AN EVALUATION OF "OLD AGE" TRAITS IN TRANSITION ANALYSIS AND MANDIBULAR RIDGE RESORPTION IN AGE ESTIMATION OF OLDER INDIVIDUALS

AN EVALUATION OF "OLD AGE" TRAITS IN TRANSITION ANALYSIS AND MANDIBULAR RIDGE RESORPTION IN AGE ESTIMATION OF OLDER INDIVIDUALS

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ABSTRACT

Mandibular ridge resorption reflected by mandibular bone height and the two "old age" traits, breakdown of the dorsal margin of the pubic symphysis and posterior exostoses of the iliac auricular surface, were tested for their potential as old age indicators. Samples with no known age-at-death come from the Lankhills School, Andover Road, and Hyde Street cemetery collections in Winchester, UK. The collections were dated to the 4th century AD, a time of Imperial Roman rule.

Results showed that mandibular bone height decreases with increasing age, however the correlation is only statistically significant in females. Statistically significant positive correlations exist between age-at-death and the two "old age" traits. Further, correlations between mandibular bone heights and the two "old age" traits were more pronounced in males. In general, mandibular ridge resorption, breakdown of dorsal margin of pubic symphysis and posterior exostoses of the iliac auricular surface can aid in the identification of old individuals; however, differences between the sexes is pronounced, indicating that besides age, sex-related factors, either physiological or cultural, play a role in the morphological changes of these skeletal features. Females tend to show more severe mandibular ridge resorption due to systemic bone loss affected by hormonal change around menopause. On the other hand, the two pelvic "old age" traits have stronger relationship with mandibular bone height in males because these two traits have more regular and predictable patterns of morphological changes. These changes are likely to be associated with the different roles of male and female pelves in reproduction.

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DECLARATION OF ACADEMIC ACHIEVEMENT

The research conducted for this thesis was completed by Xuan Wei, under the supervision of Dr. Megan Brickley. The age and sex data were collected by Xuan Wei and L. Creighton Avery for the SSHRC Project (Insight Grant, File number 435-2013-1006, ID number 169793), with permission for the use of the data for this thesis. Access to the skeletal collection was granted by Winchester Excavation Committee, Winchester Museums and Oxford Archaeology. Research design was developed in consultation with Dr. Megan Brickley. Data analysis was conducted independently by Xuan Wei. Dr. Megan Brickley and Dr. Tracy Prowse have provided critical evaluation and suggestion throughout the length of this research. Additionally, Dr. Megan Brickley has graciously provided funding for the fieldwork of this research through the aforementioned SSHRC Project.

Chapter 1. Introduction

Growing old is the natural life trajectory of every person. Although senescence is a stage of physiological as well as psychological and social change that humans are expected to go through, the experience of getting and being old can be highly variable in different cultures across space and time. Social and cultural constructions define “old age” differently, however as a methodological study, this thesis defines “old” to be over 50 years of age, since beyond this age it is very difficult for most currently employed age estimation methods to produce accurate and precise results. Old people form an important part of both modern and past societies, but at present they are understudied in bioarchaeology due to this difficulty with their identification in the archaeological record.

Recently, the problem that old people are almost always “invisible” in bioarchaeological studies has been raised (Gowland, 2007). The most crucial factor that contributes to the under-representation of old adults in bioarchaeological studies is the inability of age estimation methods to efficiently identify old individuals (i.e. people over the age of 50). It may be true that fewer old individuals are present in archaeological skeletal samples than in contemporary societies, but an important factor resulting in this under-representation is that old individuals are more likely to have experienced age-related bone loss and pathological conditions that result in poor bone preservation (Gowland, 2007; Jackes, 2011). The influence of contemporary Western perceptions that old adults are physically deteriorating and therefore unimportant certainly does not help raise the awareness of studying older age people in ancient times (Gowland, 2007). The use of life expectancy (which is largely dependent on infant mortality rate) in paleodemography gives rise to the misinterpretation that many people in the past did not live to old age (Lucy, 2005). This study aims to tackle the first problem that addresses the inability to estimate age of old adults, and asks the question: can we pick out old individuals from a skeletal assemblage?

There are many problems associated with age estimation of human skeletal remains. One of them is that for currently available age estimation methods, the inaccuracy and imprecision are more marked with increasing age, limiting the level of detail and specificity that studies can achieve (Saunders et al., 1992; Wittwer-Backofen et al., 2004; Milner and Boldsen, 2012). Old adults tend to be under-aged, and the age ranges that could be estimated often are open-ended (e.g. 50+ years as seen in the auricular surface age estimation method) or span over several decades (e.g. 23-84 years old as seen in the Suchey-Brooks pubic symphysis age estimation method). This pilot study using a Romano-British sample attempts to address these issues by testing the correlation between age and three skeletal features previously identified as old age-related by other researchers: mandibular ridge resorption (Mays, 2014), breakdown of the dorsal margin of the pubic symphysis (Boldsen et al., 2002; Milner and Boldsen, 2012), and extensive posterior exostoses of the iliac auricular surface (Boldsen et al., 2002; Milner and Boldsen, 2012).

Mandibular ridge resorption is the atrophy and reduction of mandibular bone on the occlusal surface after tooth loss or extraction (Atwood, 1971). Studies done in clinical and archaeological samples found age to be an important factor associated with mandibular bone resorption (e.g. Kalk and Baat, 1989; Mays, 2014). The pubic symphysis has been extensively studied as an age indicator (e.g. Todd, 1921; Brooks and Suchey, 1990). Specifically, the dorsal margin of the symphyseal face shows early age-related changes (Meindl et al., 1985). During the development of the transition analysis age estimation method, Boldsen et al. (2002) found that the breakdown of the dorsal margin is usually present in old individuals. Another feature discovered by Boldsen et al. (2002) to be related to old age is the presence of extensive exostoses in the posterior area of iliac auricular surface. This feature has also been documented, but not studied in detail by previous researchers (e.g. Lovejoy et al., 1985).

Skeletons used in this study are drawn from adult individuals from the Late Romano-British (4^{th} century AD) cemeteries at Lankhills Special School, and two smaller cemetery sites, Andover Road and Hyde Street, all located in Winchester, UK.

This study examines the methodological problem of identifying old individuals in past societies using aspects of a recently discussed age estimation technique and an age-related bony change, transition analysis on the innominate and resorption of the mandibular ridge. The goals of this study are: 1) to test the relationship between age and mandibular ridge resorption, 2) to test the relationships between age and the two “old age” traits, and 3) to test the relationships between mandibular ridge resorption and the two “old age” traits. By exploring the correlations between these traits, this study will evaluate their potential to aid in the identification of old individuals in an archaeological sample.

Chapter 2. Background

This chapter presents background information on old adult age estimation, the three skeletal features that were tested in this study, and the experience of old age in different societies and in the ancient Roman World.

2.1 The problems associated with old adult age estimation

It is very difficult to accurately and precisely estimate adult age-at-death, as critiqued by multiple scholars (e.g. Jackes, 2000; Prince, 2004). After completion of development and growth, the gradual and persistent maintenance, remodeling, and degeneration processes of the skeleton are largely affected by environmental and cultural factors, such as nutrition, traumatic events, the intensity level of activities and daily routines, and the physiological consequence of these factors. These external influences make the ageing of the skeletal system highly variable between individuals and populations, and thus make age estimation problematic (İşcan et al., 1984; Ritz-Timme et al., 1999). Consequently, being exposed to these external factors for longer periods, older individuals will have greater variability in age-related changes affecting their skeletons. A lack of diagnostic characteristics associated with different stages of old age makes distinguishing sub-groups within the old age group impossible. Due to this limitation, only open-ended age ranges (i.e. 50+) or very broad age ranges can be generated from currently available age estimation methods. Table 2.1 summarizes six different age estimation methods and the oldest age ranges they can produce. Authors have critiqued that the age distribution generated using current age estimation methods tends to resemble the age distribution of the reference sample that the methods were developed from (Bocquet-Appel and Masset, 1982). Age estimation using conventional methods essentially is assigning individuals with unknown age into fixed age ranges based on morphological similarities with reference samples. The reference samples used to develop these methods (such as the ones listed in Table 2.1) are made up of primarily young and middle aged individuals; therefore age mimicry causes a greater chance of older individuals being under-aged. A recent study showed that body size also affects the accuracy of age estimation methods (Merritt, 2015). It was found by Merritt (2015) that larger individuals tend to be over-aged and vice versa. Merritt (2015) further argued that archaeological samples might be at the risk of being under-aged due to their relatively smaller body size when using age estimation methods developed from modern, relatively larger-sized samples. This use of modern methods on archaeological samples may lead to the misinterpretation that there were fewer old individuals in an archaeological skeletal assemblage (Merritt, 2015).

Table 2.1. Different age estimation methods and their oldest age ranges

Age estimation methods	Oldest age range		
Epiphyseal fusion (Cardoso, 2008; 2010)	Females: 22+	Males 26+	
Pubic symphysis morphology (Suchey and Brook, 1990)	Females: 42-87	Males: 34-86	
Iliac auricular surface morphology (Lovejoy et al. 1985)	60+		
Cranial suture closure (Meindl and Lovejoy, 1985)	Ectocranial lateral-anterior sutures: 33-76	Extocranial sutures: 23-76	Endocranial vault sutures: 50-80
Sternal rib ends morphology (İşcan and Loth, 1989)	70+		
Molar dental wear (Brothwell, 1981)	45+		

2.2 Mandibular ridge resorption

2.2.1 Terminology

In the body of literature related to the resorption of the mandibular alveolar ridge, many different terms are used instead of one well-defined universal term. In this list of terms, alveolar ridge atrophy (e.g. Mercier and Lafontant, 1979; Schliephake et al., 1997) and residual ridge resorption (e.g. Wical and Swoope, 1974; Ortman et al., 1989; Klemetti, 1996) are commonly used. Other terms used include alveolar/residual ridge reduction (e.g. Atwood and Coy, 1971; Tallgren, 1972; von Wowern and Kollerup, 1992), mandibular bone resorption (e.g. Sennerby et al., 1988), and different combinations of words are seen as well. Kingsmill (1999) briefly discussed the confusion of terminology. The author stated that since the alveolar bone proper (the very thin layer of bone immediately adjacent to periodontal tissue) disappears fairly fast after tooth loss (de Van, 1935), the term "residual ridge resorption" is used to "encompass all the changes that accompany bone loss after tooth extraction" (Kingsmill, 1999: 386). In this thesis, the term mandibular ridge resorption is used because measurements include phases in which alveolar bone proper is still present (i.e. when a tooth is in the socket or was lost postmortem).

2.2.2 Etiology of mandibular ridge resorption

Mandibular ridge resorption is a form of bone remodeling that happens after extraction or loss of teeth, characterized by the loss of bone (Atwood, 1971). Due to multiple factors, the shape of the alveolar crest of the mandible (as well as the maxilla, which is not discussed in this thesis) undergoes changes that are "chronic, progressive, irreversible, and cumulative" (Atwood, 1971: 270). These factors include: metabolic causes such as age, sex, and hormone levels; functional causes such as how much masticatory force is applied to the mandibular ridge; anatomical causes such as the size and shape of the mandibular ridge; and localized causes such as disease-related inflammation (Atwood, 1971; Kingsmill, 1999).

2.2.3 Morphology of mandibular ridge resorption

Atwood (1963, 1971) and Cawood and Howell (1988) proposed a 6-stage system to describe the morphology of mandibular ridge resorption, which is summarized in Table 2.2. During earlier stages, exposed trabecular bone and macroscopic pitting (Solar et al., 1998) may be visible on the alveolar surface due to incomplete filling of the tooth socket or degenerative alterations of the alveolar crest (Atwood, 1971; Pietrokovski, 1975; Reich et al., 2011). In later stages, concave depression of the alveolar crest or the mandibular body can often be observed, and in some extreme cases the mental foramen may even be exposed on the occlusal surface (Reich et al., 2011).

Table 2.2. Stages of morphological change of mandibular ridge resorption (After Atwood 1963, 1971; Cawood and Howell 1988)

Stage	Description of Morphology
1	Pre-extraction: when the tooth is still in socket, or is lost postmortem.
2	Tooth loss happens a short time before death. There may be a little remodeling starting to fill in the socket, but the ridge around the socket may still be sharp.
3	The socket is completely filled in; the surface of the alveolar process becomes smooth and well-rounded, but height is not visibly reduced.
4	The alveolar crest becomes a thin and sharp “knife-edge” shape, but the width and height of the mandible do not reduce very significantly.
5	Alveolar process is lost due to resorption; the mandible height and width are reduced and the top of the mandible is rounded and flat.
6	Excessive resorption makes the mandible display a concaved morphology, and the lower border of the mandible sometimes may show resorption as well.

2.2.4 Relationship between mandibular ridge resorption and age

Mandibular ridge resorption is a universal yet variable process (Atwood and Coy, 1971). It is universal because bone resorption occurs regardless of location after tooth loss. Despite more extensive denture wearing, modern people share a similar pattern of changes in shape and height with their ancient counterparts (Reich et al., 2011). There is variability in this process because the rate of resorption differs between the mandible and maxilla, different groups of people, at different time periods after tooth loss, and even within one individual at different tooth locations (Atwood, 1971; 1973; Atwood and Coy, 1971; Sennerby et al., 1988; Humpheries et al., 1989; Denissen et al., 1993). Among the list of factors that can affect the severity of mandibular ridge resorption, age is a significant one. Kalk and Baat (1989) used modern edentulous elderly people to test the correlation between the patient’s age, duration of edentulousness, and severity of ridge resorption. They found a correlation between age and duration of edentulousness, as well as between duration of edentulousness and resorption; however, the direct relationship between age and resorption was not discussed (Kalk and Baat, 1989). Mays (2014) tested the correlation between age and mandibular height in a 19th century Dutch skeletal sample with known age. In this study, an approximately linear relationship was found between increasing age and decreasing mandibular height. This correlation exists in both females and males, but is stronger in females.

2.2.5 Relationship between mandibular ridge resorption and sex

As briefly mentioned in Section 2.1.2, systemic factors are one of the three major causes affecting the rate and severity of mandibular ridge resorption. Within systemic factors, hormonal balance plays a significant role in maintaining bone quality and density; hence it may have a direct influence on mandibular ridge resorption. A large body of literature has focused on the relationship between age-related osteoporosis and the rate and severity of mandibular ridge resorption, and some find this relationship not very convincing (Hildebolt, 1997; Bollen et al., 2004; Felton, 2009). Some studies have found a correlation between osteoporosis and mandibular ridge resorption (e.g. Bays and Weinstein, 1982; Kribbs et al., 1983; Hirai et al., 1993), while others did not (e.g. Atkinson and Woodhead, 1968; Klemetti et al., 1993; Bollen et al., 2004). Bone density and its potential link to mandibular ridge resorption has also been explored by multiple scholars; some studies have shown that mandibular bone resorption is more severe in edentulous people who have low bone density of the radius (e.g. Henrikson and Wallenius, 1974; Rosenquist et al., 1978; Bays, 1983).

Within the studies focusing on bone porosity/density and its correlation with mandibular ridge resorption, researchers have explored the different manifestations of mandibular bone resorbing process in males and females, since the hormonal levels in different sexes is expressed differently; women tend to be affected by hormone-related bone quality and density decrease after menopause (Albright et al., 1941). Engström et al. (1985) discovered that in groups of edentulous people, alveolar bone height was significantly different between males and females, which they believe is a result of sex differences in mandibular ridge resorption. Soikkonen et al. (1996) also found that mandibular ridge resorption was more severe in edentulous females with osteopenia. Similar conclusions that mandibular ridge resorption is significantly stronger in females, especially those who have passed menopause, can be found in other publications (e.g. Dyer and Ball, 1980; Daniell, 1983; Humphries et al., 1989; Baat et al., 1993; Jahangiri et al., 1997).

2.3 An introduction to the two "old age" traits

This section presents a brief introduction of the transition analysis age estimation method and the two "old age" traits that are features scored as part of this method.

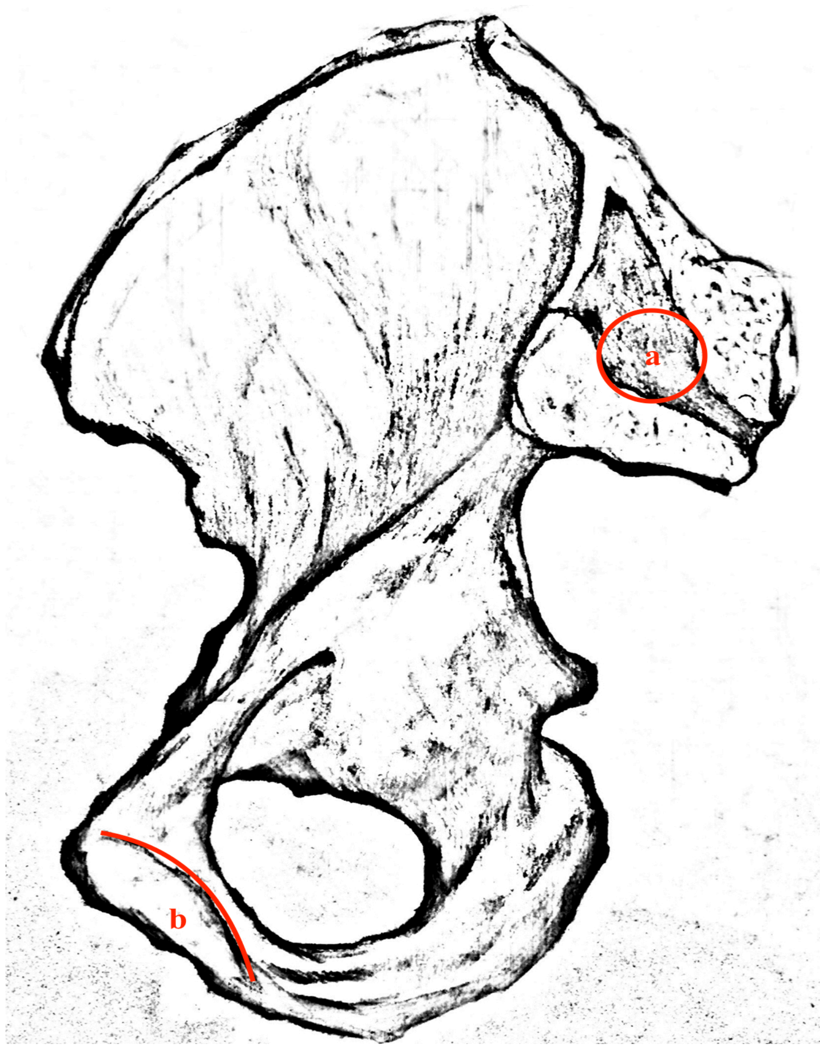
2.3.1 Transition analysis

Transition analysis is an age estimation method using Bayesian statistical analysis instead of the traditional method of assigning individuals into fixed age ranges. It employs three skeletal elements, cranial sutures, the pubic symphysis, and the iliac auricular surface (Boldsen et al., 2002). This age estimation method calculates an age range based on assigned scores of up to 33 skeletal features. Theoretically, different scores and their combinations have the potential to assign each individual to a unique age range. However, despite having the potential to reduce the influence of age mimicry, this method does not perform better than other conventional age estimation methods (e.g. Bethard, 2005; Milner and Boldsen, 2012). Although less than promising results were produced, there are two features within the scoring system of transition analysis that may potentially be suggestive of advanced age; the breakdown of the dorsal margin of the pubic symphysis, and the presence of extensive exostoses on the retroauricular surface directly posterior to the auricular joint surface (Boldsen et al., 2002; Milner and Boldsen, 2012). The presence of both features may indicate that an individual is likely to be of old age, possibly over 80 years old (GR Milner, personal communication, June 5, 2016). These two traits are discussed in the following two sections.

2.3.2 The dorsal margin of the pubic symphysis

The pubic symphysis has been studied as early as the mid 18th century (Becker et al., 2010). It is classified as either a secondary cartilaginous joint (Standring, 2008) or a fibrocartilaginous joint (Rosse and Gaddum-Rosse, 1997). The articular surface of the symphysis is covered in hyaline cartilage and can sustain a small range of motion (Frick et al., 1991). The association between age and morphological changes of this joint surface was recognized very early on, and was subsequently studied by physical anthropologists in the development of age estimation methods (e.g. Todd, 1921; Gilbert and McKern, 1973; Brooks and Suchey, 1990; White and Folkens, 2005). The dorsal margin is the posterior edge of the symphyseal face (the location is shown in Figure 2.1). It is the attachment site of posterior pubic ligament (Becker, 2010). This area, along with the posterior half of the symphyseal face, is the first skeletal landmark to show age-related changes (Gilbert and McKern, 1973; Meindl et al., 1985). The flattening of the dorsal demiface starts at as early as late puberty and originates from the mid-third; from here a margin extends toward superior and inferior directions, forming a margin between the symphyseal face and the posterior surface of the pubic bone (Gilbert and McKern, 1973). It is noted that in females the morphological changes in this area are more rapid than in males (Gilbert and McKern, 1973). Studies have shown an increase in osteoclastic resorption of the symphyseal margins occurring in pregnant women (Vix and Ryu, 1971; Putschar, 1976). This could potentially contribute to the different morphological change patterns suggested by Gilbert and McKern (1973). The breakdown of the dorsal margin is characterized by erosion of this feature. The scoring criteria are detailed in Section 3.5. It is noted that biomechanical studies of the pubic symphysis are lacking (Becker et al., 2010), which limits a fuller understanding of the developmental and degenerative processes of this joint.

Figure 2.1. The locations of the two "old age" traits in transition analysis



a: Posterior exostoses area; b: dorsal margin of pubic symphysis. Illustration by Lucy Wei.

2.3.3 Posterior exostoses of iliac auricular surface

The auricular surface of the ilium has also been studied to develop age estimation methods (e.g. Lovejoy et al., 1985; Buckberry and Chamberlain, 2002), however the posterior exostoses area was not a focus of research. The retroauricular area refers to the region between the auricular surface and the posterior inferior iliac spine (Buikstra and Ubelaker, 1994). In modern clinical literature it is often called the iliac tuberosity and is the attachment site of the posterior sacroiliac ligament, a main stabilizer of the sacrum (Dreyfuss et al., 2004; Patel et al., 2014). Since this bony landmark is the insertion location of a strong stabilizing ligament, it is more appropriate to be considered an enthesis, which is defined as “the area where a tendon, a capsule or a ligament attaches to bone” (Villotte and Knusel, 2013: 135).

