	44-50
	2	19	26	75	53	56	12.4	47-59
Component erosion	1	25	25	74	46	42	14.2	40-51
	2	15	31	72	50	53	13.3	43-58
Component face topography	2	66	18	87	38	35	15.5	34-42
	3	46	20	76	47	43	13.9	43-51
	4	80	26	88	49	47	14.5	46-52
	5	24	29	73	49	50	12.9	43-54
Composite score	1	21	25	74	39	35	11.8	34-45
	2	42	23	74	47	46	13.8	42-51
	3	27	29	75	52	55	12.2	48-57

Shorter height group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	15	25	74	44	37	16.5	35-53
	2	24	26	74	44	43	11.1	39-49
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	27	25	76	47	48	11.2	43-52
	2	4	31	75	55	56	18.1	—
Component erosion	1	8	26	74	46	46	15.7	33-59
	2	6	31	60	46	46	12.3	33-59
Component face topography	2	25	19	74	39	35	15.5	33-46
	3	22	26	76	46	40	14.0	39-52
	4	36	26	88	50	48	14.6	45-55
	5	9	29	60	**45**	48	12.5	36-55
Composite score	1	13	25	74	39	35	12.7	32-47
	2	15	26	74	47	46	14.7	38-55
	3	6	31	58	46	**44**	10.5	35-57

Taller height group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	11	23	59	38	38	11.7	30-46
	2	42	25	75	49	50	12.9	45-54
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	32	25	75	46	41	14.1	41-51
	2	14	26	67	53	56	11.0	47-60
Component erosion	1	17	25	74	45	42	14.0	38-53
	2	8	32	72	52	55	14.5	40-64
Component face topography	2	27	20	66	36	32	13.1	30-41
	3	15	31	74	46	40	13.8	38-54
	4	33	28	75	49	46	14.6	44-54
	5	15	29	73	51	54	13.1	44-58
Composite score	1	7	27	59	41	38	11.5	30-51
	2	22	23	74	44	42	13.4	39-50
	3	20	29	75	54	56	12.2	48-60

Lighter group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	16	23	87	42	36	17.5	33-51
	2	25	28	75	48	46	10.9	43-53
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	22	25	75	47	48	13.2	41-53
	2	3	49	58	54	54	20.3	—
Component erosion	1	7	25	58	43	42	12.8	31-55
	2	6	33	60	49	48	10.0	38-59
Component face topography	2	37	18	87	39	35	16.7	34-45
	3	17	26	70	43	40	11.3	37-49
	4	37	27	88	51	50	14.8	46-56
	5	8	29	59	**46**	**48**	11.1	36-55
Composite score	1	13	25	51	37	35	7.4	32-41
	2	15	23	70	47	49	13.5	40-55
	3	4	41	75	58	58	13.9	—

Heavier group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	12	26	74	47	45	16.6	36-57
	2	44	25	74	47	46	12.9	43-51
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	34	29	74	46	44	12.1	42-50
	2	14	26	75	53	56	13.6	45-61
Component erosion	1	18	26	74	47	43	14.9	39-54
	2	9	31	72	51	56	15.7	39-63
Component face topography	2	21	20	74	39	38	15.3	32-46
	3	21	20	74	46	43	14.0	39-52
	4	30	26	72	47	43	13.5	42-52
	5	16	29	73	51	55	13.8	43-58
Composite score	1	7	27	74	45	38	17.0	30-61
	2	22	26	74	44	40	13.5	38-50
	3	21	29	72	50	54	11.8	45-56

Gracile group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	13	25	74	42	40	14.3	33-51
	2	29	25	75	46	46	13.4	41-51
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	25	25	75	45	40	13.4	39-50
	2	8	26	75	57	56	14.9	44-69
Component erosion	1	16	25	74	45	43	15.1	37-53
	2	5	33	59	52	56	10.9	38-66
Component face topography	2	21	19	74	37	35	16.0	30-45
	3	14	29	60	41	40	8.8	36-46
	4	26	26	75	49	48	15.1	42-55
	5	11	29	73	49	54	14.0	39-58
Composite score	1	11	25	74	44	40	14.4	34-53
	2	14	26	53	**38**	39	9.2	32-43
	3	14	29	75	53	56	13.0	46-61

Robust group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	10	23	60	36	34	10.7	29-44
	2	30	31	74	47	46	11.2	43-52
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	25	32	74	49	48	11.0	45-54
	2	6	31	60	47	48	10.9	36-59
Component erosion	1	8	33	74	48	46	13.7	37-60
	2	8	31	72	48	47	16.3	35-62
Component face topography	2	26	19	66	36	33	12.8	31-41
	3	15	26	74	48	46	13.9	40-55
	4	31	27	88	50	46	14.1	44-55
	5	11	31	72	50	49	12.4	42-59
Composite score	1	8	27	47	35	34	6.7	30-41
	2	19	23	74	48	49	13.2	41-54
	3	8	31	72	49	**46**	12.5	38-59