Entheseal changes have been studied quite extensively. Some studies explored robusticity and morphology of entheses to draw implications about activities and occupational stress (e.g. Kennedy, 1983; Peterson, 1998; Al Oumaoui et al., 2004), while others argued that entheseal change may in fact have a stronger relationship with age than activity levels (e.g. Weiss, 2003; Milella et al., 2012; Henderson et al., 2013). However, these studies focused mostly on major muscle groups such as those in the upper and lower limbs (e.g. Wilczak, 1998; Cardoso and Henderson, 2010; Niinimäki and Sotos, 2013; Nolte and Wilczak, 2013). These studies were concerned mainly with the muscle groups that have the most activity frequency and intensity. Entheses such as the posterior exostoses to which stabilizing ligaments attach are understudied. There seems to be very few studies on entheseal changes of the os coxae. Cardoso (2008) recorded entheseal changes of the ischial tuberosity and iliac crest as part of a larger study looking at gender differences in a 20th century Portuguese sample, but he did not record changes at retroauricular area. Campanacho and Santos (2013) attempted to investigate the relationship between activity levels and entheseal changes of several bony landmarks of the pelvis including the retroauricular area, but failed to obtain valid results for all landmarks except the iliac crest. Thus, the potential relationship between age and the presence of posterior exostoses is currently not well understood. Studies on the sacroiliac joint are primarily concerned with two problems: 1) the etiology and treatment of lower back pain associated with this joint, and 2) sacroiliac joint ankylosis. Research aimed at investigating both of these questions tends not to include the retroauricular area as part of the joint. As a result, no information on the manifestation of bony protuberances at this site can be drawn from this body of literature.

During the development of the transition analysis age estimation method, Boldsen and colleagues (2002) found the common presence of extensive bony exostoses covering the entire area of the examined surface in old individuals who were likely to be over 80 years old in their sample (GR Milner, personal communication, June 5 2016). Previously, Lovejoy et al. (1985) suggested the roughening of retroauricular surface area is associated with advanced age, but no scoring system was developed until transition analysis was introduced. Detailed morphological descriptions are outlined in Section 3.4.

2.4 Bioarchaeology of old individuals

There have not been many studies on old people in archaeology and bioarchaeology; the elderly of the past remain largely invisible (Gowland, 2007). This situation is multifactorial. Culturally and socially, archaeologists are affected by the Western conception of “old age” as a negative image that represents weakness, unproductivity and insignificant social role compared to the youthful, energetic younger generation (Gowland, 2007). Gilchrist (2004) cautioned that it is not appropriate to interpret age constructions of past societies based on contemporary stereotypes. Biologically, when people age, the bones gradually lose their density and structure, become more porous and brittle than those of younger people, and are more prone to taphonomic changes when buried; thus they are generally less likely to be well preserved (Gowland, 2007; Jackes, 2011). Methodologically, the use of life expectancy to construct demographic views of past societies causes a bias that points to the false conclusion that few people in the past lived into their old age (Chamberlain, 2006). Life expectancy is highly sensitive to infant mortality rate, which tends to be high in archaeological populations. A high infant mortality rate will significantly lower life expectancy, but this does not necessarily mean that only very few people live into old age. Most importantly, current age estimation methods are not able to accurately and precisely identify older adults and assign them to an age range that is small enough to perform detailed studies of old age experience in the past (Bocquet-Appel and Masset, 1982). Jackes (2000: 418) argued that "there can be little doubt that people lived into old age-even in times of conflict, disease and famine-despite the fact that standard paleodemographic methods would give no indication of this". Gilchrist (2004) proposed that age should be considered as not only a biological but also a cultural and historical construction. However without a confident estimation of biological age, the link between biological and social construction of age cannot be fully interpreted. Therefore, the missing part of bioarchaeology and archaeology that should be dedicated to the study of old people is eagerly waiting to be filled, and whether or not biological anthropologists can identify old individuals is crucial in this endeavor.

2.5 Who is considered old in different societies

Different time periods may have different ideas of when a person is regarded as entering "old age". In the Middle Ages, a chronological definition of the starting point of old age was between 60 and 70 years old (Shahar, 2005). In the 17th century, the belief that "one is as old as one looks or acts" was popular (Botelho, 2005: 113), while women were seen as old once they entered menopause (Botelho, 2005).

In contemporary Western society, there are quite a few ways in which people define "old age". In some academic research, "old age" is usually linked with retirement age (Roebuck, 1979), which can be different between countries. For example, the retirement age in Canada is 65 for both sexes ("Canada Public Pension", n.d.); while in China, retirement age is 60 for males and 50-55 for females (Congressional-Executive Commission on China, 1979). Other than retirement age, physical conditions, especially diseases, are also commonly used to identify "old age". For example, Anand et al. (2008) used "old age disease" to describe cancer and suggested that high cancer detection rate was found in people over 50 years old, implying age 50 as the start of "old age". In a study investigating overweight and coronary heart disease in old age in modern US society, subjects were 77-86 years old (Harris et al. 1997). However, other than indicating the age range of study subjects, these studies did not specifically define what "old age" is. Apart from retirement and disease, we are all too familiar with the notion associating grey and white hair, wrinkles, and loss of memory with old age. It is clear that there is no set definition of “old age” in modern times; people define themselves or others as old based on different circumstances.

2.6 Old age in the Roman World

Being old in ancient Rome had differences and similarities in comparison to being old in 21st century, the Middle Ages or the 17th century. There were different opinions about at what age Roman people viewed an individual as ‘old’. From literary sources Prowse (2011) reported a six-phase system of age stages in the Roman World, which is summarized in Table 2.3. However, Parkin (2003) stresses the importance of not associating culturally constructed age categories with the actual years of life a person has lived. The author provided a table of different starting points of “old age” seen in different Greek and Roman literary sources, which is reproduced in Table 2.4. While the Roman Empire did not have a set age for retirement or a pension system that signified the beginning of old age, chronological age as well as physical and mental health was taken into consideration when defining an individual’s age status (Harlow and Laurence, 2002). Similar to modern societies, old age in the Roman world was a socially constructed concept that could be affected by the physical appearance and mental state of the individual, as well as social circumstances (Parkin, 2003).

Table 2.3. Age stages in the Roman World (summarized from Prowse, 2011)

Age stage	Age in years
Infancy (*infantia*)	Birth-7 years
Childhood (*pueritia*)	7-14 years
Adolescence (*adulescentia*)	14-30 years
Youth (*juventus*)	30-49 years
Adulthood (*gravitas*)	50-69 years
Old age (*senectus*)	70+ years

Table 2.4. Gradus Aetatum: the age at which "old age" commences (From Parkin, 2003, p279).

Age in Years	Source
42	Hippocrates de Hebd. 5 (school. ad Pollux Onom. 2.4)
46	Cicero de Sen. 17.60: ("ita quantum spatium aetatis maiores ad senectutis initium esse voluerunt")
48	Anthologia Palatina 14.127 (Metrodorus)
49	Galen in Hipp. Aph. 3.29 (17B. 643K); Isidous Diff. 2.19.74-76
56	Hippocrates de Hebd. 5 (Philo de Opif. Mundi 36.105; Censorinus de Die Nat. 14.3; MS. Cod. Phil. 1529, 8.633L; Boissonade Anec. Graec, 2 p. 456); cf. Philostratus Vit. Soph. 1.25.543
60	Hippocrates de Articulis 41 (4.182L); Varro ap. Censorinus de Die Nat. 14.2; Pythagoras ap. Diogenes Laertius 8.10
63	Hippocrates de Hebd. 5 (Paris MS 7027, 8.646L; school. ad Hesiod W&D 447; Boissonade Anec. Grawc. 2 p. 455; 4.30.502 (5.700L); Philo de Opif. Mundi 35.104 (Solon); Censorinus de Die Nat. 14.15-16
69	Dionysius of Halicarnassus Din. 4; Ptolemy Tetrabiblos 4.10.206-7
70	Isidorus Orig. 11.2; Macrobius Comm. 1.6.76
77	Staseas and the Etruscan libri fatales (Censorinus de Die Nat. 14.5-6, 10); cf. Isidorus Diff. 2.19.74-76 (beginning of senium)

The experience of old age in the Roman Empire largely depended on social status, and social expectations and roles of individuals also changed with increasing age (Harlow and Laurence, 2002). For example Harlow and Laurence (2002) suggested individuals entering old age would be excluded from political and military activities, but were expected to pay social duties until their 70s. Parkin (2003) and Cokayne (2003) examined various historical and literary sources to get insights into how old age was depicted and viewed in the Roman World, and concluded that there were a mix of positive and negative views toward old age. Some of the most pronounced views on old age are summarized in Table 2.5.

Table 2.5. The positive and negative views of old age in the Roman World (summarized from Parkin, 2003; CoKayne, 2003)

Positive views	Negative views
Passes manual labor and focuses on spiritual labor (such as intellectual, political and educational)	Pessimistic and depressed
	Harsh on others, offensive, and easily irritated.
Can avoid lustful physical pleasures (which is thought to lead to a decrepit old age and even early death)	Loquacious, avaricious, and cowardly
	The inevitable illness and weakness of the body
Can enjoy prestige and respect if led an active public life	Declined mental acuity and memory
Philosophy and wisdom accumulated in old age will help overcome the fear of death	Stereotyped old women as disgusting, haggard, toothless, gossiping and alcoholic

A tendency to exaggerate age on tombstone inscriptions and census was noted (e.g. Hopkins, 1966, Parkin, 2003). Such age exaggeration suggests that having a very old age may be favorable or advantageous in some circumstances. Parkin (2003) also pointed out a tendency to round age up to numbers ending with 5 or 0. Age distribution from a Roman-Egypt census showed that despite the small number, old individuals did exist (Scheidel, 2001).

Research on old adults of the Roman World will certainly aid in a fuller understanding of people and society in the Roman Empire, but osteological studies focused on old age experience at this time period are scarce. Prowse (2011) employed isotopic analysis to explore dietary trends in the Roman site Isola Sacra and found that older individuals might have had greater consumption of marine protein. Gowland (2007) raised the problem of the invisibility of older people in Roman Archaeology and examined the ancient Roman perception of being old using skeletal evidence. However, there do not seem to be other archaeological researches that study old individuals of the Roman world that utilize skeletal remains. The lack of bioarchaeological analysis of old individuals leaves the majority of research on this portion of the population relying on historical and literary sources, which may under-represent or mis-represent certain groups of people, such as old women, who were often associated with negative attitudes. Therefore, the lack of osteological analysis is likely to impede the holistic understanding of the Roman World.

Chapter 3. Materials and Methods

The data recording in this study is composed of four parts: sex and age estimation, recording of mandibular bone heights at up to eight locations, scoring of auricular surface features outlined in the Transition Analysis Scoring Manual (Milner and Boldsen, 2013 a), and scoring of pubic symphysis features, also following the criteria in the Transition Analysis Scoring Manual (Milner and Boldsen, 2013 a).

3.1 Materials

The sample in this study is composed primarily of individuals from the Lankhills cemetery collection and two smaller cemetery sites, Hyde Street and Andover Road, all of which are part of the northern cemetery in Winchester, UK. All available individuals from these sites were recorded, and after examination, a total of 243 adults that met the requirements for this study (Section 3.2.1) comprised the final sample.

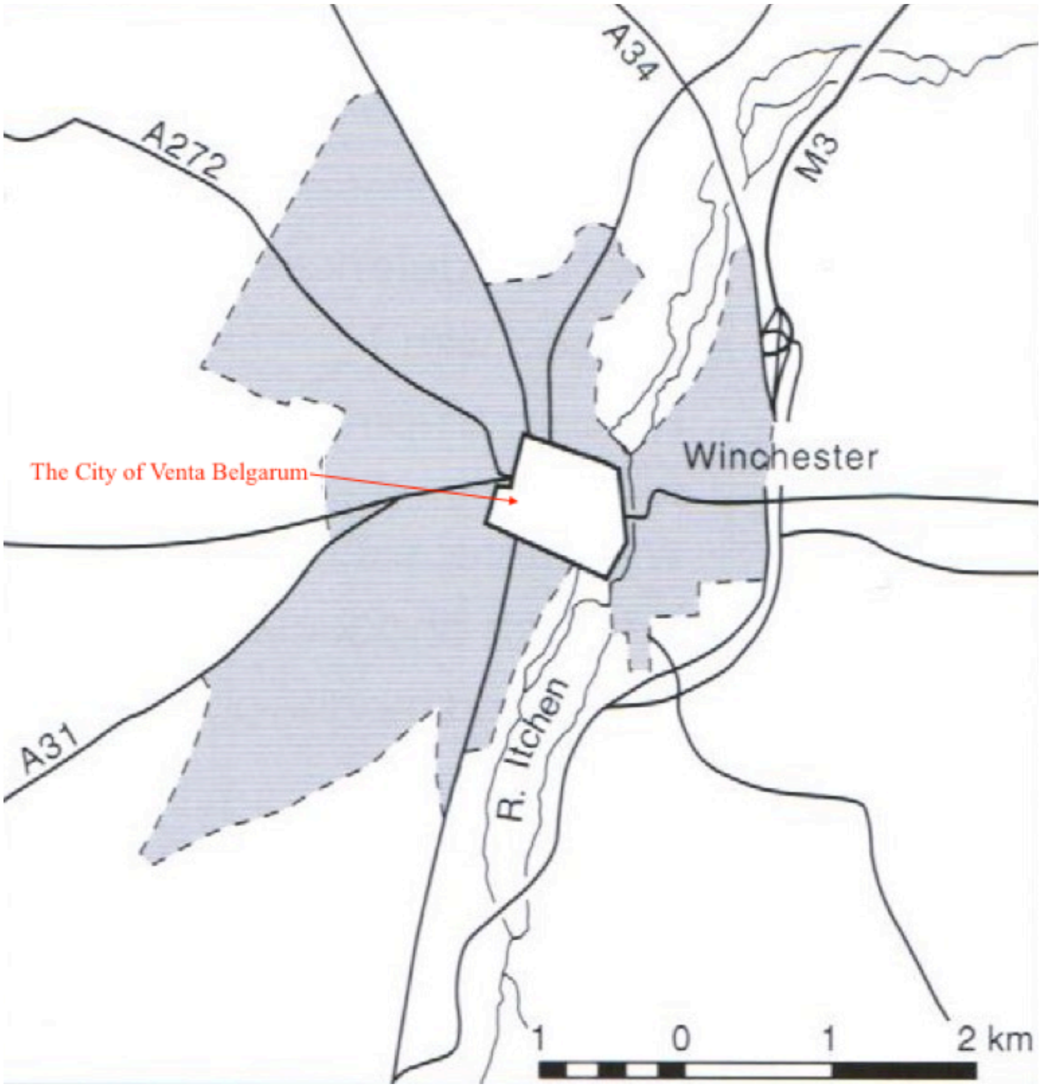
3.1.1 The city of Winchester in the Romano-British period

Winchester, known as *Venta Belgarum* during the Roman period, was the 5th largest town in Roman Britain, and was an administrative center of what is now central and southern Hampshire (Wacher, 1995; Ottaway et al., 2012). Today the city is situated in central Hampshire in the River Itchen Valley that runs East-West (Figures 3.1 and 3.2). In the Roman period apart from being a town of political administrative significance, Winchester also served as a military fort (Ottaway et al., 2012). Roads were built in multiple directions on the basis of pre-Roman roads and connected *Venta Belgarum* to other Romano-British cities (Ottaway et al., 2012). The establishment, development and decline of the city coincided with the rise and fall of Roman rule of Britain. During the 1st and 2nd centuries, wall defenses and gridded streets were constructed, while from the 2nd to 4th centuries the walls, streets, and buildings were completed and maintained, forming a thriving city. Finally, beginning in the late 4th century construction activity gradually started to decline, when roads collapsed, houses were left unmaintained, and streets were deserted (Ottaway et al., 2012). The sample used in this study all dated to approximately the 4th century AD, when the city was in its most prosperous state.

Figure 3.1. The geographical location of modern Winchester

This map is adapted from Google Maps. The red star indicates the location of the city of Winchester.

Figure 3.2. The geographical location of Roman city *Venta Belgarum*



This map is adapted from Ottaway et al., 2012, p3.

3.1.2 The Lankhills cemetery collection

In 1961, skeletal remains and artefacts were discovered on the school grounds at Lankhills, leading to excavation in two phases. The first phase was carried out from 1967 to 1972 (Clark, 1979). The second phase was carried out from 2000 to 2005 by Oxford

Archaeology (Booth et al., 2010). The site comprises the northern cemetery situated to the North of Winchester, along with several other smaller cemetery sites (Figure 3.3). Limited activities dated to as early as the Late Bronze Age (approximately 1000-700 BC) and Iron Age (approximately 800 BC-100 AD) were identified, but the main period of the use of this site dated to approximately 310 to 410 AD (Clarke, 1979). The Clarke excavation yielded a total of 451 graves that contained 439 inhumations, five empty graves, and seven cremations (Booth et al., 2010; Ottaway et al., 2012). Three hundred and seventy-five graves were fully excavated, 33 were partially excavated, and 31 were destroyed by later use of the burial site (Clarke, 1979). During the Oxford Archaeology excavation, 307 inhumations, 25 cremations, and six previously partially excavated graves were excavated (Booth et al., 2010). In total, 751 inhumations were excavated from Lankhills cemetery. The number of adults included in this study from the Lankhills collection was 221. For easy identification and separation, individuals from Clarke excavation were labeled using LANK plus the original skeleton number; individuals from Oxford Archaeology excavation were labeled using LANK-2010 plus the original skeleton number.

3.1.3 The Andover Road cemetery collection

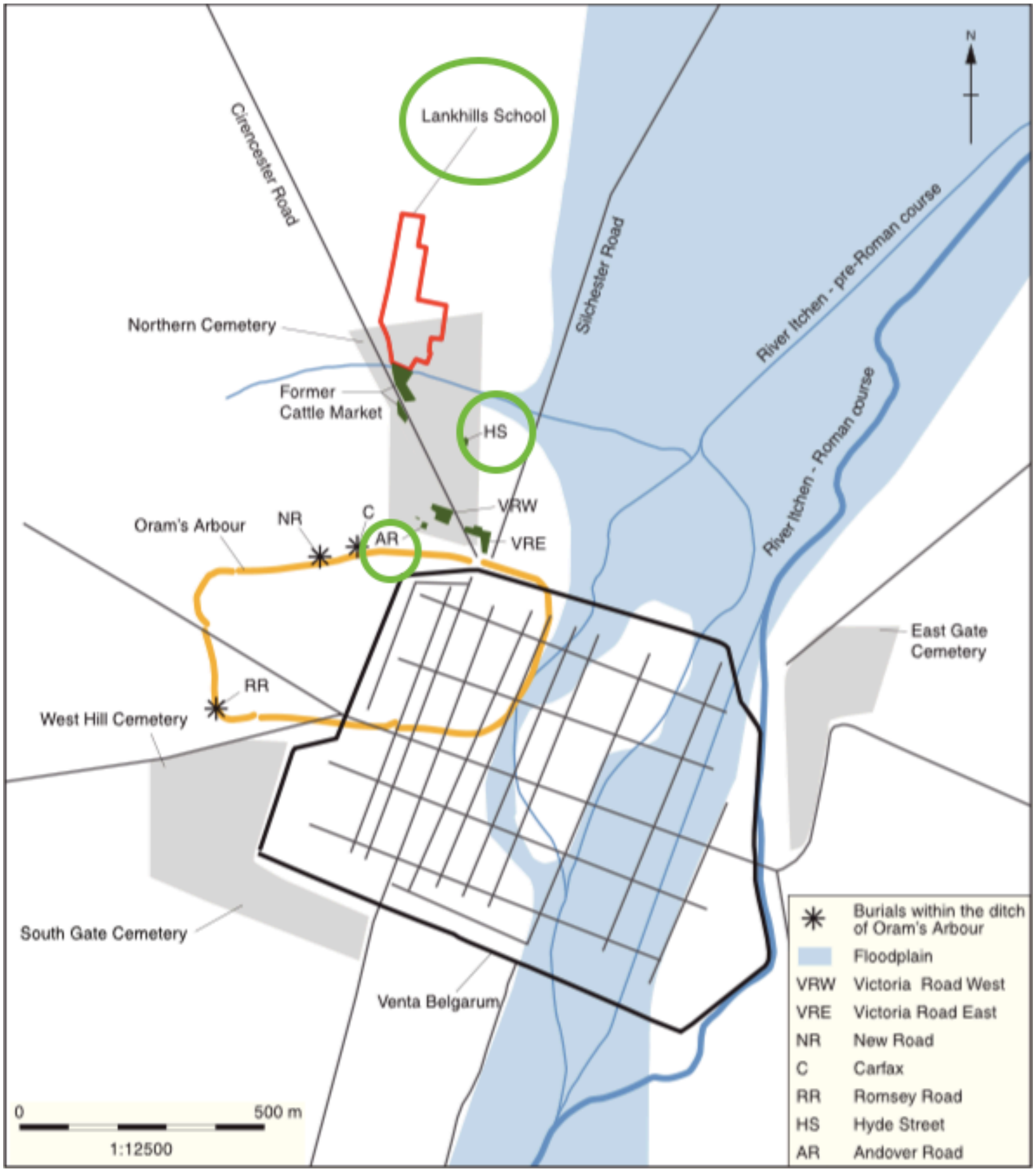
The excavation at Eagle Hotel, Andover Road, was carried out in 1998. This cemetery site was also part of the northern cemetery (Figure 3.3), with pottery sherds and coins dating to approximately the 4th century AD (Ottaway et al., 2012). A total of 48 graves were identified and recorded on site, of which 37 were excavated (Ottaway et al., 2012).

Eight of the individuals excavated were subadults and were subsequently excluded; 12 were included in this study. The skeletons from Andover Road were labeled with the code ANDR.

3.1.4 The Hyde Street cemetery collection

The burials at Hyde Street, also a part of the northern cemetery (Figure 3.3), were excavated in 1979 after human remains were found during construction (Ottaway et al., 2012). Due to its salvage nature, limited information was available from the excavation. Fifty-five burials were observed and recorded on site, 27 of which were fully excavated while the other 28 were only recorded (Ottaway et al., 2012). Ten individuals were included in the final sample for this study, and they were labeled with code HYS.

Figure 3.3. The geographical locations of the three cemetery sites



This map is adapted from Booth et al., 2010 p6. The location of Lankhills school is outlined and circled in red; the two smaller sites Andover Road and Hyde Street are also circled in green.