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	6	30	59	43	43	11.5	31-55
	2	15	29	72	47	45	11.7	40-53
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	13	30	72	45	43	11.5	38-52
	2	2	49	56	53	53	4.9	—
Component erosion	1	7	37	56	46	44	6.5	40-52
	2	6	32	72	53	54	13.9	38-67
Component face topography	2	10	24	60	46	49	12.0	37-54
	3	5	32	52	**43**	42	8.3	—
	4	10	30	46	40	41	4.6	37-44
	5	7	29	72	49	48	15.6	35-63
Composite score	1	4	30	59	**46**	**47**	12.4	—
	2	12	29	62	43	43	10.7	36-50
	3	3	41	72	56	56	15.5	—

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	7	25	70	36	32	15.6	—
	2	13	25	74	46	42	12.7	38-53
Component dorsal body + Ligamentous outgrowth of the ventral bevelling	1	15	25	76	47	42	16.3	38-56
	2	2	26	56	**41**	41	21.2	—
Component erosion	1	6	25	74	42	38	18.4	—
	2	1	—	—	—	—	—	—
Component face topography	2	10	19	70	32	26	16.5	20-44
	3	7	33	76	47	37	19.3	—
	4	5	39	67	50	45	12.8	—
	5	4	36	56	**46**	46	8.7	—
Composite score	1	4	25	37	31	31	5.1	—
	2	8	26	74	50	51	17.4	36-65
	3	5	36	56	**44**	**42**	7.7	—

Age descriptive statistics, in years, for the pubic symphysis criteria for female individuals

Group	Criteria	Score	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	Component margin changes	1	15	25	87	46	38	19.1	35-56
		2	18	28	74	50	47	14.2	43-57
	Composite score	1	13	25	74	39	35	12.9	32-47
		2	14	28	74	51	48	15.7	42-60
		3	3	58	72	63	58	8.1	—
Shorter	Component margin changes	1	9	29	70	38	34	12.6	29-48
		2	7	28	74	48	46	14.6	35-62
	Composite score	1	9	29	47	36	34	5.9	31-40
		2	6	28	74	50	46	18.1	31-69
		3	1	—	—	—	—	—	—
Taller	Component margin changes	1	4	25	74	48	**46**	21.0	—
		2	9	29	74	50	43	15.5	38-61
	Composite score	1	4	25	74	**48**	**46**	21.0	—
		2	5	29	74	46	40	17.1	—
		3	2	58	72	65	65	9.9	—
Lighter	Component margin changes	1	10	25	87	48	38	20.5	31-60
		2	8	38	58	49	47	7.9	42-55
	Composite score	1	8	25	47	36	34	7.2	30-41
		2	6	38	70	53	52	12.1	41-66
		3	2	—	—	—	—	—	—
Heavier	Component margin changes	1	5	30	74	46	38	18.0	23-68
		2	7	28	74	48	43	18.7	31-65
	Composite score	1	5	30	74	46	38	18.0	—
		2	5	28	74	**44**	40	18.9	—
		3	1	—	—	—	—	—	—
Gracile	Component margin changes	1	7	25	74	42	38	16.7	26-57
		2	8	28	74	48	43	18.1	33-63
	Composite score	1	7	25	74	42	38	16.7	26-57
		2	6	28	74	43	39	16.9	—
		3	2	58	72	65	65	9.9	—
Robust	Component margin changes	1	4	29	42	35	34	5.4	—
		2	6	41	58	48	47	6.0	41-54
	Composite score	1	5	29	47	37	34	7.3	—
		2	2	46	50	48	48	2.8	—
		3	1	—	—	—	—	—	—
Smaller area	Component margin changes	1	1	—	—	—	—	—	—
		2	3	29	43	37	39	7.2	—
	Composite score	1	1	—	—	—	—	—	—
		2	2	29	39	34	34	7.1	—
		3	0	—	—	—	—	—	—
Larger area	Component margin changes	1	3	25	70	41	29	24.9	—
		2	2	72	74	73	73	1.4	—
	Composite score	1	2	25	29	27	27	2.8	—
		2	2	70	74	72	72	2.8	—
		3	1	—	—	—	—	—	—

Age descriptive statistics, in years, for the pubic symphysis criteria for male individuals