3.2 Methodology

3.2.1 Rules of inclusion and exclusion of individuals

This study was focused on adults, especially older adults; therefore only adults, defined as those estimated to be older than 17 years of age in the samples were examined. Upon further analysis, those meeting one or more of the following criteria were excluded from the sample: 1) those whose age can only be estimated as “adults” (age estimation methodology is detailed in Section 3.2.3); 2) those who do not have any mandibular molar positions with measureable height (detailed in Section 3.2.4); 3) those whose cranial elements could not be confidently matched to postcranial elements due to mixing of remains.

3.2.2 Sex estimation

Sex estimation data were drawn from a SSHRC Project (Insight Grant, File number 435-2013-1006, ID number 169793) with permission for their use for this thesis research. The recording form used to gather data for sex estimation is included in Appendix 1. Sex estimation methodology follows Buikstra and Ubelaker (1994). Originally six categories were created: male, probable male, ambiguous, probable female, female, and undetermined. Both pelvic and cranial features were scored. When postmortem damage and/or missing elements prevented confident scorings, the individual is listed as undetermined. When the features used to estimate sex were present and scorable, but either conflicted with each other (i.e. have scores at both the masculine and feminine ends), or were scored as intermediate, the individual is listed as ambiguous.

During subsequent analysis, sex categories were condensed into 4 groups, in which "probable males" were included in "males", and "probable females" were included in "females". Sex estimation is important because the muscularity and gracility of the mandible is affected by sex differences; therefore the data in this study are grouped and analyzed according to biological sex. Further details are outlined in Section 3.2.8.

3.2.3 Age Estimation

A total of five overlapping age categories were created (young adult (17-34), young-middle adult (17-49), middle adult (35-49), middle-old adult (35+), and old adult (50+)). Due to the inaccuracy of age estimation methods (discussed in Section 2.1) and preservation limitations in archaeological data, a range of methods was used in order to incorporate as many individuals into the study as possible. Age estimation data of each method were drawn from the SSHRC project along with sex estimation data (see Section 3.2.2). The accuracy, precision and reliability of these methods were considered, and they were given different priorities to produce a final age estimation. The list of age estimation methods used is summarized in Table 3.1.

Table 3.1. List of age estimation methods employed in this study

Age estimation methods	Priority
Epiphyseal fusion (after Cardoso, 2008 a; b)	First priority
Pubic symphysis morphology (after Brooks and Suchey, 1990)	Second priority
Transition analysis of the iliac auricular surface (after Milner and Boldsen, 2013); computer software ADBOU was used to calculate age range	Third priority
Dental wear (after Brothwell, 1981; modified by Mays (personal communication, June 17th, 2015)	Fourth priority

The dental wear age estimation method was given second priority at first, but it yielded a very large portion of young adults. Booth et al. (2010) suggested that the dental wear age estimation method might be underestimating age for this specific skeletal assemblage. Therefore a decision was made to reduce the priority assigned to this change and it was moved to the 4^{th} place. The final age estimation includes an age range (e.g. 17-25 years old) and an age category (e.g. young adult).

Cardoso (2008 a, b) suggested that if one or more epiphyses (i.e., the proximal tibia, proximal humerus, iliac crest, or sternal end of clavicle) is completely fused, the individual is most likely over 17 years of age for both sexes. To further narrow down the age range when epiphyseal union could only indicate “adult”, the pubic symphysis age estimation method was used; however pubic symphyses tend not to survive very often in archaeological remains. Therefore, when the pubic symphysis was not present, transition analysis of the auricular surface was used. Research has shown that this method performs reasonably well in ageing young and much older adults (Milner and Boldsen, 2012); however, there are still significant problems associated with the large group of individuals who fall in between these two age groups. In most cases transition analysis provided a very large age range that usually spans two or more age categories created for this study.

The ageing method given the least priority is Brothwell’s dental wear method (1981). Mays et al. (1995) stated that Brothwell’s study indicated molar wear patterns in British samples have not changed much from Neolithic to medieval times, but the disproportionally large number of young individuals identified in the current study sample probably suggests that some site-specific factor is affecting the accuracy of this method. Mays also suggested that if over half of the observable molar sockets exhibit antemortem tooth loss, it is very likely that this individual is over 50 years of age (personal communication, S Mays, June 17th, 2015).

In cases where there was conflict between different age estimation methods, or the age range spanned more than one age category (e.g. 35+), weight was given following the order of priority stated in the last two paragraphs to narrow the range down to one category. For example, if an individual is aged as 22+ based on the fusion of sternal end of clavicle, dental wear indicates 25-35 years old, and pubic symphysis suggests 21-53 years old (Brooks and Suchey, 1990), the final age estimation for this individual will be "young adult". If the age estimation provided by two methods were drastically different, other explanations were sought by looking for non-age-related conditions that may result in a skewed age estimation. For example, if the pubic symphysis indicates 19-34 years old, but dental wear suggests 50+ due to advanced antemortem tooth loss, the condition of dentition was further investigated to see if tooth loss was related to dental disease such as caries, rather than age. Individuals whose final age ranges indicated young-middle and middle-old adults were included to maximize sample size. There were some individuals whose age ranges still could not be narrowed down after consulting all available methods. This inability to produce a useful age range was due to either missing skeletal elements, or contradicting expression of age-related skeletal changes with no identifiable causes. These individuals were recorded as "adult" only, and were excluded from further analysis. The age estimations produced using methods described above were used in the analysis of the following: 1) relationships between age and mandibular bone heights; 2) relationship between age and the scoring of the dorsal margin of pubic symphysis.

To prevent circular reasoning as much as possible, during analysis of the relationship between estimated age at death and the presence of posterior exostoses of the auricular surface, age estimations from previous researchers were used. Gowland (2002) provided age estimates for the Clarke excavation, and Booth et al. (2010) provided age estimation for the Oxford Archaeology excavation. The age estimation methods employed by Gowland (2002) and Booth et al. 92010) are summarized in Table 3.2. The Booth et al. (2010) age estimation has five ranges (18-25; 26-35; 36-45; 45+; 60+) while Gowland (2002) has four (18-24; 25-34; 35-49; 50+). Those assigned as only "adult" were excluded. To simplify the analytical process, the 5 categories of Booth et al. (2010) were condensed into four. The 36-45 category in Booth et al. (2010) was combined with the 35-49 category in Gowland (2002). The 45+ and 60+ categories in Booth et al. (201) were combined with the 50+ category in Gowland (2002).

Table 3.2. Age estimation methods employed by Gowland (2002) and Booth et al. (2010)

Methods employed by Gowland (2002)	Methods employed by Booth (2010)
Suchey-Brooks pubic symphysis age estimation method (Brooks and Suchey, 1990)	
Auricular surface age estimation method (Lovejoy et al., 1985)	
Auricular surface age estimation method (Buckberry, 1999, unpublished)	Auricular surface age estimation method (Buckberry and Chamberlain, 2002)
Sternal end morphology of the 4th rib (Işcan et al., 1984)	
Dental wear age estimation method (Miles, 1963; Brothwell, 1981; also modified by the author)	Dental wear age estimation method (Miles, 1963; Brothwell, 1981)
	Cranial suture closure (Meindl and Lovejoy, 1985)

3.2.4 Mandibular bone height measurements

Mandibular bone resorption cannot be measured directly, because the original height of the mandible at each location is not available in archaeological samples; what we have is the bone after potential resorption, which stops at time of death. Therefore, the degree of resorption is inferred using mandibular bone height on the buccal side, with lower height indicating more bone resorption. In this study, up to eight measurements were taken for each individual, depending on the degree of preservation, at the locations of every mandibular molar socket and mental foramen, respectively.

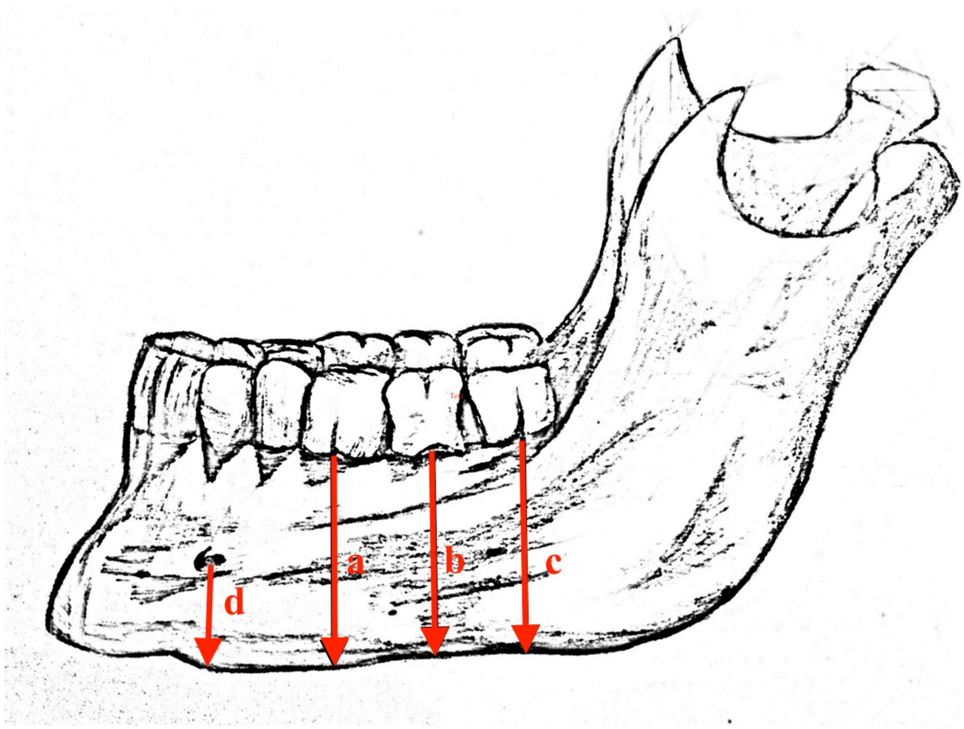
A fillable PDF form was created to record data for this study. A template of the form is included in Appendix 2. Under the mandibular ridge resorption section, four features were recorded for each molar position and two for each mental foramen. Bone presence was used to indicate whether the molar socket was measurable. If there was observable damage or modification that affected the result of mandibular bone height by more than 1mm (e.g. alveolar bone crest was broken, lower border cortex was missing, or the bone was broken and glued back), then bone presence for this molar position was recorded as “No”, and the height was not measured. For third molars, bone presence was recorded as “No” if they were congenitally absent, and corpus height was not measured. Criteria for congenitally absent third molars followed Turner et al. (1991). In a few cases where the third molars were present but never erupted out from the mandible, bone presence sections were also recorded as “No” and measurements were omitted. Bone presence was listed as “No” for mental foramen heights if the inferior edge of the foramen was damaged, or the lower border of the mandible at the foramen showed postmortem damage.

Tooth presence was the second feature recorded. If the tooth was in its socket or lost postmortem but was recovered, it was recorded as “Present”; if the tooth was lost antemortem or not recovered during excavation, it was recorded as “Not present”. For identification and siding of loose teeth, morphological characteristics of crown and roots described in White and Folkens (2005) were used as guidelines; a set of adult dentition casts were also used when necessary. In most cases where the crown was too damaged to allow identification of the tooth, fitting of roots into sockets helped with identification.

Socket remodeling was used to indicate if there was any resorption of the socket and if surrounding alveolar crest bone was present. Socket remodeling directly affects mandibular corpus height; it is also an important feature when assessing antemortem tooth loss. Therefore, it was carefully examined for every observable socket. If the socket was partially or completely filled in, or observable bone resorption was present and affected corpus height, especially on the buccal side, socket remodeling was recorded as “Present”. It should be noted that remodeling might still be present in cases where teeth are not lost antemortem. The criteria set by Buikstra and Ubelaker (1994) as well as Turner et al. (1991) for assessing antemortem tooth loss state that if the socket is partially or completely filled in, that is, bone remodeling has partially or completely obliterated the socket, it is considered antemortem tooth loss. However, when applied, this statement appears to be over simplified. During examination and recording of skeletal remains of the Lankhills collection, in many cases in which the sockets displayed advanced remodeling, the teeth were still present, either as loose teeth, or in some instances, remaining in the sockets. The finding that socket remodeling can be accompanied by a loose tooth (in which case this will not be antemortem tooth loss) raised the possibility that remodeled socket and absence of tooth does not necessarily indicate antemortem tooth loss. Therefore, antemortem tooth loss can potentially be over-diagnosed. In the study of mandibular bone resorption by Mays (2014), it was proposed that when a partially remodeled molar socket is shallow and widened accompanied by the absence of a tooth, it is considered antemortem tooth loss. Essentially, if the tooth is absent, and the remodeled socket has a widened edge that looks like a plate, it is likely to be a sign of antemortem tooth loss. On the contrary, if the absence of tooth is accompanied by socket remodeling, but the edge still remains some vertical shape that can hold the tooth in place, like a bowl, it is likely that the tooth is not lost antemortem, but rather postmortem. The procedures set out by Mays (2014) were consulted in antemortem tooth loss assessment for this study in order to avoid over-diagnosis as much as possible. It was observed during data collection that in those cases where socket remodeling was present but teeth were retained, at least some alveolar crest bone was present with relatively sharp edges, compared to smooth and rounded contour of sockets that had antemortem tooth loss. This feature was also taken into account when assessing antemortem molar loss. The degree of socket remodeling and whether it was listed as antemortem tooth loss were described in the notes section of the recording form.

Corpus height was the last feature recorded in the mandibular bone resorption section of the recording form. The measurements were taken using a Mastercraft digital caliper. Results are in millimeters and accurate to two decimal points. The methodology of taking measurements followed Mays (2014). All measurements were taken on the buccal side (an illustration is provided in Figure 3.4). When little or no ridge resorption is present, the root bifurcation site where the vertical bone ridge between the two roots reaches the alveolar crest is clearly visible. In these cases, corpus height was measured as the least distance from this point perpendicular to the lower border of the mandible. A similar procedure was followed when socket and alveolar remodeling was present, but the tooth was not lost; measurements were taken from the intersection of root bifurcation and the alveolar crest. When the tooth was not present, but the socket and alveolar bone resorption was present, or when the tooth was lost antemortem but socket was still visible, the height was measured from the midpoint between the mesial and distal margins of the socket to the lower border of mandible. If the socket was completely remodeled, the position of the socket and its midpoint was estimated using the other remaining sockets as reference. If antemortem tooth loss was advanced and all sockets were completely remodeled, a mandible of the same sex and with similar corpus length that was dentate or had observable sockets was used for comparison. Mental foramen height was measured from the most inferior point of the foramen to the lower border of the mandible (Figure 3.4).

Figure 3.4. Measurements of the mandibular bone heights, left side of mandible shown



a: bone height at 1st molar; b: bone height at 2nd molar; c: bone height at 3rd molar; d: bone height at mental foramen. Illustration by Lucy Wei.

Photographs were taken for every mandible measured. A superior view of the entire mandible was taken with a scale and label indicating site name and skeletal number. Close-ups for both sides of the mandible from lateral and superior directions were then taken, focusing on every molar socket, so that details of the alveolar crest, alveolar resorption, and socket remodeling could be clearly seen. Whenever a molar socket was not measurable, close-up photos were also taken for future reference. In cases where a tooth was loose and resorption was present, photos were taken with the tooth in and out of the socket for comparison and better observation of socket remodeling. In cases where the sockets of third molars were not entirely visible from lateral views, photos of posterior-superior or lateral-superior angles were taken.

3.2.5 Scoring of posterior exostoses of the iliac auricular surface

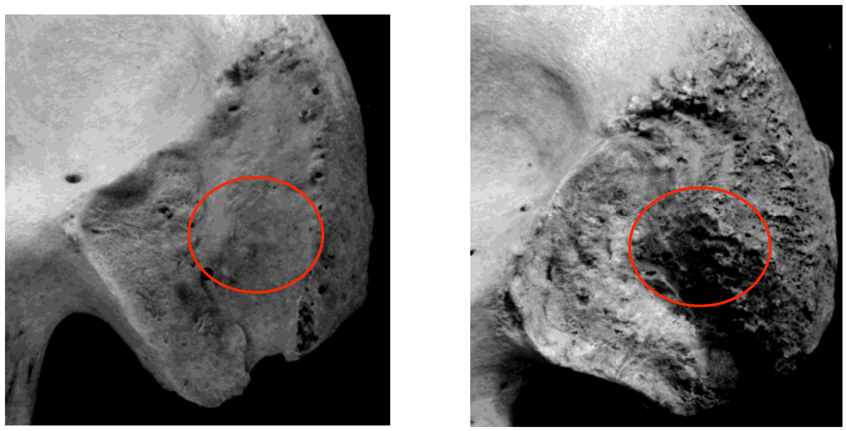
The morphology of posterior exostoses of the auricular surface is one of the two features Milner and Boldsen (2012) suggested may be indicative of old age. The posterior exostoses area is located immediately posterior to the apical region of the sacroiliac joint surface, known as the retroauricular area. The left side was recorded whenever present. If the left os coxa was not present, or the posterior exostoses area of the left side was not scorable, the right side was scored if available. In rare cases where left and right sides displayed very different morphologies, or the left side was present by may have been affected by pathology, both sides were recorded, and notes were made. The scoring of posterior exostoses followed the manual for transition analysis developed by Milner and Boldsen (2013) and scored the presence/absence and morphology of bony protuberances that develop on top of the otherwise smooth surface where ligaments attach. Table 3.3 lists the scores and their corresponding morphology. Figure 3.5 illustrates the morphology of scoring 1 and 2 (Milner and Boldsen, 2013).

Table 3.3. Transition analysis: posterior exostoses scoring criteria

Score	Morphology
1	Surface is smooth, or only a few isolated exostoses were observed that do not cover the entire surface
2	Entire surface was covered by low, rounded exostoses
3	Entire surface was covered by low but pointy exostoses

Adapted from Milner and Boldsen (2013 a, p11).

Figure 3.5 Illustrations of posterior exostoses scoring 1 and 2 (from Milner and Boldsen, 2013, b)



The photos are from Milner and Boldsen (2013 b, p.19). Left: scoring of 1: smooth. Right: scoring of 2: rounded. The red circles indicate the location of the posterior exostoses area.

Transition analysis allows the observer to give a range of scores if the observed skeletal element exhibits a mix of features from more than one score, or when some postmortem damage prevents a single score. Therefore whenever a range of scores was given, a detailed description was put down in the notes section. Fragmented posterior exostoses areas were scored as long as over 80% of the surface was recovered, however if the cortex was missing or damaged, obscuring observation of the surface, it was not scored.

Photographs were taken whenever the auricular surface was present, even if the posterior exostoses area was not scorable. A superior view of the entire os coxa was taken with a 5cm scale and a label indicating site name and skeleton number, followed by a close up of the auricular surface. If the posterior exostoses area was present, close-up photos were taken from various angles in order to show the 3-dimensional morphology of bony exostoses.

3.2.6 Scoring of the dorsal margin of the pubic symphysis

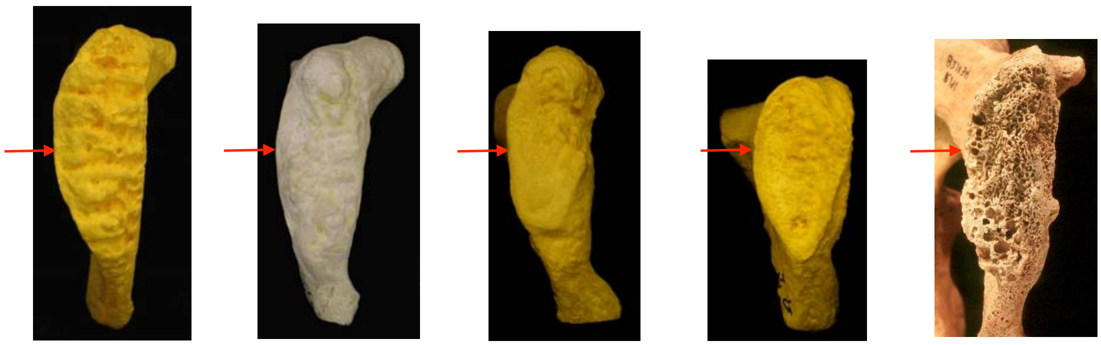
The breakdown of the dorsal margin of the pubic symphysis is the second feature Milner and Boldsen (2012) suggested may be linked to advanced age. This feature is the posterior edge of the symphyseal face, and its morphology changes throughout life. The left side was recorded whenever it was present. If the left side was not recovered, or it was too damaged to be scorable, the right side was scored instead. The scoring of the dorsal margin followed the guidelines in the transition analysis manual (Milner and Boldsen, 2013, a) and is summarized in Table 3.4. Photographic illustrations of each score are summarized in Figure 3.6.

Table 3.4. Transition analysis: dorsal margin of pubic symphysis scoring criteria

Score	**Morphology**
1	Margin is wavy and serrated due to the extension of furrows and ridges of the symphyseal face onto the margin.
2	"Flattening incomplete": at least 1cm of the margin has been flattened, entire margin is undulated.
3	"Flattening complete": the margin is almost entirely flattened due to the obliteration of ridges and furrows on the dorsal demiface of the symphyseal surface
4	At least 1cm of long ridge that resembles a rim is present
5	At least 1cm of the margin shows erosion or pitting

Adapted from Milner and Boldsen (2013 a, p.7).

Figure 3.6. Illustration of the scoring of the dorsal margin of pubic symphysis (from Milner and Boldsen, 2013, b)



The photos are from Milner and Boldsen (2013 b, p.10). From left to right: scoring of 1: serrated; scoring of 2: flattening incomplete; scoring of 3: flattening complete; scoring of 4: rim; scoring of 5: breakdown. Red arrows indicate the location of the dorsal margin of pubic smphysis.

As noted in Section 3.2.5, transition analysis of the pubic symphysis also allows the observer to assign a feature to more than one score in cases of mixed characteristics or an incomplete; whenever a range of scores were given, details were described in the notes section. If there was less than 1cm of the margin that could be confidently assessed, it was marked as not scorable. Completeness and presence of postmortem damage were also recorded in the notes section.

Photographs were taken for every recorded pubic symphysis. Overview photos were taken from the anterior with a 5cm scale and given a label indicating site name and skeletal number. Close-up photos of the symphyseal face and dorsal margin were then taken from a variety of angles in order to best show the features based on which score was assigned, especially for serrated and undulated scores, since they usually required shadow to be best visualized.

3.2.7 Repeatability

A repeatability test was performed in order to test the consistency of measurements and degree of intra-observer error. The consistency of both quantitative measurements (mandibular bone height) and qualitative measurements (dorsal margin of pubic symphysis and posterior exostoses of auricular surface scoring) were tested. Twenty individuals were randomly selected from skeletons recorded as of week eight. A group of ten was randomly selected from all individuals. Another group of ten was randomly selected from individuals who had all three skeletal elements present, in order to have enough data from the scoring of dorsal margin and posterior exostoses to complete the repeatability test. After random selecting individuals without any preference for number or recording date, the 20 individuals were re-recorded. Results were then compared to the original data for these individuals. In transition analysis of the pubic symphysis and posterior exostoses of auricular surface, the consistency was calculated as the percentage of data that were scored the same. For mandibular bone heights, the consistency was statistically calculated using technical error measurement (TEM), relative TEM (r-TEM) and contribution of measurement error to sample variation (TEM^2/SD^2). TEM assesses the variability between measurements when the same specimen is measured multiple times. r-TEM is the percentage of error corresponding to the average value of the data. TEM^2/SD^2 represents how much of the variation in data is due to measurement error. The equations are summarized in Table 3.5. Detailed results of repeatability are outlined in Section 4.3 in Chapter 4.

Table 3.5. Calculations of repeatability

Technical error measurement	TEM = $\sqrt{\frac{\sum D^2}{2n}}$
Relative technical error measurement	r-TEM = $\frac{\sqrt{\frac{\sum D^2}{2n}}}{VAV} \times 100\%$
Contribution of measurement error to sample variation	$\frac{TEM^2}{SD^2}$
$\sum D^2$: Summation of deviation (difference between 2 measurements) raised to the 2nd power n=number of repeated measurements VAV: the average value of the 2 repeated measurements	

3.2.8 Statistical analysis

Statistical analysis was carried out using IBM SPSS Statistics 23. Several sets of statistics were run to test correlations between different data. First of all, an independent T-test was conducted to test sex difference of mandibular bone height to see if separation of the data was needed in the following analysis. After this, a normality test was performed in order to determine what kind of correlation coefficient should be used. Results are detailed Chapter 4. Then, a correlation coefficient was calculated to test correlations between: 1) age and mandibular bone heights at all molar locations, respectively; 2) age and scoring of the dorsal margin of the pubic symphysis; 3) age and scoring of the posterior exostoses of the iliac auricular surface; 4) the scorings of the two “old age” pelvic traits; 5) mandibular bone heights and scoring of the dorsal margin of the pubic symphysis, respectively; and 6) mandibular bone heights and scoring of the posterior exostoses, respectively. Spearman’s correlation coefficient was suitable for all these analyses since at least one of the variables in each test was categorical, and was not normally distributed.

Chapter 4. Results

4.1 Introduction

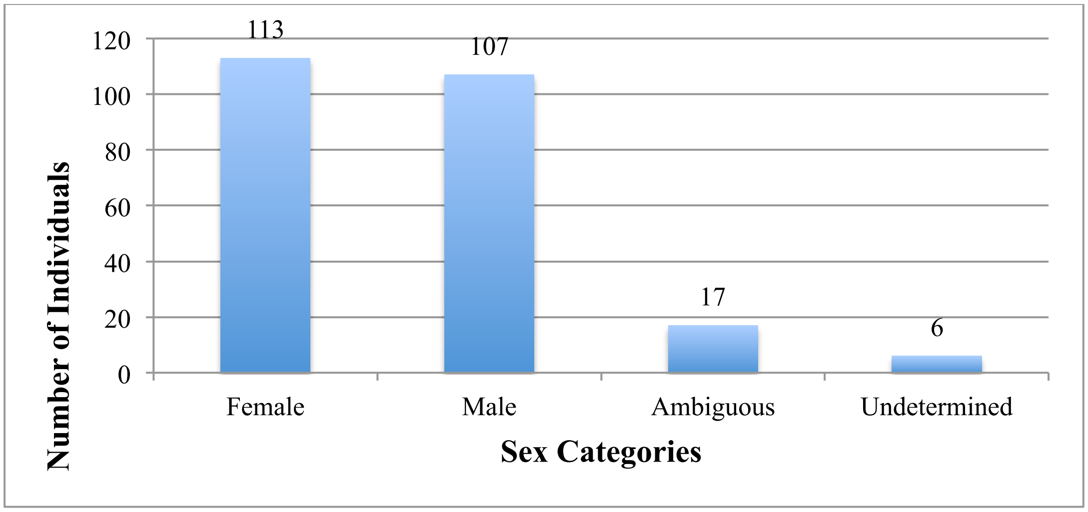
This chapter presents results obtained from the analysis of mandibular height and old age traits in this study. Estimated age and sex distribution are presented, followed by the results of consistency tests that tested for intra-observer error. The results of the statistical analyses undertaken are laid out in the third section.

4.2 Age and sex distribution

The sample contained a total of 243 individuals, each of which was assigned to one of the 4 sex categories and one of the 5 age categories. A complete list of age and sex estimates is included in Appendix 3. Two age distributions are presented because two age estimations methods were employed using several age estimation techniques in different orders of priority.

Sex distribution of the sample is illustrated in Figure 4.1, showing that there are roughly equal numbers of males and females in this sample (113 females and 107 males). Seventeen individuals were estimated to be ambiguous, and five individuals were designated as "undetermined".

Figure 4.1. Sex distribution

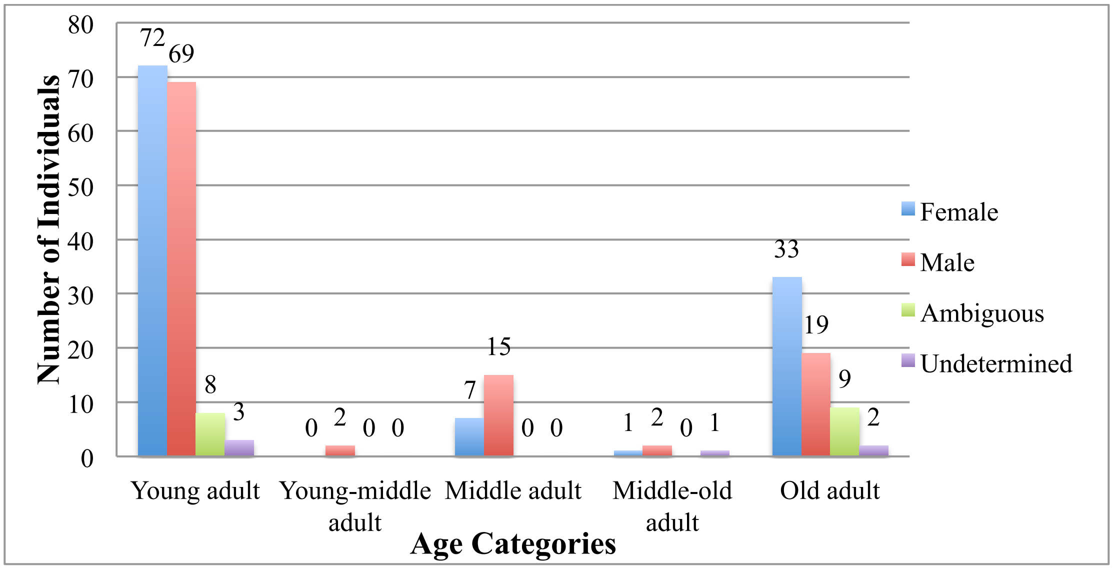


The numbers on the bars indicate the number of individuals in each sex category.

As set out in Section 3.2.3 two different age distributions were created. The first one, illustrated in Figure 4.2, has dental wear as the second priority (first priority was given to epiphyseal fusion method). Due to the problems associated with the dental wear method, detailed in Section 3.2.2, a second age distribution was created and is illustrated in Figure 4.3. Details of the priority of age estimation methods are outlined in Section 3.2.2. Figure 4.2 shows that the young adult category has the largest number of individuals (n=152), while fewer individuals were assigned into the "middle adult" groups (n=22). Sixty-three individuals were estimated to be in the old adult category.

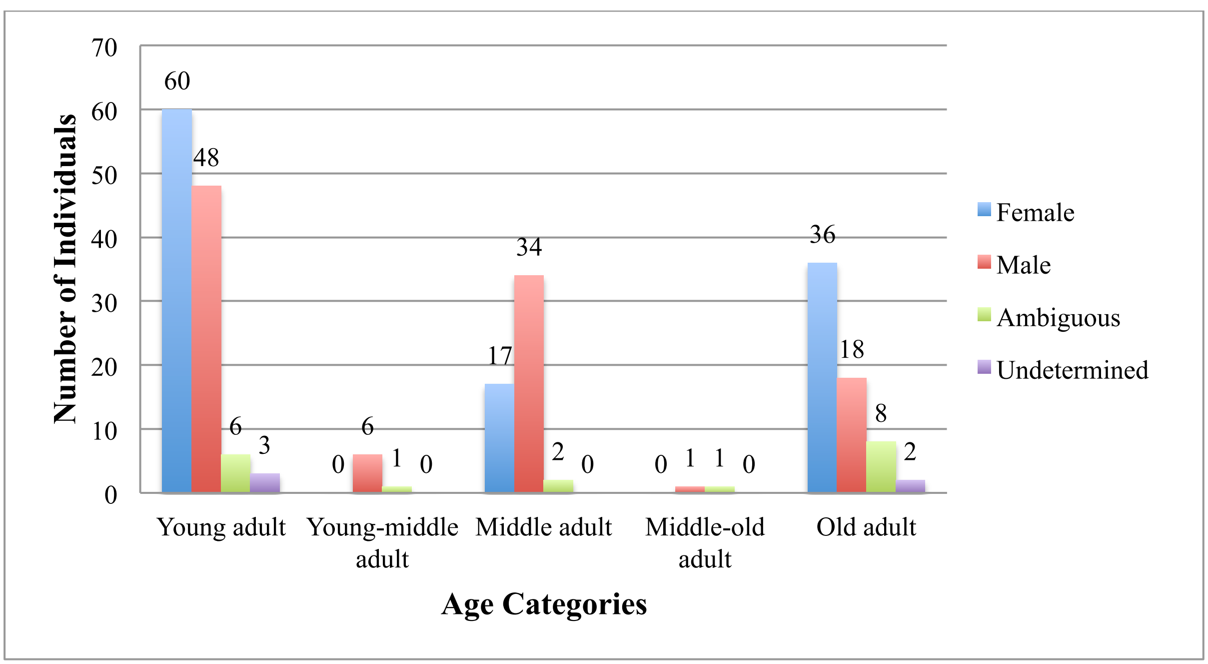
Figure 4.3 shows the second round of final age estimation summary, which has dental wear as the last priority (detail of priority order is provided in section 3.2.2). The young adult group still takes up the largest portion, but the number is greatly reduced. Meanwhile, the number of individuals in middle adult group has increased.

Figure 4.2. Age and sex distribution: 1st round age estimation (dental wear as 2nd priority)



The numbers on the bars indicate the number of individuals of each sex, within each age category.

Figure 4.3. Age and sex distribution: 2nd round age estimation (dental wear as the last priority)



The numbers on the bars indicate the number of individuals of each sex, within each age category.

4.3 Repeatability of test results

To assess intra-observer error, a repeatability test was performed. All data for this test are included in Appendices 4 and 5.

Two types of data were recorded for this test. The first type was anthropometric measurements of mandibular bone heights. A statistical method was used to assess consistency, details are provided in Section 3.2.4, and the results are listed in Table 4.1.

As shown in Table 4.1, the error percentages corresponding to the total average of variables (represented by r-TEM) are all less than 5%. The contribution of measurement error to sample variation (represented by TEM^2/SD^2) are all less than 5% except for one location, the right mental foramen height, which is less than 10%.

Table 4.1. Repeatability test results for mandibular bone height measurements

Variables	n	TEM	r-TEM	TEM^2/SD^2
LM1	17	0.2957	1.09%	0.85%
LM2	15	0.3842	1.47%	1.88%
LM3	14	0.4584	1.75%	2.04%
LMFH	17	0.1396	1.06%	1.09%
RM1	18	0.2551	0.97%	1.02%
RM2	18	0.5774	2.29%	4.73%
RM3	18	0.2988	1.11%	1.26%
RMFH	18	0.2970	2.25%	8.89%

LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height; n: number of measurements; TEM: technical error of measurement; r-TEM: relative technical error measurement; TEM^2/SD^2: contribution of measurement error to sample variation.

The second type of data that are tested for intra-observer error are categorical data, which is the scoring of transition analysis features on the pubic symphysis and auricular surface. Data consistency was measured by the percent of repeated scorings that are identical. All data are included in Appendix 6, while a summary is presented in Table 4.2.

Table 4.2. Repeatability of transition analysis features scoring

Variables	N	Consistent data	Inconsistent data	Percentage
PS side	13	13	0	100%
Topography	13	13	0	100%
Texture	13	11	2	84.62%
Superior protuberance	7	7	0	100%
Ventral margin	13	12	1	92.31%
Dorsal margin	13	12	1	92.31%
AS side	13	13	0	100%
Posterior exostoses	13	12	1	92.31%
Total	98	93	5	94.90%

PS: pubic symphysis; AS: auricular surface. n: number of measurements.

As illustrated in Table 4.2, all features apart from “Texture” have a consistency of over 90%. The scoring of “Texture”, which has the lowest accuracy, was found to be over 80% consistent. Overall, the tests revealed a consistency of 94.9%, which indicates that the impact of intra-observer error is relatively low.

4.4 Statistical results

This section presents the statistical results of the following: 1, the statistical summary and distribution of all the data; 2, the correlation between age and mandibular bone heights; 3, the correlation between estimated age and "old age" traits of transition analysis; 4, the correlation between "old age" traits and mandibular bone heights.

4.4.1 Mean, median, standard variation, and distributions

In this section, the mean, median and standard deviation of numerical data of mandibular bone height measurements are summarized in Table 4.3, and the distributions of the data are summarized in Table 4.4. The distribution of the data is important because it determines whether parametric or nonparametric statistical tools should be used in data analysis.

Table 4.3. Mean, median and standard deviation of mandibular measurements*

Variables	Mean	Median	Standard Deviation
LM1	26.7398	26.8200	3.9515
LM2	25.1853	25.2900	3.6855
LM3	26.4778	26.5200	3.7225
LMFH	13.8305	13.7950	1.5957
RM1	25.8942	26.0900	3.9991
RM2	24.7847	24.7550	3.5595
RM3	26.0139	26.0000	3.5862
RMFH	13.6947	13.7250	1.6859

*All measurements are in millimeters. LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height.

As illustrated in Table 4.4, the data have a combination of normal and non-normal distributions. For skewness and kurtosis, data are considered to have a normal distribution when the z-scores are between ± 2.58 ($p=0.01$). In the Kolmogorov-Smirnov test and Shapiro-Wilk tests for distribution, data are considered to be normally distributed when the score is larger than p, which in this test equals 0.05. Therefore, the distribution of the left mental foramen height and right mandibular bone height at all molar positions are not normally distributed. Left mandibular bone heights at all molar positions and right mental foramen heights are normally distributed.

Data relating to sex and age categories, as well as scoring of the pelvic features were not normally distributed because they are classified as nominal and ordinal data. Therefore, nonparametric statistical methods were used. Parametric statistical methods were used to test differences of mandibular bone height between males and females. Results are summarized in Section 4.4.2.

Table 4.4. Distributions of numerical data

Variables	Skewness z-score (p=0.01)	Kurtosis z-score (p=0.01)	Kolmogorov-Smirnov (p=0.05)	Shapiro-Wilk (p=0.05)	Distribution
LM1	-1.0568	1.4829	0.200	0.071	Normal
LM2	-1.6897	0.3960	0.200	0.314	Normal
LM3	-1.7371	0.4145	0.200	0.207	Normal
LMFH	-3.6723	-0.4731	0.200	0.899	Not normal
RM1	-2.0000	3.6294	0.200	0.021	Not normal
RM2	-1.705	4.044	0.200	0.030	Not normal
RM3	3.386	4.375	0.200	0.01	Not normal
RMFH	0.130	0.857	0.200	0.841	Normal

LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height.

4.4.2 Sex differences in mandibular bone heights

Biological males tend to be more robust than biological females on average. Therefore, it should be tested whether there is a statistically significant difference between the sexes in order to determine if the data need to be separated for further analysis to avoid inaccuracy. An independent-samples T-test was run for each location where measurements were taken. Although the independent-samples T-test is a parametric test, it is very robust for nonparametric data as well (Laerd Statistics, n.d.). The results are summarized in Table 4.5. The p-value for testing equal variance and significance are both 0.05.

Table 4.5. Sex difference of mandibular bone heights*

Variables	N (female)	Mean ±Std. Dev (female)	N (male)	Mean ±Std. Dev (male)	Equal variance	2 tailed significance
LM1	85	25.12±3.16	90	23.38±3.93	Violated	<0.0005
LM2	89	23.94±3.26	91	26.50±3.57	Not violated	<0.0005
LM3	69	23.68±3.27	74	28.22±3.20	Not violated	<0.0005
LMFH	83	13.30±1.58	89	14.29±1.47	Not violated	<0.0005
RM1	92	24.46±3.37	92	27.24±4.23	Violated	<0.0005
RM2	90	23.38±2.86	92	26.34±3.66	Violated	<0.0005
RM3	73	24.28±3.38	86	27.70±3.13	Not violated	<0.0005
RMFH	93	12.99±1.65	96	14.33±1.58	Not violated	<0.0005

*All measurements are in millimeters. LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height. n: number of individuals.

For all locations, the differences between males and females are statistically significant ($p<0.05$). For the left first molar, right first molar and right second molar, the assumption of homogeneity of variances was violated. In these cases, the Welch test was performed and therefore the results are valid. In further analysis that involves mandibular bone heights the data will be separated by sex.

4.4.3 Correlations between age and mandibular bone heights

A complete list of mandibular bone height measurements is included in Appendix 6. Spearman's correlation coefficient was performed to assess if there is a correlation between mandibular bone heights and age. As mentioned in Section 3.2.3, due to problems with dental wear age estimation, two rounds of statistical analyses were done (3.2.2); the first one with dental wear as 2nd priority, and second one with dental wear as the last priority. Results are summarized in Table 4.6 for the first round and in Table 4.7

for the second round.

Table 4.6. Correlations between age categories and mandibular bone heights 1st round (dental wear as 2nd priority)

Variables	N (female)	r_s (female)	p (female)	Statistically significant	N (male)	r_s (male)	p (male)	Statistically significant
Age-LM1	85	-0.288	0.007	Yes**	90	-0.186	0.079	No
Age-LM2	89	-0.336	0.001	Yes**	91	-0.194	0.065	No
Age-LM3	69	-0.323	0.007	Yes**	74	-0.150	0.203	No
Age-LMFH	83	0.060	0.588	No	89	-0.153	0.153	No
Age-RM1	92	-0.235	0.024	Yes*	91	-0.202	0.055	No
Age-RM2	90	-0.278	0.008	Yes**	91	-0.199	0.059	No
Age-RM3	73	-0.318	0.006	Yes**	85	-0.156	0.155	No
Age-RMFH	93	-0.027	0.796	No	95	-0.048	0.647	No

*: The correlation is significant at the 0.05 level; **: the correlation is significant at the 0.01 level. LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height. n: number of individuals. r_s: the statistical measure of correlation between dependent variables (mandibular bone heights at each molar and mental foramen position) and independent variable (age). p: level of significance.

In the first round of statistical analysis, a slight to medium correlation is statistically significant between age and mandibular bone heights at molar sockets for females, but not for males. For both sexes, age and mandibular bone heights at the mental foramen do not have a statistically significant correlation.

Table 4.7. Correlations between age categories and mandibular bone heights 2nd round (dental wear as the last priority)

Variables	N (female)	r_s (female)	p (female)	Statistically significant	N (male)	r_s (male)	p (male)	Statistically significant
Age-LM1	85	-0.107	0.329	No	90	-0.200	0.059	No
Age-LM2	89	-0.302	0.004	Yes**	91	-0.048	0.651	No
Age-LM3	69	-0.284	0.018	Yes*	74	-0031	0.791	No
Age-LMFH	83	-0.049	0.659	No	89	0.066	0.541	No
Age-RM1	92	-0.174	0.095	No	91	-0.107	0.314	No
Age-RM2	90	-0.209	0.048	Yes*	91	-0.120	0.259	No
Age-RM3	73	-0.300	0.010	Yes**	85	-0.022	0.840	No
Age-RMFH	93	-0.124	0.235	No	95	0.090	0.384	No

*: The correlation is significant at the 0.05 level; **: the correlation is significant at the 0.01 level. LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height. n: number of individuals. r_S: the statistical measure of correlation between dependent variables (mandibular bone heights at each molar and mental foramen position) and independent variable (age). p: level of significance.

In the second round of statistical analysis, a slight to medium correlation is statistically significant again only in females except for the left first molar, but not in males. Similar to the first round, no statistically significant correlation was found between age and mandibular bone heights at the mental foramen. In this round the age estimations used dental wear as the least priority.

4.4.4 Correlations between estimated age at death and the two "old age" traits

A complete list of the scoring of the two "old age" traits is included in Appendix 7. Spearman's correlation coefficient was calculated to assess the correlation between age and the two "old age" traits in transition analysis, as well as the correlation between the two traits themselves. Age estimations from Gowland (2002) and Booth et al. (2010) were used (see Section 3.2.3 for details).

Although when calculating the final age estimation using transition analysis software ADBOU (Milner and Boldsen, 2013), sex is one of the variables that needs to be inputted, the actual scoring of features does not take sex differences into account. Therefore, in this section the sexes are combined and those with an ambiguous or undetermined sex estimation are included. Age category is one of the variables in this statistical analysis, and every individual in the sample has two age estimations because of the problem associated with dental wear (see Section 3.2.2); therefore two rounds of statistical analysis were also conducted. Results are summarized in Table 4.8 (dorsal margin of pubic symphysis), Table 4.9 (auricular surface) and Table 4.10 (the correlation between the two pelvic traits).

Table 4.8. Correlations between age and dorsal margin scoring 1st and 2nd Rounds

Variables	N	r_s	p	Statistically significant
Age (1st round)-dorsal margin	98	0.592	P<0.0005	Yes**
Age (2nd round)-dorsal margin	98	0.770	P<0.0005	Yes**

**: The correlation is significant at the 0.01 level.
n: number of individuals. r_s: the statistical measure of correlation between dependent variables (the scoring of dorsal margin) and independent variable (age). p: level of significance.

There is a positive correlation between age and the age-related breakdown of the dorsal margin of pubic symphysis for both rounds. However, when age estimation is adjusted to minimize the problem of dental wear, the correlation is significantly stronger.