Group	Criteria	Score	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	Component margin changes	1	14	23	70	41	40	14.4	33-50
		2	55	25	75	48	46	12.0	44-51
	Composite score	1	8	27	59	39	36	10.8	30-48
		2	28	23	66	44	43	12.4	40-49
		3	24	29	75	51	55	12.1	46-56
Shorter	Component margin changes	1	10	23	70	46	45	14.3	36-56
		2	26	25	67	**44**	**42**	10.7	39-48
	Composite score	1	5	32	59	44	42	10.8	—
		2	17	23	60	43	44	11.7	37-49
		3	8	31	67	47	44	11.3	37-56
Taller	Component margin changes	1	3	26	33	29	27	3.8	—
		2	24	29	75	51	55	12.1	46-56
	Composite score	1	2	27	35	31	31	5.7	—
		2	9	26	66	45	40	14.2	34-56
		3	15	29	75	53	55	12.3	46-59
Lighter	Component margin changes	1	9	23	70	42	42	13.7	31-52
		2	23	25	75	48	46	11.3	43-53
	Composite score	1	3	37	51	43	42	7.1	—
		2	16	23	60	44	45	11.0	38-50
		3	7	41	75	51	46	11.9	—
Heavier	Component margin changes	1	4	26	60	43	43	19.1	—
		2	27	26	67	46	41	12.6	41-51
	Composite score	1	4	27	59	38	34	14.2	—
		2	10	26	66	44	40	15.0	33-55
		3	15	29	67	49	55	12.4	43-56
Gracile	Component margin changes	1	6	26	59	42	43	12.4	29-55
		2	24	25	75	47	48	13.6	41-52
	Composite score	1	4	35	59	**47**	**47**	10.5	—
		2	10	26	53	38	40	9.8	31-45
		3	13	29	75	53	56	13.5	45-61
Robust	Component margin changes	1	6	23	60	38	35	13.6	23-52
		2	21	31	60	45	45	10.0	41-50
	Composite score	1	3	27	37	32	32	5.0	—
		2	15	23	66	47	49	12.9	39-54
		3	6	31	53	**43**	**44**	7.2	35-51
Smaller area	Component margin changes	1	6	30	59	43	43	10.9	32-55
		2	12	32	62	46	46	9.5	40-52
	Composite score	1	3	42	59	**51**	**51**	8.5	—
		2	11	30	62	44	44	10.7	37-51
		3	3	36	56	44	41	10.4	—
Larger area	Component margin changes	1	3	26	37	32	32	5.5	—
		2	11	25	60	44	42	10.0	37-51
	Composite score	1	2	32	37	35	35	3.5	—
		2	5	26	60	45	49	13.5	—
		3	4	39	56	46	**44**	7.4	—

APPENDIX 7 | DESCRIPTIVE STATISTICS FOR THE BASS COLLECTION: COMPONENTS AND COMPOSITE SCORE

Age descriptive statistics, in years, for the acetabulum, iliac auricular surface and pubic symphyseal components and composite score: number of individuals (N), minimum (min), maximum (max), mean, median, standard deviation (SD) age and 95% confidence interval for the mean (95% CI). Cases were highlighted in bold when a more advanced stage showed a lower age mean and/or median when compared with the previous stage.

Acetabulum

Total sample (without group division): age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	18	19	50	39	40	8.9	34-43
	2	124	25	92	56	55	15.1	53-59
	3	51	43	90	68	68	11.7	65-71
Component fossa	1	55	19	90	53	52	14.4	50-57
	2	135	26	92	59	59	15.7	56-61
Composite score	1	7	19	90	46	39	22.4	25-67
	2	91	26	92	53	51	14.8	50-56
	3	66	31	90	63	62	13.4	60-66

Shorter height group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	4	29	46	40	42	7.8	—
	2	39	25	82	53	52	13.7	48-57
	3	14	44	78	65	65	9.3	59-70
Component fossa	1	25	29	78	51	52	11.6	46-56
	2	27	29	77	57	58	13.6	52-63
Shorter	1	3	38	56	44	39	10.1	—
	2	32	29	78	53	52	13.0	48-57
	3	13	31	77	61	64	12.6	54-69

Taller height group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	8	19	46	33	34	8.4	26-40
	2	30	31	92	53	50	14.5	47-58
	3	14	50	81	62	62	9.0	57-68
Component fossa	1	10	19	66	49	49	13.9	39-59
	2	45	26	92	53	51	15.7	48-58
Composite score	1	2	19	46	33	33	19.1	—
	2	23	26	92	47	43	16.4	40-54
	3	20	46	81	60	60	8.6	56-64

Lighter group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	6	29	46	40	42	7.5	—
	2	36	25	82	54	53	13.6	50-59
	3	15	44	78	64	64	10.2	59-70
Component fossa	1	27	29	78	51	51	11.5	47-56
	2	23	31	77	58	60	14.1	51-64
Composite score	1	3	38	46	41	39	4.4	—
	2	31	29	78	53	52	13.2	48-58
	3	13	31	77	61	60	12.5	53-68

Heavier group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	6	19	41	32	34	7.9	23-40
	2	34	29	92	53	50	15.3	47-57
	3	13	50	81	63	62	7.9	58-67
Component fossa	1	9	19	86	52	**55**	18.6	38-67
	2	49	26	92	53	52	15.3	49-58
Composite score	1	2	19	56	38	38	26.2	—
	2	25	26	92	48	43	17.3	41-56
	3	20	46	81	60	61	8.7	56-64

Gracile group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	7	19	45	33	35	8.6	25-41
	2	29	25	92	54	55	17.1	47-60
	3	9	61	76	67	64	5.4	62-71
Component fossa	1	12	19	61	47	49	12.5	39-55
	2	34	26	92	55	58	17.4	49-61
Composite score	1	3	19	56	38	39	18.5	—
	2	20	26	92	48	46	17.0	40-56
	3	13	49	77	66	64	7.8	61-71

Robust group: age descriptive statistics for the acetabulum criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	5	29	46	39	41	7.9	—
	2	40	31	75	52	51	11.3	48-55
	3	19	44	81	62	60	10.2	57-67
Component fossa	1	23	29	78	52	51	11.7	47-58
	2	38	31	81	55	53	12.7	50-59
Composite score	1	2	38	46	42	42	5.7	—
	2	35	29	78	52	49	13.1	47-56
	3	20	31	81	57	57	10.2	52-62

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	8	26	50	40	42	8.8	33-48
	2	52	26	90	53	51	13.9	49-57
	3	10	44	88	67	68	13.3	57-76
Component fossa	1	28	31	78	50	46	11.4	46-54
	2	44	26	88	56	55	15.7	51-60
Composite score	1	3	38	46	41	39	4.4	—
	2	31	29	78	53	52	13.2	48-58
	3	13	31	77	61	60	12.5	53-68

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component lunate surface	1	7	19	48	38	41	10.0	28-47
	2	37	29	92	56	55	15.5	51-61
	3	16	47	80	63	63	9.4	58-68
Component fossa	1	13	19	90	**60**	**61**	19.1	48-71
	2	50	29	92	56	54	14.1	52-60
Composite score	1	2	19	56	38	38	26.2	—
	2	25	26	92	48	43	17.3	41-56
	3	20	46	81	60	61	8.7	56-64

Iliac auricular surface

Total sample (without group division) group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	168	26	92	58	57	15.5	55-60
	2	48	19	90	**56**	**55**	14.9	52-61
Component porosity	1	112	26	92	55	52	15.9	52-57
	2	67	19	88	56	56	13.0	53-59
Component osteophytic changes	2	70	19	82	51	50	13.8	48-54
	3	64	29	92	62	60	16.4	58-66
	4	34	32	88	62	64	13.8	58-67
Composite score	1	102	26	92	53	51	15.3	50-56
	2	72	19	90	57	56	13.2	53-60
Composite score total	1	64	26	92	52	50	16.1	48-56
	2	59	19	86	55	54	13.2	52-59
	3	18	41	90	62	61	14.6	55-69

Shorter height group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	53	29	82	55	54	13.2	51-59
	2	9	33	67	54	**52**	10.3	46-62
Component porosity	1	34	29	82	52	51	14.0	47-57
	2	20	31	75	56	55	10.5	51-61
Component osteophytic changes	2	24	29	78	50	49	12.7	45-55
	3	19	29	76	56	57	12.2	50-62
	4	9	39	77	59	64	12.3	50-69
Composite score	1	35	29	78	51	49	13.4	46-56
	2	17	33	71	56	56	9.5	51-61
Composite score total	1	23	29	78	49	46	12.4	44-54
	2	20	29	77	54	52	12.4	48-60
	3	2	60	64	62	62	2.8	—

Taller height group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	41	26	92	51	49	16.1	46-56
	2	19	19	73	55	59	14.0	48-61
Component porosity	1	31	26	92	50	50	15.1	44-55
	2	21	19	81	52	51	15.6	45-59
Component osteophytic changes	2	21	19	70	44	46	12.6	39-50
	3	13	33	92	60	63	18.9	49-72
	4	11	32	77	**58**	**61**	12.5	49-66
Composite score	1	30	26	92	49	46	16.9	43-56
	2	22	19	73	52	55	12.7	47-58
Composite score total	1	16	26	92	44	39	16.1	35-53
	2	15	19	81	51	51	15.9	43-60
	3	8	43	70	58	60	8.5	51-66