Table 4.9. Correlation between age and posterior exostoses scoring

Variables	N	r_s	p	Statistically significant
Age (Gowland 2002 & Booth et al. 2010)-posterior exostoses	83	0.292**	P=0.01	Yes

**: The correlation is significant at the 0.01 level.

n: number of individuals. r_S: the statistical measure of the correlation between dependent variables (scoring of posterior exostoses) and independent variable (age). p: level of significance

There is a weak, but statistically significant, positive correlation between Gowland's (2002) and Booth et al.'s (2010) age estimations and the scoring of posterior exostoses.

Table 4.10. Correlation between the scoring of the two "old age" traits

Variables	N	r_s	p	Statistically significant
Dorsal margin-posterior exostoses	68	0.346	0.004	Yes**

**: The correlation is significant at the 0.01 level.

n: number of individuals. r_S: the statistical measure of the correlation between the two variables. p: level of significance

There is a statistically significant, but slight, positive correlation between the score of the dorsal margin of the pubic symphysis and posterior exostoses of the auricular surface.

4.4.5 Correlations between mandibular bone heights and the two "old age" traits

Spearman's correlation coefficient tests were run to test the relationship between the decrease of mandibular bone height and scoring of pelvic features. A summary is presented in Tables 4.11 and 4.12.

Table 4.11. Correlations between mandibular bone heights and dorsal margin scoring

Variables	N (female)	r_s (female)	p (female)	Statistically significant	N (male)	r_s (male)	p (male)	Statistically significant
LM1	31	-0.177	0.341	No	48	-0.301	0.038	Yes *
LM2	29	-0.249	0.193	No	48	-0.142	0.336	No
LM3	25	-0.348	0.088	No	43	0.043	0.786	No
LMFH	31	-0.010	0.958	No	46	-0.271	0.069	No
RM1	33	-0.194	0.279	No	49	-0.339	0.017	Yes*
RM2	34	-0.271	0.121	No	49	-0.401	0.004	Yes**
RM3	31	-0.343	0.059	No	45	-0.255	0.091	No
RMFH	32	-0.245	0.176	No	52	-0.194	0.169	No

*: The correlation is significant at the 0.05 level; **: the correlation is significant at the 0.01 level.
LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height. n: number of individuals. r_S: the statistical measure of the correlation between the two variables p: level of significance.

Interestingly, the statistically significant correlations are only seen in males, and not at every location. Data presented in Table 4.11 summarize these findings and show that there is a weak negative correlation at the left first molar and right first molar for males, while at right second molar there is a medium negative correlation, also only for males.

Table 4.12. Correlations between mandibular bone heights and posterior exostoses scoring

Variables	N (female)	r_s (female)	p (female)	Statistically significant	N (male)	r_s (male)	p (male)	Statistically significant
LM1	35	-0.170	0.923	No	43	-0.372	0.014	Yes*
LM2	39	-0.327	0.042	Yes*	43	-0.166	0.288	No
LM3	32	-0.518	0.002	Yes**	37	-0.329	0.047	Yes*
LMFH	35	-0.229	0.187	No	42	-0.163	0.303	No
RM1	41	-0.132	0.412	No	45	-0.235	0.120	No
RM2	42	-0.110	0.487	No	47	-0.436	0.002	Yes**
RM3	37	-0.270	0.106	No	42	-0.447	0.003	Yes**
RMFH	40	-0.243	0.131	No	48	-0.255	0.081	No

*: The correlation is significant at the 0.05 level; **: the correlation is significant at the 0.01 level.
LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height. n: number of individuals. $r_{S:}$ the statistical measure of the correlation between the two variables p: level of significance.

For the correlations between mandibular bone heights and scoring of posterior exostoses of the auricular surface (summarized in Table 4.12), statistically significant results are seen in both females and males, but not at every location. Females have only two locations, left second and third molars, at which heights have a negative correlation with the presence of posterior exostoses. For males, left first and third molars sites, as well as right second and third molar sites show weak negative correlations between mandibular bone heights and the presence of posterior exostoses.

Chapter 5. Discussion

This chapter discusses the findings in five parts. First, the correlations between age and mandibular bone heights are examined. The association between mandibular bone loss and age-related general bone loss in females is explored. Second, the correlations between estimated age and the "old age" traits are analyzed. Different etiologies of the two "old age" traits are considered to explain the different correlations between sexes. Third, the direct relationship between mandibular bone heights and "old age" traits are investigated to see if there is a potential to use these traits in combination to help identify old individuals. Then, the significance of this study in the wider bioarchaeological work on the subject of studying older people in the past is discussed. Finally, several limitations of this study are addressed.

5.1 Correlations between estimated age-at-death and mandibular bone heights

The first finding of this study is that there is a significant negative correlation between age-at-death and mandibular bone heights, but only in females at the second and third molar locations (see Table 4.7).

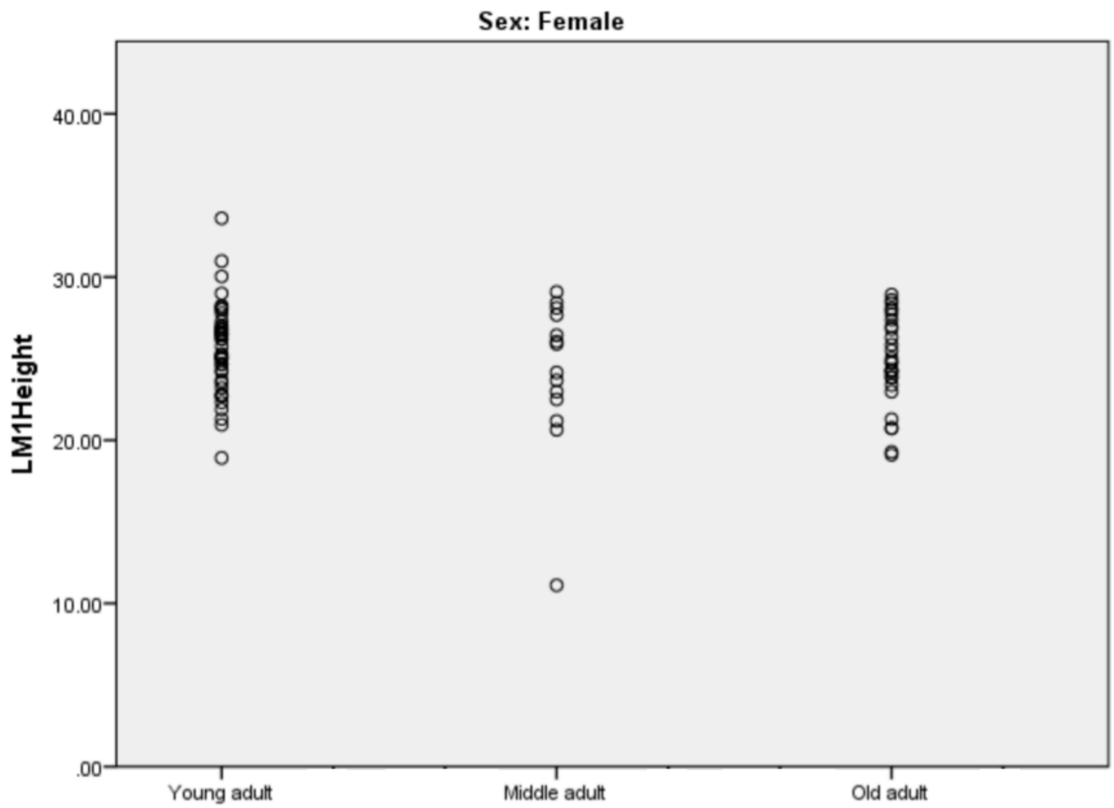
It is well established in the literature that people in both past and present societies experience bone loss and its consequences, such as osteoporosis, with advancing age (e.g. Mays, 2006; Agarwal and Grynpas, 2009; Cho and Stout, 2011; Tella and Gallagher, 2014; Wright et al., 2014). This age-related bone loss affects both men and women, but women are at a higher risk of developing age-related bone loss and the loss tends to be more severe due to change in hormonal levels after menopause (Riggs and Melton, 1995;

Riggs et al. 1998). The onset of menopause causes a decrease in estrogen levels, which increases local factors that favour osteoclastic processes (Chan and Duque, 2002). Following tooth loss, bone around the socket gradually remodels and fills in the tooth socket; with the mechanical load now directly applied to the alveolar ridge, bone resorption begins to occur (Atwood, 1971; Kingsmill, 1999). It is highly possible that the more severe age-related general bone loss in women amplifies the effect of the naturally occurring resorption process after tooth loss. Rosenquist et al. (1978) found that patients with mandibular bone resorption tend to have less bone mass in the radius, and thus argued that systemic factors affect bone loss in the mandible. The fact that the correlation exists only among females is consistent with some clinical studies, such as Humphries et al. (1989), who investigated mandibular bone resorption and age in a modern edentulous group. They found a correlation coefficient of 0.51 ($p=0.001$) among females but no correlation in males (Humphries et al., 1989). Hirai et al. (1993) reported a statistically significant difference ($p=0.0063$) in the average mandibular bone height between females and males, with females having shorter mandibular bone height. They also found a statistically significant correlation between the height of mandible and severity of osteoporosis ($p=0.01$, $r=-0.42$), with females occupying larger proportions in every level of osteoporosis severity. Although measuring techniques of mandibular bone height differ (e.g. Humphries et al. 1989 used radiographic methods and the current study used direct measurement of bone height), the current study supports the clinical findings that mandibular bone resorption is more marked with advancing age in females.

Mental foramen height was measured as a stable reference point because it has a fixed position in relation to the mandibular lower border (Thomas, 1965). The mental foramina serve as openings for nerves and blood vessels. Foramina are located at some distance from the alveolar crest and so it is rare for them to be affected by the bone resorption process at the mandibular ridge, although there are a few cases in which the resorption is so advanced that the mental foramina were on the occlusal surface. In a previous study on a Dutch archaeological sample by Mays (2014), a correlation was found between mandibular bone height at the mental foramen and age in both sexes, but only among those who showed left first molar antemortem tooth loss, which is different from this study. It is possible that in the current study the correlation was not strong enough to be detected by the statistical methods employed, since the data were pooled, instead of separating those with and without antemortem tooth loss. It is also possible that the resorption at the lower border of the mandible does not contribute significantly to overall mandibular bone height reductions, since no clinical research of mandibular bone resorption at the lower border was found. The inconsistency between the current and previous (Mays, 2014) work could be the result of different methodology. Mays (2014) separated the sample into those with and without antemortem tooth loss, and found correlation in the group with antemortem tooth loss, while in this study all data were pooled because the samples size was too small to consider them separately. It could also indicate inter-population variation of mandibular resorption at the lower border.

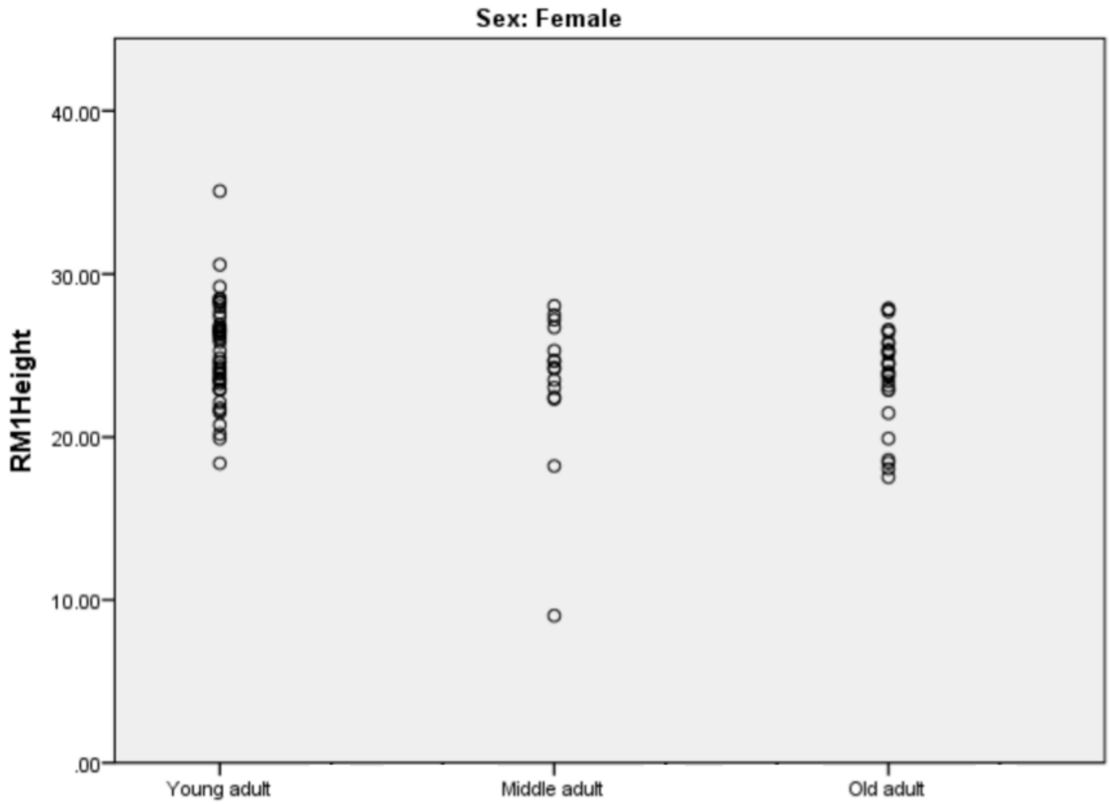
A lack of correlation between mandibular bone heights at first molar sites and age requires more investigation. Mays (2014) found that for females, mandibular bone heights were negatively associated with age at all locations except the right second molar. First molars are the first permanent molars to erupt, generally around 4-8 years of age (Buikstra and Ubelaker, 1994), and so are exposed to the oral environmental for the longest period. Longer exposure time for the first permanent molar may lead to higher level of dental diseases such as caries and periodontal disease that could promote tooth loss. The subsequent bone resorption at the first permanent molar socket may be primarily a result of early onset of dental disease rather than age. Mays (2014) argued that the longer the tooth has been lost, the more inter-individual differences will appear, causing more variability in bone height. If there was indeed a larger range of mandibular bone heights for older people, it may explain the lack of correlation at first molar sites as the first molars are frequently lost the earliest and thus have the most variability in the amount of bone resorbed. However, due to the broad age categories used in this study, a clear tendency of increasing height intervals with age is not visible on scatter plots of the data (Figures 5.1 and 5.2). In fact, the interval is actually smaller in the “old adult” group (Figures 5.1and 5.2). For left first molar position, the height interval of young adult group is 14.68mm, while in old adult group it is 9.81mm. For right first molar position, the height interval of young adult is 16.7mm, while in old adult group it is 10.33mm. It is possible that first molars being lost early in life can actually cause the height of the residual ridge to be less different, rather than more different between individuals as suggested by Mays (2014), since resorption is not at a constant rate and will get slower as time passes (Denissen et al., 1993).

Figure 5.1. Scatter plot of female left 1st molar mandibular bone height



LM1Height=left 1st molar mandibular height

Figure 5.2. Scatter plot of female right 1st molar mandibular bone height



RM1Height=Right 1st molar mandibular height

During the data collection process, mandibular ridge resorption was found to be present at some locations where the teeth were still in the sockets. Some literature suggests that mandibular ridge resorption occurs after tooth loss (e.g. Atwood, 1971; Sennerby et al. 1988; Klemetti, 1996; Mays, 2014), however it is clear that some bone loss occurs in the absence of loss of teeth. Resorption prior to tooth loss is most likely to be explained by pathological causes, such as inflammation caused by periodontal disease (Page, 2002), rather than age. Disease-induced mandibular bone resorption could be indicative of oral hygiene practices or food preferences in the population from which the sample was drawn. However, this question is beyond the scope of this study and therefore is not explored further.

The fact that patterns of mandibular ridge resorption found in this study have both similarities and differences with other clinical and archaeological studies suggests that mandibular ridge resorption is both a universal and an individual process (Atwood and Coy, 1971). Although resorption is an inevitable consequence of tooth loss, the degree/amount of resorption can be different between sexes, populations, and even individual molar positions. It is clear that mandibular ridge resorption has complex etiologies, with age being only one aspect of bone loss. While severe mandibular ridge resorption is generally indicative of old age, no clear distinctions in resorption based on age have been produced. At present it is not clear at what height a molar position should be classified as having 'severe' mandibular ridge resorption, and the age at which people start to experience advanced mandibular ridge resorption is highly variable. Results of this study suggest that mandibular ridge resorption should be used with caution when assessing age of past people. In the study by Mays (2014), dental caries and calculus rates of the Dutch sample were compared to the post-medieval Spitalfield collection, and an early-20th-century Portuguese sample. The author concluded that although there are differences in caries and calculus rates, they do not significantly affect mandibular bone resorption severity and rate (Mays, 2014). However, when considering age estimation using mandibular ridge resorption, population differences could play a vital role since specificity may be important in improving accuracy and precision. Therefore, population-specific dental condition as well as general physiological bone quality should all be taken into account.

5.2 Correlations between estimated age-at-death and "old age" traits

Positive correlations are found in this study between increasing age-at-death and the scoring of both "old age" traits, as well as between the two "old age" traits themselves (Tables 4.8-4.10). The correlation between age and "old age" traits confirms the findings by Boldsen et al. (2002) during their examination of the Todd Collection.

The pubic symphysis has been studied and used as an age estimation method from the 1920s onwards (e.g. Todd, 1921; Gilbert and McKern, 1973, Brooks and Suchey, 1990). Specifically, Gilbert and McKern (1973), as well as Meindl et al. (1985) argued that the dorsal margin usually shows the first signs of degeneration. Todd (1921) also pointed out that the dorsal margin is developmentally the oldest part of the pubic symphysis, and is generally the most informative of degenerative progression. Therefore, when the erosion of the dorsal margin exceeds 1 cm as described in the transition analysis scoring criteria (Milner and Boldsen, 2013 a), it means not only that degenerative changes have occurred as the individual ages, but also that the process has been going on for a period of time. Scoring the dorsal margin of pubic symphysis thus puts the potential age estimation at some time after the onset of bone breakdown, and indicates an advanced age, likely over 80 years old (GR Milner, personal communication, June 5 2016).

The exostoses area located posterior to the auricular joint surface (retroauricular area) has received less attention in the literature. In age estimation methods using the auricular surface of the ilium, Lovejoy et al. (1985) mentioned that the retroauricular area tends to get rougher and more irregular with age. However, transition analysis (Boldsen et al., 2002; Milner and Boldsen, 2013) is the first age estimation method to describe and quantify the different stages of irregularity in this area. The correlation between age and the presence of posterior exostoses is present (r_s= 0.292), but is much weaker than that found between age-at-death and breakdown of dorsal margin of pubic symphysis (r_s= 0.592, 0.770). There are only three stages described in transition analysis for this feature, while the dorsal margin of the pubic symphysis has five stages. This probably means that the morphological changes occurring at the posterior exostoses area have fewer features expressing age-related progression. It would appear there is more individual variability when these features start to develop, compared to the pubic symphysis, and thus explains the weaker correlation. Although the two "old age" traits have different levels of correlation associated with age, during age estimation process, the presence of these two traits adds to the possibility that the individual may be of advanced age.

5.3 Correlations between mandibular bone heights and "old age" traits

Findings of the relationship between mandibular bone heights and "old age" traits are very interesting. It seems that although mandibular heights and "old age" traits are both linked to age, a direct correlation between the two is weaker than might be expected. Correlations were statistically significant only in males at some of the molar positions for the dorsal margin of pubic symphysis. For the posterior exostoses, significant relationships were observed in both sexes, but males have more molar positions at which the heights were correlated with the scoring, although the correlation values were similar to those for the pubic symphysis (see Tables 4.11 and 4.12). As briefly introduced in the Background chapter, it seems that the two features of the pelvis labeled "old age" traits by Boldsen et al. (2002) show different patterns of change in the ageing skeleton. The breakdown of the dorsal margin of the pubic symphysis is a degenerative process, while the appearance of posterior exostoses is better considered as an entheseal change, which can involve both bone growth and degeneration. Due to the differences found in each of the old age traits, they are discussed separately.

Similar to other joint surfaces of the skeleton, the pubic symphysis goes through predictable patterns of change with increasing age. As an individual grows older, signs of morphological changes usually start to show up first at the dorsal demiface, which is the posterior half of the symphyseal face (Gilbert, 1973; Gilbert and McKern, 1973). The breakdown of the dorsal margin is argued to be indicative of advanced age (Boldsen et al. 2002). However, in this study correlations were only found at first molars and right second molar positions in males but not in females at any molar positions.

The reason that the correlation between mandibular bone heights and the scoring of dorsal margin of pubic symphysis is weaker than the direct relationship between age and pubic symphysis is probably that age is not the single contributor of either mandibular ridge resorption or the two "old age" traits. Therefore, when testing the indirect relationship between mandibular ridge resorption and the presence of "old age" pelvic traits, the correlation will be affected by factors other than age. This holds true for posterior exostoses as well.

During early development of the pubic symphysis age estimation method and its subsequent revision and testing, it was found that the female pubic symphysis ages differently than males (Gilbert, 1973). Gilbert (1973) also tested and argued that the standard used for ageing male pubic symphyses is not suitable for ageing female pubic symphyses as it tends to underage older females due to different rates of metamorphic changes. Transition analysis does not have differentiated scoring for males and females; therefore the accuracy may potentially decrease when using the same standard for both sexes. When experimenting with the ADBOU software for transition analysis, inputting the same scores for males and females produced different results that indicate females tend to be aged slightly younger (as shown in Table 5.1), which is similar to the pattern identified by Gilbert (1973). Results of this test is shown in Table However, since the current study was not done with a known age-at-death sample, and real life scoring would be much less simple than the scores used in this test, whether females were under-aged cannot be determined.

Table 5.1. Transition analysis age estimation using auricular surface with same scores and different sexes

Test numbers	Scores									Age estimations (in years)	
	ST (1-3)	IT (1-3)	SC (1-5)	AC (1-5)	IC (1-5)	IT (1-3)	SE (1-6)	IE (1-6)	PE (1-3)		
Test 1	2	2	4	3	4	2	4	3	3	M	47.7-91.7
										F	47.6-91
Test 2	3	3	5	5	5	3	6	6	3	M	70.2-110
										F	69.3-110
Test 3	1	1	1	1	1	1	1	1	1	M	15-23.7
										F	15-22.2
Test 4	2	2	3	3	3	2	4	4	2	M	26.2-88.4
										F	27.5-87.4

ST: superior topography; IT: inferior topography; SC: superior characteristics; AC: apical characteristics; IC: inferior characteristics; IT: inferior texture; SE: superior exostoses; IE: inferior exostoses; PE: posterior exostoses. M: male; F: female. Numbers in parentheses indicate range of scoring.