Lighter group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	48	29	82	55	54	13.5	51-59
	2	10	33	67	55	57	9.9	48-62
Component porosity	1	35	29	82	53	51	13.6	48-57
	2	15	31	75	55	54	11.8	49-62
Component osteophytic changes	2	22	31	78	52	49	12.5	46-57
	3	15	29	76	54	56	13.3	47-62
	4	12	32	77	58	62	14.4	49-62
Composite score	1	34	29	78	51	50	13.3	47-56
	2	14	33	71	56	57	10.0	50-62
Composite score total	1	23	31	78	50	46	12.2	44-55
	2	15	29	77	53	52	13.8	45-60
	3	3	55	64	60	60	4.5	—

Heavier group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	47	26	92	51	51	15.5	47-56
	2	18	19	73	54	57	14.3	47-61
Component porosity	1	30	26	92	49	48	15.5	43-55
	2	27	19	81	53	54	14.1	47-59
Component osteophytic changes	2	23	19	70	43	43	12.0	38-49
	3	17	33	92	60	61	16.5	52-69
	4	9	43	70	59	61	8.0	53-65
Composite score	1	31	26	92	49	46	16.7	43-55
	2	25	19	73	53	55	12.3	48-58
Composite score total	1	16	26	92	43	39	16.1	35-52
	2	20	19	81	53	54	14.2	46-60
	3	8	43	86	62	62	12.8	52-73

Gracile group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	39	26	92	52	51	17.3	47-58
	2	16	19	73	55	59	15.3	47-63
Component porosity	1	30	26	92	51	49	17.5	44-57
	2	16	19	73	53	56	15.2	45-61
Component osteophytic changes	2	21	19	70	42	42	12.5	37-48
	3	13	33	92	63	63	16.1	53-72
	4	7	39	77	**60**	**61**	11.7	49-71
Composite score	1	28	26	92	49	45	17.1	42-55
	2	17	19	73	54	58	14.4	47-62
Composite score total	1	16	26	92	43	39	15.9	35-52
	2	14	19	77	51	56	16.1	42-61
	3	5	55	70	63	63	5.4	56-69

Robust group: age descriptive statistics for the auricular surface criteria for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	55	29	81	54	52	12.6	50-57
	2	12	41	67	54	54	8.9	48-60
Component porosity	1	35	29	78	51	50	11.5	47-55
	2	25	31	81	54	52	12.3	49-59
Component osteophytic changes	2	24	31	78	52	49	11.7	47-57
	3	19	29	81	54	54	13.9	47-61
	4	13	32	77	58	61	12.8	50-65
Composite score	1	37	29	81	51	50	13.3	47-56
	2	22	37	71	54	52	9.0	50-58
Composite score total	1	23	31	78	49	48	12.4	44-55
	2	21	29	81	54	52	12.5	48-59
	3	5	43	65	56	59	8.6	—

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	39	29	82	56	54	13.9	52-61
	2	13	43	73	**54**	54	9.7	48-60
Component porosity	1	35	29	82	53	50	12.7	49-57
	2	14	43	81	59	60	11.7	52-66
Component osteophytic changes	2	23	29	82	53	49	13.9	47-59
	3	15	43	88	59	56	14.0	51-67
	4	10	39	80	58	58	12.0	49-66
Composite score	1	31	29	82	54	50	14.1	49-59
	2	16	43	73	57	57	9.7	52-62
Composite score total	1	20	29	82	52	48	14.2	45-58
	2	21	39	81	56	54	11.4	51-61
	3	3	46	60	**54**	55	7.1	—

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Trait	Score	N	Min	Max	Mean	Median	SD	95% CI
Component granularity	1	40	31	92	50	50	14.6	45-55
	2	17	19	90	53	52	17.9	43-62
Component porosity	1	36	31	92	52	51	17.7	46-58
	2	19	19	65	**48**	50	11.3	43-54
Component osteophytic changes	2	20	19	59	46	49	10.4	41-51
	3	17	33	92	55	52	20.0	45-66
	4	5	47	86	64	61	14.1	—
Composite score	1	30	31	92	49	46	16.4	43-56
	2	25	19	90	52	52	15.2	46-59
Composite score total	1	18	31	92	51	44	18.6	42-60
	2	15	19	58	47	50	10.3	41-52
	3	8	41	90	64	61	17.0	50-78