Several authors have pointed out that trauma during parturition could also affect the appearance of the symphyseal face, especially the dorsal demiface (Gilbert, 1973; Gilbert and McKern, 1973; Meindl et al., 1985). The pulling of ligaments around the dorsal margin during pregnancy and childbirth may leave pitting on the symphyseal face edge, making the symphysis appear older in women (Steward, 1957; Angel, 1969; Gilbert and McKern, 1973). Cox and Scott (1992) investigated the relationship between parity status and five pelvic characters: preauricular sulcus, dorsal pubic body pitting, anterior sacrum sulci and extension of the pubic tubercle in the Spitalfields skeletal collection. The authors found no statistical significance between parity status and dorsal pubic body pitting (Cox and Scott, 1992). The lack of relationship between dorsal pubic body pitting and parity status further supports the argument that the morphological changes of the female pubic symphysis is not as regular as those observed in males. In the transition analysis scoring manual, it stated that researchers should be cautious when approaching specimens with birth trauma, and when the trauma causes extensive disfiguration and pitting of the dorsal margin, the specimen should not be scored (Milner and Boldsen, 2013 a). However, there is no clearly defined point at which the pubic symphysis should be deemed 'unscorable'. It seems that judgment on scoring can only be made through accumulation of experience. In cases where the pubic symphyses are partially affected by birth trauma but still scorable, it is possible to over-estimate the age-at-death when only the dorsal margin is assessed.

Correlation between mandibular ridge resorption and posterior exostoses were significant in females at the left second and third molar positions, as well as in males at left first, right second, and both third molar positions (see Table 4.12). The changes in posterior exostoses with advancing age have a different manifestation than those found at the dorsal margin of the pubic symphysis. While the dorsal margin shows bone degeneration with age, posterior exostoses should be considered as entheseal developments. However, as discussed in Section 2.3.3, the fact the posterior exostoses area is an enthesis hardly receives any attention in clinical or archaeological studies. There are a few that have studied entheses of the pelvis, and while they have found no relationship between pelvic entheseal changes and activity level or occupation (Cardoso, 2008; Campanacho and Santos, 2013), the posterior exostoses area was not their focus. Cardoso and Henderson (2010) studied enthesopathies of the humerus and found no association between activity and enthesopathies; rather, they found age to be the single most significant factor in the formation of enthesopathies. Other researchers have also found significant relationships between old age-at-death and entheseal development (e.g. Rogers et al., 1997; Robb, 1998; Wilczak, 1998; Molnar, 2006; Weiss, 2007). Although the locations are different, it is reasonable to suggest that entheses on the posterior exostoses area of the ilium share similarities with other muscle attachment sites; the bone responds to the gradual accumulation of mechanical stress over time, but is also accompanied by age-related degenerative processes (Milella et al., 2012). Therefore it is expected that similar to other muscle/ligament attachment sites, the posterior exostoses area also shows age-related entheseal change.

Merritt (2015) tested the influence of body size on age estimation using four age estimation methods and found age-related changes at the joints examined (i.e. sternal rib ends, auricular surface, and pubic symphysis) among individuals with larger body size. Therefore, it is possible that larger body size and heavier mechanical loads from more body weight may explain why more significant relationships showed up in males. For example, Milella et al. (2012) found that males have higher frequencies of entheseal change in a study on a contemporary Italian skeletal collection that explored the effect of sex, age and activity level on the morphology of entheses of the shoulder girdle, upper and lower limbs. Nolte and Wilczak (2013) argued that body size as well as age affects the surface area of the bicep muscle attachment. In research that studied upper limb and upper back muscle attachment sites, Wilczak (1998) found that while both females and males had smaller entheses when they were younger (in other words, entheses grew larger with age), statistically significant correlations only showed up in males. It should be noted that, as previously mentioned, these studies did not focus on the sacroiliac joint and posterior exostoses areas, therefore caution should be taken when drawing analogies between these two studies and the results presented here. Henderson et al. (2013) pointed out that the effect of age is different for each enthesis, entheseal feature, or even side, and that when examining entheseal changes, bone formation, erosion, pitting and porosity should all be considered. However, in transition analysis, only the bone formation that causes the iliac surface under observation to appear coarse and roughened is taken into account. Therefore, although the presence of exostoses is an age-related change, it seems that other aspects of age-related enthesopathies are not fully studied and recorded at this site, limiting the understanding of the relationship between age and this entheseal location.

Another line of reasoning that may explain why males show a stronger correlation than females is that some studies show that older males have a higher rate of sacroiliac joint ankylosis. Solonen (1957) described different joint development in males and females; while males have their sacroiliac ligaments increase in strength, female joints become more mobile in puberty. The increase in strength in males may be due to a higher mechanical load, and less mobility may be the cause of higher rate of ankylosis in men. For instance, Brooke (1924) reported 37% ankylosis joints in his sample of 105 male sacroiliac joints of all ages, and 70% ankylosis joints in males over 50 years of age, while none of the 105 female sacroiliac joints showed ankylosis. Willis (1944) proposed that the onset of ankylosis in men starts as early as 35 years of age. Several authors have come to the conclusion that after 50 years of age, fibrous intra-articular bridging as well as partial or complete ankylosis can be observed very frequently in men (Brooke, 1924; Robinson, 1931; Schunks, 1938; Francis, 1952). In more recent studies, it was also reported that higher incidences of ankylosis, partial fibrous ankylosis, and para-articular synostosis were found in males over 50 years old (Dreyfuss et al., 1995; Dreyfuss et al., 2004). In another study, François et al. (2000) reported that presence of new bone within the interrosseous sacroiliac ligaments was one of the most common age-related findings. In François et al. (2000) study, more males than females have this bone formation within ligament, but the sample size was too small (n=12 in males, 8 in females) to be conclusive. It may be implied that similar bony growths could explain the presence of posterior exostoses. However, none of these studies specifically addressed the formation of posterior exostoses, and when discussed, they are usually merely mentioned as ligament attachment sites and are called the iliac tuberosity. It is unclear whether ankylosis of the sacroiliac joint includes bone growth of the retroauricular area, or if posterior exostoses can be seen as a stage of sacroiliac joint ankylosis. To conclude, this specific area and its bony changes are understudied and therefore no decisive conclusion can be drawn about the relationship between exostosis formation and older age-at-death. It is possible that being a ligament attachment site with little movement both contribute to the formation of exostoses and their more prominent presence in males.

5.4 Limitations of this study

There are limitations associated with this study that may have affected the results. First of all, as with many bioarchaeological investigations the sample size was small. Although a total of 243 individuals were included, a large number of them did not have all three skeletal elements available for measuring or scoring. When subdividing samples into different sex and age groups, the numbers get even smaller. The small sample size may significantly affect the effectiveness of statistical methods in two ways: 1) it makes the correlations too weak to be detected; and/or 2) the calculated correlation may actually be nothing more than background noise.

Poor preservation produces a considerable reduction in the numbers of measurable and scorable individuals. Compared to pubic symphysis and iliac auricular surfaces, the mandibles were better preserved in this sample, but there were still many cases in which the alveolar crest and/or the lower border were damaged postmortem and were not measurable. Taphonomic alterations that make bones appear to be cracked and peeled were very common in the Lankhills collection. The survival of pubic symphyses was the worst of the three skeletal elements assessed. When the pubic symphysis was present, it tended to be incomplete or have some degree of taphonomic change on the symphyseal face. The dorsal margin is also prone to postmortem damage and the cortical surface was frequently observed to have peeled away, exposing the trabecular bone. Preservation problems may affect the accuracy of scoring, or make the specimen unscorable. The auricular surface has a slightly higher rate of presence; however, in a large number of cases the cortical bone surface was partially or completely weathered off, which makes the distribution and morphology of exostoses unobservable This preservation issue was also pointed out by Brickley et al. (2016). Given that the bones of older individuals are known to be more fragile it is probable that their bones are more likely to have been excluded due to poor preservation (Gowland, 2007).

Second, this study was based on a sample with no known age-at-death. Lack of known age affects the accuracy of the tests since age estimation can only assign an individual to one of the 5 broad categories. In this sense, even though statistically significant correlations were found, they can only be based on estimated age categories. These broad age categories in turn prevent more detailed regression analyses that could be used to further study the relationship between the three skeletal features and age-at-death, and the potential of developing regression equations. It is also possible that some individuals were assigned to the wrong age category because of individual variations of traits used for age estimation. Since this is a sample with unknown age-at-death, all conclusions have to be based on the estimated age rather than actual age.

Third, the age estimation methods used on this collection have some overlap with the traits tested in this study (detailed in Section 3.2.3). When testing for correlations between age and the presence of posterior exostoses, age estimations undertaken by previous researchers (Gowland, 2002; Booth et al., 2010) were used to prevent circular reasoning. However, the auricular surface age estimation method developed by Lovejoy et al. (1985) was used by these researchers. Although no scorable stages were laid out in Lovejoy et al. (1985), roughening of retroauricular surface area was described as a trait for old age. Similarly, transition analysis criteria developed for pubic symphysis was also largely based on the Suchey-Brooks method. Suchey-Brooks pubic symphysis morphology age estimation method is so extensively used that it is impossible to produce age estimations of the Lankhills collection without this method. Therefore, as much as circular logic should be prevented, it cannot be entirely avoided.

5.5 Overall evaluation of this study

This study was conducted to test three features that may be used to identify old (50+) individuals in skeletal assemblages. As discussed earlier, individuals age differently, influenced by many physiological as well as cultural and environmental factors. This variability makes estimating age based solely on skeletal materials extremely difficult when a high level of accuracy and precision is expected. As a preliminary study, this research demonstrated the potential of mandibular ridge resorption, breakdown of dorsal margin of pubic symphysis and posterior exostoses of iliac auricular surface to be used as old age indicators. Mandibular bone height was correlated with age, which may help age estimation after tooth loss, when dental wear is not applicable (Mays, 2014). However, the current study cannot provide a regression equation to calculate age, therefore the level of mandibular ridge resorption and its potentially corresponding age range cannot be identified yet. The scoring of the two “old age” traits were also correlated with age, confirming findings from previous studies (Boldsen et al. 2002, Milner and Boldsen, 2012). As mentioned in Section 2.3.1, the presence of the two “old age” traits may potentially identify individuals over 80 years old. The correlation between age and the two old age traits found in this study suggests the potential of a similar age range to be applied to a Romano-British population. If a subgroup of the usual old age group (50+ years old) can be identified, many new discussions regarding the old age experience in the Roman World might be generated. For example, Harlow and Laurence (2002), Parkin (2003) and Cokayne (2003) all pointed out that old women in the Roman World were often associated with very negative images. Did such unfriendly social environment affect the physical health of old women? Did old women of different social status receive differential treatment that may be reflected in their skeletal remains? The understanding of socially under-represented groups is largely limited if most of the sources regarding their life and experience in the past come from literary accounts. Bioarchaeological studies can fill in some of the blanks left by historians and writers. The correlations between mandibular ridge resorption and the two "old age" traits, although weak, imply the potential of employing all three skeletal features in age estimation. Specifically, when advanced mandibular ridge resorption is present with the presence of the breakdown of the dorsal margin of pubic symphysis and thick, extensive posterior exostoses on auricular surface, it is likely indicative of old age. The contradicting sex-based difference results seen in the correlation between age and mandibular bone resorption and the correlation between mandibular bone resorption and the scoring of the two "old age" traits need further study. Limitations addressed in Section 5.4 suggest that although this study has encouraging preliminary results, it currently does not further improve the actual accuracy or precision of estimating age of old adults. Thus, a more comprehensive and thorough study on known age-at-death samples to further narrow down age ranges produced for old individuals is needed. The question raised in the Introduction "can we pick out older individuals from a skeletal assemblage" is far from being fully answered. Traits that have been previously associated with old age are demonstrated to be also indicative of advanced age in this Romano-British sample, but the issue of how accurate and precise these traits can be, and how specific of an age range they can help to create remains unclear. Bone has a limited repertoire of responses and while there are general patterns and trends that can be used to indicate age in broad terms, the specificity is greatly limited. Adding the fact that age estimation is essentially an application of a statistical pattern onto individuals, margins of error will always exist. On the other hand, taking into account socially and culturally induced environmental as well as biological factors to create time period and population-based age estimation criteria may be helpful in increasing the specificity. Nonetheless, if too many variables are consulted at the same time, the ability of statistics to generate patterns will be greatly reduced.

Chapter 6. Conclusions and future directions

In this study, it has been shown that mandibular ridge resorption reflected by mandibular bone heights has a correlation with increasing age, which is consistent with other research. Discrepancy was also found because the correlation was only statistically significant in females, while some studies suggested the correlation exists in males too. A lack of statistical significance in males suggests that Romano-British females were affected more severely by age-related bone loss in the mandible compared to their male counterparts, just like females in modern societies. This indicates that despite differences in lifestyles, including diet and oral hygiene practices, age is still an important factor contributing to mandibular ridge resorption, suggesting the potential of mandibular ridge resorption in helping identify older individuals in archaeological samples. However consideration of individual and population variations should be taken into account if a higher level of specificity is desired.

Statistically significant relationships between estimated age at death and the scoring of the dorsal margin of pubic symphysis and posterior exostoses were found in this study, which is also in line with previous research. This result implies that these two features are present in older individuals fairly consistently in different samples, indicating their possibility to be reliable old age indicators across different populations.

When testing the relationship between mandibular bone resorption and the two “old age” traits, statistically significant relationships were more prominent in males than in females for both “old age” traits despite their different etiologies. Differences in the manifestation patterns between the sexes may be partially responsible for significant correlations mainly show up in males but not females, however a lack of anatomical and biomechanical studies of the pubic symphysis and retroauricular area of the iliac auricular surface limits the understanding and further implication of morphological changes of these two skeletal landmarks. Sample size and other non-age-related factors might have also affected the results.

Results show that the three skeletal features studied in this research do have the potential to aid in the identification of older individuals. However, there are many problems affecting their presence and morphology that could complicate the age estimation process. A mix of encouraging results and difficult obstacles means more detailed and systematic studies are needed. Although the combined presence of the three skeletal traits is likely to be suggestive of old age, the current study does not produce an age ranges that can be applied to populations, and proves once again that estimating the age of old adults is tough given the multifactorial nature of the ageing process. However, this fact should not discourage researchers from tackling this problem as the importance of older adults has begun to be recognized.

Future studies are sorely needed. Using a known-age-at-death sample is strongly suggested in order to obtain more convincing results. During the analysis of the results, it was noted that studies on the morphological and physiological changes of the pubic symphysis, and more so the posterior exostoses area, were lacking. The shortage of high-quality biomechanical studies of the pubic symphysis and posterior exostoses prevents a more in-depth examination of the sexual differences observed in age-related progression of these changes. Much research has focused on the anatomical function and pathological manifestation of the sacroiliac joint surface, while little attention is paid to the adjacent retroauricular area. Also, while Boldsen et al. (2002) only identified the posterior exostoses as related to old age, it would be interesting to explore whether the other two adjacent area where exostoses are also found, namely the superior and inferior exostoses areas, share similar relationships with advanced age.

Boldsen et al. (2002) have argued that there could be more old-age related skeletal features that have not yet been found or tested. It is vital that while accepting there is an inherent limitation, age-bone relationships should be explored for multiple skeletal elements and in multiple populations in order to get a more holistic and thorough understanding of the interaction between bone and its environment over time. The lack of specificity in age estimation of old adults may be somewhat compensated by the combined use of as many skeletal features as possible.

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APPENDICES

Appendix 1. Sex and age estimation form

This form was created by Dr. Megan Brickley and Dr. Tracy Prose for the SSHRC Project (Insight Grant; File number :453-2013-1006, ID number: 169793). Permission was granted to use age and sex data for this research.

Sex/Age Estimation Date:________Site:______________

Observer:__________SK#_________________

Age Estimation – Juvenile

Dental Development (following Gustafson and Koch 1974)

Deciduous Dentition

Maxilla				
	Left	Right	Unsided 1	Unsided 2
m^2				
m^1				
c				
i^2				
i^1				

Mandible				
	Left	Right	Unsided 1	Unsided 2
m_2				
m_1				
c				
i_2				
i_1				

Permanent Dentition

Maxilla				
	Left	Right	Unsided 1	Unsided 2
M^2				
M^1				
PM^2				
PM^1				
C				
I^2				
I^1				

Mandible				
	Left	Right	Unsided 1	Unsided 2
M^2				
M^1				
PM^2				
PM^1				
C				
I^2				
I^1				

Scoring: - = could not be assessed; 1 = start of mineralization; 1.5 = past start of mineralization, but not yet at complete crown; 2 = complete crown; 2.5 = crown complete, but not certain if eruption has occurred; 3 = eruption in progress; 3.5 eruption complete (teeth are in occlusion), but not certain if root is fully formed; 4 = eruption and root complete

If M3s are present, record side & development here: Max __ Max _____ Mand ____ Mand_____

Long Bone Length
(in mm)

	Left	Right
Femur		
Tibia		
Fibula		
Humerus		
Radius		
Ulna		

Notes:

Epiphyseal Fusion (following Cardoso 2008 a, b) - Fusion should be scored on **left** bone only. If left is not present right should be scored.

Femur: 1 - proximal epiphysis; 2 – greater trochanter; 3 – lesser trochanter; 4 – distal epiphysis
Tibia: 1 – proximal epiphysis; 2 – distal epiphysis
Humerus: 1 – proximal epiphysis; 2 – distal epiphysis; 3 – medial epicondyle
Radius: 1 – proximal epiphysis; 2 – distal epiphysis
Pelvis: 1 – iliac crest; 2 – ischial epiphysis
Clavicle: 1 – sternal epiphysis

	Side	Epiphysis 1	Epiphysis 2	Epiphysis 3	Epiphysis 4
Femur					
Tibia					
Humerus					
Radius					
Pelvis					
Clavicle					
Other					

Scoring: - = could not be assessed; 1 = non-union (epiphysis and diaphysis are completely separate); 2 = partial union; 3 – complete union (all visible aspects of epiphysis are united)

Summary Information

Dental Dev. Age Estimate	Long Bone Length Age Estimate	Epiphyseal Fusion Age Estimate	Dental Wear Age Estimate (if applicable)
Notes:			

Dental Wear (modified from Brothwell 1965) – for older adolescents and adults (M1 must be erupted and in occlusion)

Maxilla		
	Left	**Right**
M3		
M2		
M1		

Mandible		
	Left	**Right**
M3		
M2		
M1		

Modified scoring: - = could not be assessed; score - 1-13 (refer to diagram)

Notes:

Sex Estimation-Adult

Will not be attempted for those <16 years old. For those 16+ years the features of the skull/mandible and pelvis set out in Buikstra and Ubelaker (1994) will be used.

Pelvis		
	Left	**Right**
Ventral Arc (1-3) *		
Subpubic Concavity (1-3) *		
Ischiopubic Ramus Ridge (1-3) *		
Greater Sciatic Notch (1-5) *		
Preauricular Sulcus (1-4) *		
Estimated Sex		

Skull		
	Left	**Right**
Nuchal Crest (1-5) *		
Mastoid Process (1-5) *		
Supraorbital Margin (1-5) *		
Glabella (1-5) *		
Mental Eminence (1-5) *		
Estimated Sex		

Notes:

In all cases (skull and pelvis) the left should be preferentially scored. When the left side is absent, the right can be scored.
* after observations described in Buikstra & Ubelaker 1994 (pp. 16-21):
0-3 scale: - (blank) = not observable; 1 = female; 2 = ambiguous; 3 = male
0-4 scale: - (blank) = no sulcus; 1 = sulcus is wide (>0.5cm) and deep; 2 = sulcus is wide but shallow; 3 = sulcus is well defined but narrow; 4 = sulcus is a narrow (<0.5cm), shallow, and smooth-walled depression.
0-5 scale: - (blank) = not observable; 1 = female; 2 = probable female; 3 = ambiguous; 4 = probable male; 5 = male

Age Estimation-Adult

Pubic Symphysis Scoring System (following Brooks and Suchey 1990; Suchey and Katz 1986)

	Left	**Right**
Phase		

Notes:
Scoring: - = could not be assessed; phases 1-6 (see Buikstra and Ubelaker, 1994: 23-24)

Auricular Surface Scoring System – Transition Analysis (following Boldsen et al. 2002:101-103) (can record multiple stages for a single feature)[1]

	Left		**Right**	
	Min	Max	Min	Max
Superior Topography (1-3)				
Inferior Topography (1-3)				
Superior Characteristics (1-5)				
Apical Characteristics (1-5)				
Inferior Characteristics (1-5)				
Inferior Texture (1-3)				
Superior* Exostoses (1-6)				
Inferior* Exostoses (1-6)				
Posterior Exostoses (1-3)				

Notes:

[1]Record the left auricular surface. When the left is absent, the right can be recorded but do not mix the two sides. Scoring: - = could not be assessed; see Boldsen et al. 2002
* Superior and Inferior Posterior Iliac Crest

Summary Information – Adult Age and Sex

Age[1]	
Sex[2]	

[1]Young adult (20-34), middle adult (35-49), old adult (50+)
[2]After Buikstra and Ubelaker (1994: 21): undetermined; female; probable female; ambiguous; probable male; male

Appendix 2. Thesis recording form

Site:	Date:	Observer:
Burial #:		Sex:

Transition Analysis: Pubic Symphysis				
	Left		Right	
	Min	Max	Min	Max
Topography (1-4)				
Texture (1-4)				
Sup. Protuberance (1-4)				
Ventral Margin (1-7)				
Dorsal Margin (1-5)				
Notes:				
Photos taken:				

Record the left side. If the left side is not present then record the right side. If pathology or anomaly present record both sides for comparison. Scoring follows Milner & Boldsen 2013. Dash indicates the feature is not assessable, or that photos are not taken due to the absence of skeletal element(s).

Transition Analysis: Auricular Surface	
Photos taken:	

Dash indicates the skeletal element is not present and therefore photos are not taken

Old Age Traits		
Dorsal margin of pubic symphysis:		Score:
Post. Exostoses:		Score:

Old age traits are defined as breakdown of dorsal margin of the pubic symphysis and a broad and continuous zone of posterior exostoses of the auricular surface in Milner & Boldsen 2012. Dash indicates the skeletal element is not present and therefore the feature is not assessable.