Pubic symphysis

Total sample (without group division): age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	24	19	90	51	53	15.4	44-57
	2	131	26	92	57	55	14.8	54-59
Component erosion	1	92	19	92	53	50	15.1	50-56
	2	36	34	90	64	64	13.8	59-69
Component face topography	2	24	19	78	50	48	16.3	43-57
	3	41	33	82	57	54	12.8	53-61
	4	129	26	92	60	60	15.9	57-63
	5	31	31	88	61	60	15.0	56-67
Composite score	1	3	34	42	38	39	4.0	—
	2	52	26	82	51	52	11.0	48-54
	3	92	26	92	59	59	16.0	55-62
Composite score total	1	12	26	57	41	40	9.9	35-47
	2	59	26	80	51	50	11.6	48-54
	3	39	33	92	67	70	15.3	62-72

Shorter height group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	12	34	68	52	55	10.3	46-59
	2	33	29	82	56	54	13.3	52-61
Component erosion	1	27	29	76	55	56	11.5	50-59
	2	9	34	78	58	60	14.1	48-69
Component face topography	2	10	31	78	50	48	14.7	39-60
	3	13	38	82	58	54	11.2	51-65
	4	30	29	77	**56**	57	13.7	51-61
	5	8	46	78	60	60	9.3	52-68
Composite score	1	3	34	42	38	39	4.0	—
	2	16	29	82	53	52	12.1	47-60
	3	22	29	78	58	59	12.7	52-63
Composite score total	1	6	34	56	44	44	7.9	36-52
	2	16	29	71	54	52	10.9	48-60
	3	7	46	78	64	64	12.2	53-76

Taller height group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	7	19	66	45	51	17.7	29-62
	2	48	26	92	53	51	15.3	48-57
Component erosion	1	32	19	92	48	46	17.3	42-54
	2	13	43	83	61	61	11.5	54-68
Component face topography	2	4	19	74	47	48	25.8	—
	3	12	33	72	48	51	11.3	41-56
	4	41	26	92	55	55	15.3	50-60
	5	7	31	83	**53**	55	18.2	36-70
Composite score	1	0	—	—	—	—	—	—
	2	15	31	66	47	50	12.2	41-54
	3	38	26	92	54	55	16.1	49-60
Composite score total	1	3	31	37	33	32	10.3	—
	2	23	26	66	46	46	11.0	42-51
	3	16	33	92	64	65	16.7	55-73

Lighter group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	13	34	68	54	56	10.7	47-60
	2	37	26	82	56	55	14.0	51-60
Component erosion	1	29	26	77	55	55	13.0	50-60
	2	11	34	78	58	60	13.3	49-67
Component face topography	2	10	31	78	50	48	14.7	39-60
	3	14	37	82	56	53	11.8	49-63
	4	37	26	77	56	55	14.0	51-60
	5	7	52	78	62	60	8.0	54-69
Composite score	1	2	34	42	38	38	5.7	—
	2	12	45	82	58	55	10.9	51-65
	3	22	29	78	57	59	14.3	51-63
Composite score total	1	4	34	49	43	44	6.5	32-53
	2	15	32	71	54	52	10.8	48-60
	3	6	60	78	71	75	7.5	63-79

Heavier group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	6	19	57	41	42	15.8	—
	2	45	29	92	54	52	15.6	49-58
Component erosion	1	31	19	92	49	46	17.6	43-56
	2	11	44	83	62	63	11.6	54-70
Component face topography	2	4	19	74	47	48	25.8	—
	3	11	33	72	49	51	11.8	41-57
	4	35	29	92	56	57	16.0	51-62
	5	8	31	83	**52**	**51**	17.2	38-67
Composite score	1	0	—	—	—	—	—	—
	2	18	29	63	45	47	11.1	40-51
	3	39	26	92	56	55	16.0	50-61
Composite score total	1	5	31	56	39	37	10.1	—
	2	24	26	68	47	49	11.3	42-52
	3	18	33	92	63	63	17.0	54-71

Gracile group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	10	19	68	48	57	16.0	37-60
	2	38	26	92	54	54	16.8	49-60
Component erosion	1	31	19	92	49	46	16.8	43-55
	2	8	44	83	66	67	11.3	57-76
Component face topography	2	6	19	63	42	41	16.1	25-59
	3	13	33	82	54	54	14.6	45-63
	4	32	26	92	56	58	16.6	50-62
	5	5	31	83	56	**55**	19.5	32-80
Composite score	1	2	39	42	41	41	2.1	—
	2	19	29	82	49	52	14.3	42-56
	3	25	26	92	56	58	17.0	49-63
Composite score total	1	5	31	56	40	38	10.1	—
	2	19	26	68	47	46	13.0	41-54
	3	10	35	92	67	71	16.7	55-79

Robust group: age descriptive statistics for the pubic symphysis criteria for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	9	34	66	51	51	10.6	43-60
	2	43	29	81	54	52	12.5	50-58
Component erosion	1	28	32	81	54	51	12.8	49-59
	2	14	34	78	56	55	11.7	49-63
Component face topography	2	8	31	78	**54**	**53**	17.5	40-69
	3	12	37	71	52	51	9.1	47-58
	4	39	29	81	55	55	12.9	51-59
	5	10	33	78	57	60	11.8	49-66
Composite score	1	1	—	—	—	—	—	—
	2	12	37	66	53	51	8.3	47-58
	3	35	29	81	55	55	13.4	50-59
Composite score total	1	4	34	49	42	42	7.1	—
	2	20	32	71	52	51	9.6	47-56
	3	13	33	81	62	61	14.1	53-70

Smaller joint surface area group: age descriptive statistics for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	10	31	68	51	53	13.5	42-61
	2	38	29	82	53	52	14.4	49-58
Component erosion	1	35	29	75	50	49	13.1	46-55
	2	8	34	78	62	65	13.5	50-73
Component face topography	2	8	34	78	54	**53**	14.3	42-66
	3	12	33	82	53	**52**	15.6	43-63
	4	27	29	75	53	**51**	13.7	47-58
	5	8	31	78	57	60	13.7	45-68
Composite score	1	2	34	42	38	38	5.7	—
	2	29	29	82	52	52	12.3	47-56
	3	40	26	90	57	57	16.4	52-62
Composite score total	1	8	31	49	40	40	6.4	35-46
	2	36	26	80	51	50	13.1	47-56
	3	15	35	88	64	64	15.1	56-73

Larger joint surface area group: age descriptive statistics for the pooled sex sample

Criteria	Stage	N	Min	Max	Mean	Median	SD	95% CI
Component margin changes	1	3	32	58	47	51	13.5	—
	2	36	29	92	55	55	14.9	50-60
Component erosion	1	20	32	92	55	54	17.3	47-63
	2	11	43	73	58	58	10.3	51-65
Component face topography	2	1	—	—	—	—	—	—
	3	12	39	72	54	53	7.9	49-59
	4	25	29	92	57	55	17.5	50-65
	5	5	33	64	**52**	58	12.8	—
Composite score	1	0	—	—	—	—	—	—
	2	16	26	63	49	51	10.4	44-55
	3	46	29	92	60	61	15.9	56-65
Composite score total	1	3	26	57	38	32	16.4	—
	2	23	39	71	51	51	9.2	47-55
	3	23	33	92	68	70	15.5	61-75

Age descriptive statistics, in years, for the composite score total for female individuals

Group	Stage	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	1	6	34	57	46	46	7.6	38-54
	2	20	44	80	58	58	10.1	53-63
	3	15	50	90	72	75	11.3	66-78
Shorter	1	1	—	—	—	—	—	—
	2	8	44	71	56	55	9.6	48-64
	3	3	64	78	72	75	7.4	—
Taller	1	3	34	49	43	46	7.9	—
	2	5	45	67	52	49	8.9	—
	3	3	60	77	70	74	9.1	—
Lighter	1	2	42	46	44	44	2.8	—
	2	9	44	71	55	52	9.7	47-62
	3	4	60	78	72	75	8.0	—
Heavier	1	2	34	49	42	42	10.6	—
	2	4	45	66	53	51	9.1	—
	3	2	64	77	71	71	9.2	—
Gracile	1	2	42	46	44	44	2.8	—
	2	7	45	71	55	52	10.0	46-65
	3	2	64	74	69	69	7.1	—
Robust	1	2	34	49	42	42	10.6	—
	2	6	44	67	53	51	8.9	44-62
	3	4	60	78	73	76	8.4	—
Smaller area	1	5	34	49	43	46	5.8	—
	2	19	44	80	57	58	9.9	52-62
	3	11	50	88	70	74	11.6	62-77
Larger area	1	1	—	—	—	—	—	—
	2	1	—	—	—	—	—	—
	3	4	70	90	79	77	8.3	—

Age descriptive statistics, in years, for the composite score total for male individuals