Mandibular Ridge Resorption								
	LM1	LM2	LM3	LMtFH	RM1	RM2	RM3	RMtFH
Bone Presence								
Tooth Presence								
Socket remodeling								
Corpus height (mm)								
Notes:								
Photos taken:				Yes				

LM1: left 1st molar; LM2: left 2nd molar; LM3: left third molar; RM1: right 1st molar; RM2: right 2nd molar; RM3: right 3rd molar; LMtFH: left mental foramen; RMtFH: right mental foramen. Socket remodeling follows the definition of antemortem tooth loss in Buikstra & Ubelaker (1994) and Turner et al. (1991): socket remodeling is recorded as yes if the socket is partially or fully filled in (resorbed), and as no if the socket is open and smooth, with no signs of filling. Corpus height measuring method follows Mays (2014). Dash indicates the skeletal element is not present and therefore the feature is not assessable or measurable, or that photos are not taken due to absence of skeletal element(s).

Other comments:

Age estimation (conventional method):	
Age estimation (TA) (point & Range):	

Appendix 3. Final sex and age estimation results

Skeleton #	Sex	Age 1st Round	Age 2nd Round
LANK 006	Female	Young adult	Young adult
LANK 008	Ambiguous	Young adult	Young adult
LANK 011	Male	Young adult	Young adult
LANK 015	Male	Old adult	Middle adult
LANK 016	Male	Young adult	Young adult
LANK 017	Female	Young adult	Middle adult
LANK 018	Female	Young adult	Young adult
LANK 019	Female	Old adult	Middle adult
LANK 020	Male	Young adult	Young adult
LANK 021	Female	Young adult	Old adult
LANK 024	Female	Young adult	Young adult
LANK 025	Male	Young adult	Young adult
LANK 029	Female	Young adult	Young adult
LANK 031	Female	Middle adult	Middle adult
LANK 035	Male	Young adult	Middle adult
LANK 036	Male	Old adult	Old adult
LANK 037	Male	Young adult	Middle adult
LANK 038A	Female	Young adult	Young adult
LANK 039	Ambiguous	Young adult	Young adult
LANK 045	Female	Old adult	Old adult
LANK 047	Male	Middle adult	Middle adult
LANK 053	Female	Young adult	Old adult
LANK 058	Undetermined	Young adult	Young adult
LANK 061	Male	Young adult	Middle adult
LANK 064	Male	Young adult	Young adult
LANK 067	Male	Middle adult	Young-middle adult
LANK 070	Female	Old adult	Old adult
LANK 074	Female	Young adult	Young adult
LANK 076	Male	Young adult	Young adult
LANK 078	Male	Young adult	Young adult
LANK 087	Female	Young adult	Young adult
LANK 089	Female	Young adult	Young adult
LANK 094	Male	Old adult	Old adult
LANK 096	Male	Young adult	Old adult
LANK 097	Male	Young adult	Young adult

LANK 098	Female	Young adult	Young adult
LANK 101	Female	Old adult	Old adult
LANK 104	Male	Young adult	Young adult
LANK 107	Male	Young adult	Young adult
LANK 112	Male	Young adult	Young adult
LANK 119	Ambiguous	Young adult	Old adult
LANK 123	Male	Young adult	Young adult
LANK 128	Male	Middle adult	Young-middle adult
LANK 130	Ambiguous	Young adult	Young adult
LANK 137	Female	Young adult	Young adult
LANK 140	Male	Young adult	Middle adult
LANK 141	Male	Middle adult	Middle adult
LANK 158	Ambiguous	Young adult	Young-middle adult
LANK 161	Male	Young adult	Young adult
LANK 165	Ambiguous	Old adult	Old adult
LANK 166	Male	Old adult	Old adult
LANK 168	Female	Old adult	Middle adult
LANK 171	Female	Young adult	Young adult
LANK 191	Female	Young adult	Young adult
LANK 192	Male	Young adult	Young adult
LANK 194	Female	Young adult	Young adult
LANK 201	Female	Young adult	Young adult
LANK 203	Female	Young adult	Young adult
LANK 208	Male	Young adult	Young adult
LANK 214	Female	Young adult	Young adult
LANK 218	Female	Old adult	Old adult
LANK 220	Undetermined	Young adult	Young adult
LANK 225	Male	Young adult	Middle adult
LANK 226	Male	Young adult	Young adult
LANK 227	Male	Young adult	Old adult
LANK 229	Female	Old adult	Old adult
LANK 232	Female	Young adult	Young adult
LANK 233	Ambiguous	Old adult	Old adult
LANK 249	Female	Old adult	Old adult
LANK 256	Female	Young adult	Young adult
LANK 260	Male	Young adult	Young adult
LANK 266	Female	Young adult	Young adult

LANK 270	Female	Young adult	Young adult
LANK 272	Female	Middle adult	Old adult
LANK 273	Female	Old adult	Middle adult
LANK 277	Male	Middle adult	Old adult
LANK 287	Male	Middle adult	Middle adult
LANK 291	Male	Young adult	Young adult
LANK 293	Male	Young adult	Young adult
LANK 299	Male	Old adult	Middle adult
LANK 305	Male	Young adult	Middle adult
LANK 306	Male	Young adult	Middle adult
LANK 307	Female	Middle adult	Old adult
LANK 315	Female	Young adult	Young adult
LANK 319	Male	Young adult	Old adult
LANK 328	Female	Young adult	Old adult
LANK 330	Female	Old adult	Old adult
LANK 331	Male	Old adult	Middle adult
LANK 332	Female	Young adult	Young adult
LANK 340	Female	Young adult	Young adult
LANK 343	Female	Young adult	Young adult
LANK 349	Male	Middle-old adult	Old adult
LANK 352	Male	Young adult	Young adult
LANK 356	Male	Middle adult	Middle adult
LANK 358	Female	Middle-old adult	Middle adult
LANK 362	Male	Old adult	Middle adult
LANK 365	Female	Young adult	Young adult
LANK 367	Female	Young adult	Old adult
LANK 374	Female	Young adult	Young adult
LANK 379	Female	Middle adult	Old adult
LANK 380	Male	Old adult	Middle adult
LANK 386	Female	Old adult	Middle adult
LANK 397	Male	Young adult	Young adult
LANK 398	Female	Young adult	Young adult
LANK 399	Ambiguous	Old adult	Old adult
LANK 408	Male	Young adult	Middle adult
LANK 411	Ambiguous	Old adult	Middle adult
LANK 413A	Male	Young adult	Old adult
LANK 414	Ambiguous	Young adult	Young adult
LANK 427	Male	Young adult	Young adult
LANK 430	Female	Old adult	Middle adult

LANK 437	Male	Old adult	Old adult
LANK 441	Female	Middle adult	Middle adult
LANK 445	Female	Young adult	Middle adult
LANK 447	Male	Middle adult	Young-middle adult
LANK 448	Female	Old adult	Old adult
LANK-243	Female	Young adult	Young adult
LANK 2010-0012	Male	Young adult	Middle adult
LANK 2010-0025	Male	Young adult	Middle adult
LANK 2010-0032	Male	Young adult	Young adult
LANK 2010-0050	Female	Young adult	Middle adult
LANK 2010-0055	Female	Middle adult	Old adult
LANK 2010-0061	Female	Young adult	Middle adult
LANK 2010-0077	Female	Young adult	Young adult
LANK 2010-0084	Female	Young adult	Young adult
LANK 2010-0093	Female	Young adult	Young adult
LANK 2010-0108	Male	Young adult	Young adult
LANK 2010-0134	Male	Young adult	Middle adult
LANK 2010-0212	Female	Old adult	Old adult
LANK 2010-0232	Ambiguous	Old adult	Old adult
LANK 2010-0259	Male	Young adult	Young adult
LANK 2010-0271	Female	Young adult	Old adult
LANK 2010-0281	Male	Middle adult	Middle adult
LANK 2010-0284	Female	Old adult	Old adult
LANK 2010-0317	Female	Young adult	Young adult

LANK 2010-0429	Female	Old adult	Old adult
LANK 2010-0435	Female	Old adult	Middle adult
LANK 2010-0441	Male	Young adult	Young adult
LANK 2010-0451	Male	Young adult	Young adult
LANK 2010-0479	Female	Young adult	Young adult
LANK 2010-0489	Undetermined	Old adult	Old adult
LANK 2010-0522	Male	Old adult	Middle adult
LANK 2010-0543	Male	Middle adult	Young-middle adult
LANK 2010-0554	Male	Old adult	Old adult
LANK 2010-0559	Female	Old adult	Middle adult
LANK 2010-0566	Male	Young adult	Young adult
LANK 2010-0579	Male	Young adult	Young adult
LANK 2010-0593	Male	Young adult	Young adult
LANK 2010-0616	Male	Young adult	Middle adult
LANK 2010-0623	Female	Young adult	Young adult
LANK 2010-0636	Ambiguous	Old adult	Old adult
LANK 2010-0642	Male	Young adult	Young adult
LANK 2010-0652	Male	Young adult	Young adult
LANK 2010-0661	Female	Old adult	Middle adult
LANK 2010-0683	Male	Young adult	Middle adult
LANK 2010-0686	Ambiguous	Young adult	Young adult
LANK 2010-	Male	Young adult	Middle adult

0702			
LANK 2010-0709	Female	Young adult	Young adult
LANK 2010-0717	Male	Young adult	Young adult
LANK 2010-0776	Male	Young adult	Young adult
LANK 2010-0792	Female	Young adult	Young adult
LANK 2010-0806	Female	Old adult	Old adult
LANK 2010-0861	Male	Old adult	Middle adult
LANK 2010-0879	Female	Young adult	Old adult
LANK 2010-0908	Female	Young adult	Old adult
LANK 2010-0914	Female	Young adult	Old adult
LANK 2010-0917	Female	Young adult	Young adult
LANK 2010-0922	Female	Young adult	Young adult
LANK 2010-0932	Ambiguous	Young adult	Young adult
LANK 2010-0938	Male	Young adult	Young adult
LANK 2010-0971	Male	Young adult	Young adult
LANK 2010-1002	Female	Young adult	Young adult
LANK 2010-1022	Male	Young adult	Young adult
LANK 2010-1052	Ambiguous	Old adult	Old adult
LANK 2010-1082	Female	Old adult	Old adult
LANK 2010-1084	Female	Young adult	Young adult
LANK 2010-1091	Female	Young adult	Young adult
LANK 2010-1103	Female	Young adult	Young adult

LANK 2010-1119	Male	Middle-old adult	Middle-old adult
LANK 2010-1134	Female	Old adult	Middle adult
LANK 2010-1137	Male	Young-middle adult	Middle adult
LANK 2010-1156	Female	Old adult	Old adult
LANK 2010-1173	Female	Old adult	Old adult
LANK 2010-1191	Male	Young adult	Young adult
LANK 2010-1209	Male	Old adult	Middle adult
LANK 2010-1214	Female	Young adult	Young adult
LANK 2010-1219	Male	Middle adult	Middle adult
LANK 2010-1223	Male	Young adult	Middle adult
LANK 2010-1227	Female	Young adult	Old adult
LANK 2010-1232	Male	Middle adult	Young-middle adult
LANK 2010-1247	Male	Young-middle adult	Young-middle adult
LANK 2010-1258	Female	Middle adult	Old adult
LANK 2010-1274	Male	Old adult	Old adult
LANK 2010-1281	Female	Young adult	Young adult
LANK 2010-1284	Female	Young adult	Young adult
LANK 2010-1289	Male	Young adult	Young adult
LANK 2010-1341	Female	Old adult	Old adult
LANK 2010-1361	Female	Old adult	Old adult
LANK 2010-1369	Undetermined	Old adult	Old adult
LANK 2010-	Male	Middle adult	Middle adult

1393			
LANK 2010-1416	Female	Young adult	Young adult
LANK 2010-1474	Undetermined	Young adult	Young adult
LANK 2010-1481	Male	Young adult	Young adult
LANK 2010-1512	Female	Young adult	Young adult
LANK 2010-1517	Male	Old adult	Middle adult
LANK 2010-1522	Male	Old adult	Old adult
LANK 2010-1532	Female	Young adult	Young adult
LANK 2010-1552	Female	Young adult	Young adult
LANK 2010-1557	Female	Old adult	Old adult
LANK 2010-1598	Female	Old adult	Old adult
LANK 2010-1608	Ambiguous	Old adult	Old adult
LANK 2010-1621	Female	Old adult	Old adult
LANK 2010-1637	Female	Young adult	Young adult
LANK 2010-1640	Male	Middle adult	Old adult
LANK 2010-1697	Male	Young adult	Young adult
LANK 2010-1738	Female	Young adult	Young adult
LANK 2010-1793	Female	Old adult	Young adult
LANK 2010-1802	Male	Young adult	Middle adult
LANK 2010-1852	Male	Middle adult	Young adult
LANK 2010-1882	Male	Old adult	Old adult
LANK 2010-1894	Male	Young adult	Young adult

ADNR 318	Male	Young adult	Old adult
ADNR 319	Female	Old adult	Young adult
ANDR 306	Male	Young adult	Young adult
ANDR 311	Female	Old adult	Old adult
ANDR 312	Ambiguous	Old adult	Middle adult
ANDR 320	Female	Young adult	Young adult
ANDR 324	Female	Old adult	Middle adult
ANDR 331	Male	Young adult	Young adult
ANDR 333	Female	Young adult	Young adult
ANDR 334	Undetermined	Middle-old adult	Middle-old adult
ANDR 338	Female	Young adult	Young adult
ANDR 339	Female	Young adult	Young adult
HYS 001	Male	Young adult	Young adult
HYS 002	Female	Young adult	Young adult
HYS 007	Male	Young adult	Young adult
HYS 012A	Female	Young adult	Young adult
HYS 012B	Male	Old adult	Old adult
HYS 013	Female	Young adult	Old adult
HYS 016	Male	Old adult	Old adult
HYS 017	Male	Young adult	Middle adult
HYS 025	Male	Young adult	Young adult
HYS 027	Female	Young adult	Young adult

Appendix 4. Repeatability test-mandibular bone height measurements

LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height. NP: not present.

Skeleton #	LM1	LM2	LM3	LMFH	RM1	RM2	RM3	RMFH
LANK 019	20.64	20.38	23.98	13.15	23.03	24.16	24.84	13.49
LANK 019R	21.67	20.36	23.25	13.37	22.88	24.30	24.86	13.66
LANK 035	27.86	26.36	27.16	15.38	27.59	26.09	26.52	14.19
LANK 035R	28.03	26.11	27.39	15.42	27.41	25.95	26.86	13.92
LANK 067	28.18	26.48	24.09	13.64	26.48	24.99	23.01	13.30
LANK 067R	27.94	26.69	24.27	14.25	26.51	24.91	23.07	13.54
LANK 098	NP	NP	NP	NP	24.84	22.24	22.74	10.57
LANK 098R	NP	NP	NP	NP	24.74	22.29	22.82	12.15
LANK 107	24.97	22.72	22.58	12.03	24.48	22.45	24.50	11.94
LANK 107R	24.67	22.22	22.35	11.96	24.41	22.64	24.29	11.88
LANK 112	29.01	26.77	27.13	12.10	NP	28.06	28.78	13.07
LANK 112R	29.10	26.95	26.90	11.97	NP	28.15	28.63	13.04
LANK 130	29.32	29.02	29.80	11.98	29.95	27.24	28.66	12.81
LANK 130R	29.17	28.98	30.40	11.85	29.64	27.10	28.52	13.06
LANK 141	NP	NP	NP	11.01	28.05	26.32	28.07	11.72
LANK 141R	NP	NP	NP	11.13	28.27	26.24	27.73	11.91
LANK 158	25.57	25.30	NP	11.47	28.04	NP	29.41	12.70
LANK 158R	26.02	24.96	NP	11.64	27.83	NP	29.51	13.05
LANK 168	22.98	20.07	23.50	13.83	22.44	18.92	25.67	13.35
LANK 168R	24.05	21.80	22.33	13.76	21.31	22.29	24.21	13.20
LANK 191	26.23	NP	NP	12.44	24.61	23.01	25.35	NP
LANK191R	26.14	NP	NP	12.58	24.64	23.57	25.29	NP
LANK 201	NP	NP	NP	NP	29.21	25.71	NP	13.78
LANK 201R	NP	NP	NP	NP	28.98	25.91	NP	13.91
LANK 249	26.82	27.29	23.44	13.83	25.72	23.78	24.73	13.74
LANK 249R	26.44	27.03	22.90	14.02	25.24	24.06	24.78	13.77
LANK 266	27.29	27.13	NP	13.46	28.00	26.02	25.92	13.77
LANK 266R	27.30	26.24	NP	13.42	28.02	26.01	26.36	14.05

LANK 272	26.98	25.75	22.83	12.73	23.97	27.15	27.02	12.38
LANK 272R	27.32	25.79	24.47	12.93	24.00	27.28	26.68	12.40
LANK 277	36.06	30.83	33.93	NP	28.34	31.63	32.08	14.36
LANK 277R	36.05	30.79	33.49	NP	28.33	31.45	32.26	14.50
LANK 315	23.68	24.86	25.23	12.21	21.64	21.16	26.49	12.07
LANK 315-R	23.54	25.07	25.16	12.29	22.31	21.37	26.97	11.77
LANK 343	28.26	27.07	28.82	13.87	28.52	26.37	27.67	14.61
LANK 343R	28.24	27.05	28.74	13.94	28.37	26.33	27.58	14.65
LANK 386	29.09	28.28	28.63	15.66	NP	NP	32.31	NP
LANK 386R	29.34	28.14	28.34	15.48	NP	NP	31.91	NP
LANK 427	29.38	NP	26.53	15.01	28.97	26.17	NP	14.27
LANK 427R	29.25	NP	26.13	15.18	29.20	26.21	NP	14.49

Appendix 5. Repeatability test of dorsal margin and posterior exostoses scores

PS side: pubic symphysis side; Top min: topography minimum score; Top Max: topography maximum score; Tex Min: texture minimum score; Tex Max: texture maximum score; SP Min: superior protuberance minimum score; SP Max: superior protuberance maximum score; VM Min: ventral margin minimum score; VM max: ventral margin maximum score; DM Min: dorsal margin minimum score; DM Max: dorsal margin maximum score; AS side: auricular surface side; PE Min: posterior exostoses minimum score; PE Max: posterior exostoses maximum score. NP: not present; -: not scorable.

Skeleton #	PS side	Top Min	Top Max	Tex Min	Tex Max	SP Min	SP Max	VM Min	VM Max	DM Min	DM Max	AS side	PE Min	PE Max
LANK 019	R	6		1		4		5		4		NP		
LANK 019R	R	6		1		4		5	6	4		NP		
LANK 035	L	5		2		-		4		4		L	2	
LANK 035R	L	5		1	2	-		4		4		L	2	
LANK 067	NP											NP		
LANK 067R	NP											NP		
LANK 098	R	3		1		-		3		2		R	2	3
LANK 098R	R	3		1		-		3		1	2	R	2	3
LANK 107	L	2		1		-		2		1	2	L	2	
LANK 107R	L	2		1		-		2		1	2	L	2	
LANK 112	L	2		1	2	2		2	3	1		L	1	
LANK 112R	L	2		1	2	2		2	3	1		L	1	
LANK 130	NP											NP		
LANK 130R	NP											NP		
LANK 141	R	5		2		3		3		4		L	2	

LANK 141R	R	5		2		3		3		4		L	2	
LANK 158	NP											NP		
LANK 158R	NP											NP		
LANK 168	L	5		3		4		5		4	5	L	3	
LANK 168R	L	5		2		4		5		4	5	L	3	
LANK 191	R	4		1		4		5		1		L	3	
LANK 191R	R	4		1		4		5		1		L	3	
LANK 201	NP											NP		
LANK 201R	NP											NP		
LANK 249	L	6		2		-		7		5		L	3	
LANK 249R	L	6		2		-		7		5		L	2	
LANK 266	NP											NP		
LANK 266R	NP											NP		
LANK 272	R	6		4		-		7		5		R	3	
LANK 272R	R	6		4		-		7		5		R	3	
LANK 277	L	6		4		-		7		5		L	1	
LANK 277R	L	6		4		-		7		5		L	1	
LANK 315	NP											L	1	
LANK 315-R	NP											L	1	
LANK 343	NP											NP		
LANK 343R	NP											NP		
LANK	R	4		2		4		5	7	5		R	1	

386														
LANK 386R	R	4		2		4		5	7	5		R	1	
LANK 427	L	3	4	1		4		5		2		L	2	
LANK 427R	L	3	4	1		4		5		2		L	2	

Appendix 6. Mandibular bone height measurements

All measurements are in millimeters.

LM1: left 1st molar position; LM2: left 2nd molar position; LM3: left 3rd molar position; LMFH: left mental foramen height; RM1: right 1st molar position; RM2: right 2nd molar position; RM3: right 3rd molar position; RMFH: right mental foramen height. Blank indicates not present or not measurable.