Group	Stage	N	Min	Max	Mean	Median	SD	95% CI
Total sample (without group)	1	6	26	56	37	35	10.4	26-48
	2	39	26	70	48	48	10.9	44-51
	3	24	33	92	64	64	16.8	57-71
Shorter	1	3	32	56	42	38	12.5	—
	2	10	26	68	47	50	14.9	36-57
	3	11	35	92	65	64	17.0	54-77
Taller	1	2	31	37	34	34	4.2	—
	2	16	31	63	48	47	10.0	42-53
	3	6	33	70	54	57	13.8	39-69
Lighter	1	2	37	38	38	38	0.7	—
	2	16	26	68	44	41	13.1	37-51
	3	11	33	92	62	61	20.6	48-76
Heavier	1	3	31	56	40	32	14.2	—
	2	10	39	63	52	50	8.2	46-58
	3	7	52	83	64	64	10.3	55-74
Gracile	1	4	31	56	39	35	11.6	—
	2	13	29	68	47	44	13.2	39-54
	3	5	35	73	59	70	17.5	—
Robust	1	1	—	—	—	—	—	—
	2	13	26	66	48	50	10.9	41-54
	3	12	33	92	62	61	16.7	52-73
Smaller area	1	3	31	38	35	37	3.8	—
	2	17	26	68	44	46	13.1	38-51
	3	4	35	70	50	47	14.7	—
Larger area	1	2	26	32	29	29	4.2	—
	2	22	39	70	50	51	8.4	47-54
	3	19	33	92	66	64	15.9	58-74

APPENDIX 8 | LEVENE'S TEST FOR THE 2 x 3 FACTORIAL ANOVA

Levene's test for the acetabulum criteria for the Coimbra and Bass collection

Criteria	Coimbra collection		Bass collection	
	F	p	F	p
Groove	14.809	<0.001	32.819	<0.001
Rim shape	0.937	0.458	4.606	0.001
Rim porosity	20.049	<0.001	10.640	<0.001
Apex activity	6.447	<0.001	3.008	0.012
Outer edge of the fossa	1.048	0.390	1.639	0.151
Activity and porosity of the fossa	0.496	0.779	3.621	0.004
Component lunate surface	1.870	0.105	2.087	0.069
Component fossa	0.862	0.507	0.458	0.807
Composite score	1.395	0.233	0.562	0.729

Levene's test for the auricular surface morphological criteria for the Coimbra and Bass collection

Criteria	Coimbra collection		Bass collection	
	F	p	F	p
Transverse organization	6.791	<0.001	4.388	0.001
Fine granularity	3.359	0.006	18.382	<0.001
Coarse granularity	2.133	0.062	12.895	<0.001
Dense bone	2.106	0.069	2.978	0.013
Microporosity	7.732	<0.001	2.667	0.024
Macroporosity	7.190	<0.001	18.536	<0.001
Apical area	21,911	<0.001	17.548	<0.001
Lipping	9.316	<0.001	28.356	<0.001
Component granularity	2.602	0.026	16.105	<0.001
Component osteophytic changes	—	—	1.682	0.142
Component porosity + lipping	2.898	0.023	—	—
Component porosity	—	—	5.888	<0.001
Composite score	2.008	0.085	2.053	0.074
Composite score total	—	—	2.231	0.055

Levene's test for the pubic symphysis criteria for the Coimbra and Bass collection

Criteria	Coimbra collection		Bass collection	
	F	p	F	p
Billowing	13.406	<0.001	8.996	<0.001
Superior extremity	8.013	<0.001	12.350	<0.001
Inferior extremity	230.199	<0.001	127.265	<0.001
Dorsal plateau	43.622	<0.001	126.665	<0.001
Ventral rampart	14.160	<0.001	12.508	<0.001
DBPB	7.283	<0.001	5.198	<0.001
VBPB	3.124	0.010	3.378	0.006
MAOF	16.266	<0.001	4.005	0.002
Symphyseal rim	2.079	0.073	11.576	<0.001
Pubic tubercle	3.817	0.003	4.164	0.001
Ventral bevelling	55.986	<0.001	—	—
ESF	6.588	<0.001	30.548	<0.001
ESR	4.179	0.003	4.162	0.001
SFS	0.554	0.735	4.034	0.002
LOVBe	6.351	<0.001	13.093	<0.001
Component face topography	0.334	0.892	3.125	0.010
Component margin changes	7.205	<0.001	13.776	<0.001
Component erosion	2.428	0.055	18.360	<0.001
Component dorsal body + LOVBe	2.763	0.024	—	—
Composite score	3.665	0.005	3.815	0.003
Composite score total	—	—	1.272	0.286

Legend: DBPB: dorsal body of the pubic bone; VBPB: ventral body of the pubic bone; MAOF: medial aspect of the obturator foramen; ESF: erosion of the symphyseal face; ESR: erosion of the symphyseal rim; SFS: symphyseal face shape; LOVBe: Ligamentous outgrowths of the ventral bevelling.