Skeleton #	LM1	LM2	LM3	LMFH	RM1	RM2	RM3	RMFH
LANK 006					23.57	20.65		9.71
LANK 008					27.24	22.98	25.56	12.19
LANK 011	25.09	24.56	28.94	13.06	25.3	24.04	26.97	14.04
LANK 015	24.53	20.80		12.01	22.09	21.40		11.16
LANK 016	29.48	28.03	28.68		30.23	28.42	30.34	15.34
LANK 017	21.18	23.97	25.63	10.53	22.34	21.65	24.24	10.97
LANK 018	24.94	22.48			26.51	23.29		10.70
LANK 019	20.64	20.38	23.98	13.15	23.03	24.16	24.84	13.49
LANK 020	31.98	28.5	28.16	14.99	31.04	28.10	27.87	14.38
LANK 021	24.80	19.80		10.86	25.21		23.12	12.55
LANK 024	22.79	19.20		13.26				
LANK 025	34.42	34.20	32.73	15.21	27.59	26.65	28.46	14.47
LANK 029					23.62			12.29
LANK 031	26.05	24.31	25.86	10.21	25.3	22.95	22.37	11.04
LANK 035	27.86	26.36	27.16	15.38	27.59	26.09	26.52	14.19
LANK 036	24.63	25.55	23.71	13.91	20.33	24.83	27.20	16.02
LANK 037	31.93	31.68	33.91	14.74	33.96	31.4	30.29	19.10
LANK					23.88	22.81		11.59

038A								
LANK 039	31.95	28.67	29.71	16.20	29.71		27.07	13.68
LANK 045		17.92	21.29					
LANK 047	30.27	28.53	28.44	13.77	29.80	27.61	26.98	15.20
LANK 053	24.26	22.85		11.93	22.88	22.19		12.04
LANK 058	28.72	29.40	31.23	14.57	31.66			13.99
LANK 061	24.26	22.31	24.98	13.30	23.77	24.46	26.39	13.22
LANK 064	31.96	28.90		13.44	30.45	27.31	25.82	14.54
LANK 067	28.28	26.48	24.09	13.64	26.48	24.99	23.01	13.30
LANK 070					23.75	25.20	23.32	13.14
LANK 074	21.89	20.59	20.91	12.01	23.40		20.13	10.84
LANK 076	26.46	26.72	28.82	12.75				
LANK 078	35.66	31.75	30.69	17.15	34.63	31.00	31.93	17.18
LANK 087					26.30	24.18	24.51	10.33
LANK 089	26.82	25.90	26.71	12.60				
LANK 094	23.38	25.46	29.56		27.68	24.16	23.52	13.28
LANK 096	32.93	29.76	30.05	15.92	32.18	29.61	30.25	14.37
LANK 097	30.19	27.51		13.77	28.00	26.34	27.22	
LANK 098					24.84	22.24	22.74	10.57
LANK 101		18.14	22.46				16.42	9.27
LANK 104	34.68	32.87	34.1	13.47	33.04		30.71	13.54
LANK	24.97	22.72	22.58	12.03	24.48	22.45	24.5	11.94

107								
LANK 112	29.01	26.77	27.13	12.10		28.06	28.78	13.07
LANK 119		23.64	26.10		22.94	22.14	24.59	13.77
LANK 123						27.70	28.60	14.01
LANK 128	26.74	24.88		15.21	24.38	21.46	23.34	15.10
LANK 130	29.32	29.02	29.80	11.98	29.95	27.24	28.66	12.81
LANK 137						24.06	23.48	15.12
LANK 140	19.61	22.24		13.39	19.22		27.4	13.54
LANK 141				11.01	28.05	26.32	28.07	11.72
LANK 158	25.57	25.30		11.47	28.04		29.41	12.70
LANK 161		22.86		17.49	13.87	27.22		15.22
LANK 165					24.14	22.75		13.27
LANK 166	25.49	21.68		11.87	17.05	15.14		12.31
LANK 168	22.98	20.07	23.50	13.83	22.44	18.92	25.67	13.35
LANK 171	25.05	24.81	23.14	13.26		24.96		14.53
LANK 191	26.23			12.44	24.61	23.01	25.35	
LANK 192	27.23	26.47	28.15	15.10	26.09	25.14	26.02	14.59
LANK 194	23.21	24.17	27.56	17.16	22.95	24.79	25.04	14.90
LANK 201					29.21	25.71		13.78
LANK 203	33.60	31.68			35.08		30.55	
LANK 208	21.38	21.59	24.05	13.79	22.61	22.71	20.9	15.44
LANK	26.54	24.91	22.23	14.90	28.47			16.35

214								
LANK 218	24.25	21.94	23.93	14.46	26.57	24.83		12.03
LANK 220					25.35	23.94		14.07
LANK 225					24.63		23.89	14.63
LANK 226	21.33	20.76	24.43	14.22	24.63		25.51	14.71
LANK 227		27.97	29.46	15.78	28.35	27.20	28.31	14.61
LANK 229	19.11	17.39	16.73	13.45		25.76	22.60	
LANK 232	24.18	23.32	23.36	13.31				
LANK 233	29.81			13.47				
LANK 249	26.82	27.29	23.44	13.83	25.72	23.78	24.73	13.74
LANK 256	22.67	19.55		12.88				12.72
LANK 260	31.91	27.63	28.16	14.66				
LANK 266	27.29	27.13		13.46	28.00	26.02	25.92	13.77
LANK 270		25.28	26.99	13.97	27.63	24.75	26.80	14.30
LANK 272	26.98	25.75	22.83	12.73	23.97	27.15	27.02	12.38
LANK 273	28.43	23.22	29.1	12.07	24.65	23.39	23.36	11.72
LANK 277	36.06	30.83	33.93		28.34	31.63	32.08	14.36
LANK 287					27.73		29.45	15.12
LANK 291	31.47			14.75		27.46		16.49
LANK 293	33.88	29.42	26.69	17.27	33.24	30.75	28.67	16.60
LANK 299	22.45	25.59	26.51	13.29	22.27	25.85	25.73	14.94
LANK	25.91	25.90	26.07	13.54	25.52	24.74	25.47	11.68

305								
LANK 306	19.84	18.49	23.63	15.25	23.55		24.87	
LANK 307	22.98			13.29	23.76	20.97		13.44
LANK 315	23.68	24.86	25.23	12.21	21.64	21.16	26.49	12.07
LANK 319		31.70	30.02	15.84				
LANK 328	28.09	26.36	27.19	16.77	27.71	26.33	26.66	15.75
LANK 330	24.1	24.96	27.12	13.86	27.86	23.60	21.06	13.01
LANK 331	27.01	22.74	22.28	12.93	24.16	23.04	24.04	10.43
LANK 332	26.79	26.03	25.71	12.87	26.14	25.07	25.03	12.86
LANK 340	26.50	22.35	21.56	12.97	26.71		23.28	13.30
LANK 343	28.26	27.07	28.82	13.87	28.52	26.37	27.67	14.61
LANK 349	26.90	29.10	30.20	14.75				15.25
LANK 352	28.20	24.87	24.59	14.48	20.23	26.2	25.13	13.78
LANK 356	32.57			13.94	31.43	31.02	30.33	13.32
LANK 358	26.43			16.31	24.17	23.60		13.28
LANK 362	34.12		31.43	13.99				
LANK 365	26.20	25.06	25.99		23.89	24.28	26.64	12.98
LANK 367				11.09	23.96			10.96
LANK 374	26.43	24.61			26.02	24.05		14.05
LANK 379	27.96	26.60		13.69	25.27	26.29	26.25	12.76
LANK 380	31.81	22.97	28.17	14.48	30.85	28.58	31.28	17.42
LANK	29.09	28.28	28.63	15.66			32.31	

386								
LANK 397	31.28	29.85	32.39	13.85		29.08	31.74	16.74
LANK 398	26.74	25.90	24.96	14.37	26.74	26.11	26.02	15.17
LANK 399	18.39	18.66	18.76	12.52	21.10	19.79	19.93	14.48
LANK 408		26.62	27.68		28.53	23.47	28.91	14.05
LANK 411	20.33	18.18	19.75	15.78	21.39	17.65	21.36	15.44
LANK 413A	29.14	29.37	25.55	14.44	32.11	29.64	28.51	15.86
LANK 414	27.59	26.89	27.35	13.60	27.36	24.84	25.40	15.70
LANK 427	29.38		26.53	15.01	28.97	26.17		14.27
LANK 430		24.82	27.09	12.13		23.07	24.04	
LANK 437					27.69	24.76	27.59	12.14
LANK 441	22.50	25.83	25.63	13.27	24.68			13.90
LANK 445	28.11	24.61	23.64	14.17	26.72	24.66	25.33	12.15
LANK 447		18.81	21.72		25.93	24.54	25.09	12.35
LANK 448	23.83	25.14	29.51	14.09				
LANK-243		25.18	25.15	13.83				
LANK 2010-0012	33.27	30.06	32.37		30.72	29.56	31.50	14.43
LANK 2010-0025	31.53	30.44	31.42	15.17	29.42	26.99	28.72	15.68
LANK 2010-0032	27.03	24.74	26.27	14.93	26.43	25.59	26.83	13.59
LANK 2010-	27.68	26.80	29.13	13.18	24.27	22.03	23.36	13.07

0050								
LANK 2010-0055	24.30	19.14	18.13	12.80	23.15	19.54	18.74	11.47
LANK 2010-0061					27.48	24.43	25.35	14.35
LANK 2010-0077	21.30	19.45	18.61	12.08		21.16	20.23	11.68
LANK 2010-0084	28.05	26.29	27.65	14.73	24.58	28.49	28.92	13.28
LANK 2010-0093	28.17	23.54	26.32	11.40	20.75	27.1	26.91	11.51
LANK 2010-0108	28.20	25.26		13.80	28.86	27.40		14.27
LANK 2010-0134	32.07	31.06	33.08	15.92	32.37	30.00	32.93	16.07
LANK 2010-0212	28.92	25.45	24.91	15.54	25.35	22.96	24.14	13.69
LANK 2010-0232	26.95	23.25	23.50	14.65				
LANK 2010-0259	21.71	16.43		13.74	23.67	20.68		13.20
LANK 2010-0271	23.88	22.08		11.40	18.05	20.88		11.05
LANK 2010-0281	27.30	22.29		12.48	26.39	21.28		12.23
LANK 2010-0284					21.47	21.25	23.11	10.94
LANK 2010-	27.04	27.02	24.84	12.71	28.34	26.21	24.61	11.58

0317								
LANK 2010-0429	25.85	23.26	22.87	16.10	26.40	23.33	23.21	14.18
LANK 2010-0435					18.22	20.02		13.87
LANK 2010-0441					31.14	29.89	30.44	
LANK 2010-0451	29.73	28.1	29.98	14.90	27.80	26.36		
LANK 2010-0479	25.08	23.81	25.58	15.12	25.28	25.11	24.86	13.53
LANK 2010-0489	23.55	23.62		12.97	22.80	23.57	22.96	12.58
LANK 2010-0522	24.28	25.70	25.97	13.29	19.84	21.47	26.53	12.99
LANK 2010-0543	26.41	25.11	28.90	14.95				
LANK 2010-0554	31.91	30.60	31.13	16.58	32.20	29.42	29.02	18.53
LANK 2010-0559	23.66	20.71	20.80	13.94	27.20	24.65	21.53	16.62
LANK 2010-0566	32.72	29.13		14.80	32.33	28.02		14.14
LANK 2010-0579	24.37	25.06	30.47	14.88	30.74	28.57	29.19	13.75
LANK 2010-0593	30.45	27.64		12.30		25.41	24.85	
LANK 2010-	29.05	26.97	25.98	12.44	27.24	26.07	27.33	14.70

0616								
LANK 2010-0623	30.04	30.62	31.32	13.35	28.23	26.36		
LANK 2010-0636					29.36	23.36	23.89	14.41
LANK 2010-0642	32.75	29.79		13.32	32.82	30.63	30.03	14.35
LANK 2010-0652	28.43	26.54		13.01	27.06	24.28		15.51
LANK 2010-0661	11.11	12.00	15.81	10.81	9.02	10.10	11.92	
LANK 2010-0683	19.19	22.34		14.61	23.88	25.42		13.59
LANK 2010-0686	24.25	21.44		13.59				
LANK 2010-0702	25.83	21.16	25.34	13.89	27.48	24.38	28.14	12.95
LANK 2010-0709					26.44	24.26	26.30	
LANK 2010-0717	33.58	31.36	33.18	17.97		30.99	33.65	
LANK 2010-0776					25.77	24.16	25.47	13.26
LANK 2010-0792	25.29	27.12	29.80		27.37	26.85		15.08
LANK 2010-0806	23.38	24.49	24.76	13.82	25.09	24.83	27.76	14.62
LANK 2010-	26.63	26.92	25.47	13.06	18.39	17.50	18.92	13.37

0861								
LANK 2010-0879					24.44	23.07	23.79	12.09
LANK 2010-0908	25.50	23.20		13.29	19.91	21.89		13.09
LANK 2010-0914	28.61	26.43	27.32		25.8	25.69	25.32	13.95
LANK 2010-0917	25.75	25.9	24.93			27.35	27.73	16.19
LANK 2010-0922					19.91	19.37	22.41	11.10
LANK 2010-0932	28.85	29.27	30.20	15.39	26.54	25.62	26.00	14.90
LANK 2010-0938					28.96	29.75	32.12	13.31
LANK 2010-0971	26.33	25.22	23.64	14.13	27.05	26.51	28.06	12.35
LANK 2010-1002	29.00	28.63	27.45	13.47	25.83	26.39	27.80	14.85
LANK 2010-1022	28.84	20.01	28.65	15.67	22.15	21.86	24.92	15.27
LANK 2010-1052					27.06	26.10	26.30	14.65
LANK 2010-1082	19.28	19.42	21.17	9.75				
LANK 2010-1084	26.95	27.39	28.26					
LANK 2010-	18.92	23.46		12.23	20.19			12.33

1091								
LANK 2010-1103		21.9	24.39		18.38	22.95	25.33	12.58
LANK 2010-1119	32.29	28.77	28.61	14.33	30.90	30.09	28.82	14.31
LANK 2010-1134	24.15	22.84	23.81	12.81	28.05	24.53	23.92	11.79
LANK 2010-1137	28.13	26.47	30.9	15.12	28.37	27.40	30.06	15.44
LANK 2010-1156	24.72	22.48	15.39	13.26	17.53	14.30	12.48	13.19
LANK 2010-1173	28.41	23.27	26.23	14.81		25.28	28.66	
LANK 2010-1191					29.16		29.37	12.74
LANK 2010-1209	33.09	28.34	30.89	13.7	27.85	30.15	31.15	13.45
LANK 2010-1214	24.31	24.56	24.42	14.56	24.19	23.83	23.84	14.57
LANK 2010-1219	33.13	29.77	30.84	15.44	33.49	34.57	32.34	14.30
LANK 2010-1223	31.23	27.89	29.07	14.59	30.32	28.46	29.86	15.35
LANK 2010-1227	27.38			14.86				
LANK 2010-1232	27.97	26.69	27.78	16.03				16.26
LANK 2010-					20.32	18.26	25.06	14.00

1247								
LANK 2010-1258	27.72	25.17	25.34	15.20	24.49	24.60	25.50	14.46
LANK 2010-1274	22.75	24.55	25.96	16.26	28.12	28.57	31.66	16.61
LANK 2010-1281		23.99		13.79	22.90	21.09		13.52
LANK 2010-1284						24.34	27.50	17.52
LANK 2010-1289	31.74	31.77	34.22		33.21	32.40	33.15	16.08
LANK 2010-1341					24.58	22.97	23.12	13.66
LANK 2010-1361		23.53		13.73	23.43	21.99		13.14
LANK 2010-1369	21.92	20.63	26.74	11.85	23.96	21.58	25.54	12.42
LANK 2010-1393	32.17	30.31	30.41	11.59	32.68	29.99	28.23	13.60
LANK 2010-1416					26.54	25.60	27.11	12.61
LANK 2010-1474	27.41	25.53	25.13	15.61	26.60	24.30	23.79	14.73
LANK 2010-1481	27.07	25.30		11.19	25.97	25.60	26.21	12.81
LANK 2010-1512	24.69	25.77	26.03	14.18	26.88	25.74	26.89	14.37
LANK 2010-	22.68	22.38	24.42	12.82	26.45	22.32	24.75	10.72

1517								
LANK 2010-1522	23.22	22.01	22.78	14.78	21.18	20.40	21.72	14.70
LANK 2010-1532	28.02			12.18	26.33	22.93		12.64
LANK 2010-1552	20.94	27.51		14.65	28.27	26.58		14.63
LANK 2010-1557	20.74	17.35	20.98	9.85	18.42	18.87		10.63
LANK 2010-1598	25.01	24.25	24.99	12.15	26.56	26.35	25.79	12.04
LANK 2010-1608					24.98	24.42	25.02	12.99
LANK 2010-1621	21.29	20.02	21.80	14.69	18.60	17.75	19.79	13.36
LANK 2010-1637	27.78	26.16	25.10	13.37	24.33	24.44	25.15	13.83
LANK 2010-1640	27.68	28.77		16.85	25.50	30.18	30.67	15.48
LANK 2010-1697	27.81	28.58	30.14	15.41				
LANK 2010-1738					23.27	22.49	23.09	9.06
LANK 2010-1793	22.32	30.81		15.00	21.78	21.59	26.89	15.89
LANK 2010-1802	27.76	28.35	31.26	16.09				15.63
LANK 2010-					35.90	34.96	24.99	15.28

1852								
LANK 2010-1882					24.58	23.71	26.25	15.94
LANK 2010-1894	30.79	30.36	31.05	12.71	28.86	27.49	30.25	12.53
ADNR 318	26.03	26.03	26.80	15.30	27.64	23.73	26.69	15.80
ADNR 319	22.75	24.22	27.86	11.11	22.13	21.23	23.66	11.10
ANDR 306	28.96	27.85	23.33	14.99	21.74	19.45	21.28	14.85
ANDR 311	20.73	18.80	21.10	10.73	22.91	18.26	20.40	11.04
ANDR 312	20.05	19.22	20.58	14.43	23.71	22.64	21.91	13.71
ANDR 320	30.98	27.58	28.22	16.33	30.57	27.09		13.02
ANDR 324	25.89	22.62		14.60	23.5	19.77	19.39	14.20
ANDR 331	28.70	29.15	30.81	15.81	29.48	28.46	30.66	15.36
ANDR 333	26.59	23.77		13.79	21.51	21.51		13.53
ANDR 334	33.08	31.49	30.74	16.43	33.29	30.41	26.66	13.90
ANDR 338	25.08	25.50	27.48	14.31	26.58	25.38	26.21	13.76
ANDR 339	25.19	22.48	22.49	13.47	23.51	22.13	21.22	13.67
HYS 001	27.22	24.81	27.74	13.30		28.05	29.35	13.18
HYS 002		26.20	24.56					
HYS 007	27.34	26.84		12.08	26.18	26.23		14.23
HYS 012A	24.64	22.40		10.88	24.08	23.07		11.54
HYS 012B	26.62	27.35	29.76	15.41	27.92	26.21	30.11	16.24
HYS	26.29	28.53	27.20	10.77	27.86			

013								
HYS 016	21.78	22.34	24.13	12.43	22.3	19.72	19.74	14.56
HYS 017	27.42	21.53		12.32	27.88	24.81	25.88	12.75
HYS 025	33.39	31.41	29.90	16.05	31.99	29.79	31.62	15.09
HYS 027	23.52	23.13		12.66	22.90	22.13	25.24	11.28

Appendix 7. Dorsal margin and posterior exostoses scores

Skeleton #	Dorsal Margin Score	Posterior Exostoses Score
LANK 006		
LANK 008		
LANK 011	Score=4: Rim	
LANK 015	Score=4: Rim	Score=2: Rounded
LANK 016	Score=2: Flattening incomplete	Score=1: Smooth
LANK 017	Score=4: Rim	
LANK 018		
LANK 019	Score=4: Rim	
LANK 020		Score=2: Rounded
LANK 021		
LANK 024		
LANK 025		
LANK 029		
LANK 031		
LANK 035	Score=4: Rim	Score=2: Rounded
LANK 036		
LANK 037		Score=1: Smooth
LANK 038A	Score=1-2: Serrated-flattening incomplete	Score=1: Smooth
LANK 039		
LANK 045		Score=3: Pointed
LANK 047		
LANK 053		Score=3: Pointed
LANK 058		
LANK 061	Score=4: Rim	
LANK 064		
LANK 067		
LANK 070		
LANK 074		
LANK 076	Score=4: Rim	
LANK 078		Score=1: Smooth
LANK 087		
LANK 089		
LANK 094	Score=5: Break down	
LANK 096		
LANK 097		
LANK 098	Score=2: Flattening incomplete	Score=2-3: Rounded-pointed

LANK 101		Score=3: Pointed
LANK 104		Score=2-3: Rounded-pointed
LANK 107	Score=1-2: Serrated-flattening incomplete	Score=2: Rounded
LANK 112	Score=1: Serrated	Score=1: Smooth
LANK 119		
LANK 123	Score=3: Flattening Complete	Score=2: Rounded
LANK 128		
LANK 130		
LANK 137		
LANK 140		
LANK 141	Score=4: Rim	Score=2: Rounded
LANK 158		
LANK 161	Score=3: Flattening Complete	
LANK 165		
LANK 166		
LANK 168	Score=4-5: Rim-break down	Score=3: Pointed
LANK 171		
LANK 191	Score=1: Serrated	Score=3: Pointed
LANK 192		
LANK 194		
LANK 201		
LANK 203		
LANK 208		
LANK 214		
LANK 218		
LANK 220		
LANK 225	Score=4: Rim	
LANK 226	Score=2: Flattening incomplete	
LANK 227		Score=2: Rounded
LANK 229		
LANK 232		
LANK 233		
LANK 249	Score=5: Break down	Score=3: Pointed
LANK 256		
LANK 260		
LANK 266		
LANK 270	Score=3: Flattening Complete	Score=2: Rounded
LANK 272	Score=5: Break down	Score=3: Pointed

LANK 273	Score=5: Break down	
LANK 277	Score=5: Break down	Score=1: Smooth
LANK 287	Score=2: Flattening incomplete	
LANK 291	Score=2: Flattening incomplete	Score=1: Smooth
LANK 293	Score=1: Serrated	Score=1: Smooth
LANK 299	Score=5: Break down	
LANK 305	Score=3-4: Flattening complete-rim	Score=2-3: Rounded-pointed
LANK 306	Score=2: Flattening incomplete	Score=1: Smooth
LANK 307	Score=4-5: Rim-break down	
LANK 315		Score=1: Smooth
LANK 319	Score=5: Break down	
LANK 328	Score=3-4: Flattening complete-rim	Score=1: Smooth
LANK 330		
LANK 331	Score=4-5: Rim-break down	Score=2-3: Rounded-pointed
LANK 332	Score=1-2: Serrated-flattening incomplete	Score=1-2: Smooth-rounded
LANK 340		
LANK 343		
LANK 349		
LANK 352	Score=2: Flattening incomplete	Score=1: Smooth
LANK 356		
LANK 358	Score=4-5: Rim-break down	Score=1: Smooth
LANK 362	Score=3-5: Flattening complete-break down	
LANK 365	Score=1-2: Serrated-flattening incomplete	Score=1: Smooth
LANK 367	Score=5: Break down	Score=1: Smooth
LANK 374	Score=3: Flattening Complete	Score=1-2: Smooth-rounded
LANK 379	Score=4-5: Rim-break down	Score=1: Smooth
LANK 380	Score=4: Rim	Score=1-2: Smooth-rounded
LANK 386	Score=3-4: Flattening complete-rim	Score=1: Smooth
LANK 397	Score=5: Break down	Score=1: Smooth
LANK 398		Score=1: Smooth
LANK 399		
LANK 408	Score=3: Flattening Complete	Score=1-2: Smooth-rounded
LANK 411	Score=3: Flattening Complete	
LANK 413A		Score=2: Rounded
LANK 414		
LANK 427	Score=2: Flattening incomplete	Score=2: Rounded
LANK 430	Score=4-5: Rim-break down	Score=1: Smooth

LANK 437		
LANK 441	Score=2: Flattening incomplete	
LANK 445	Score=3-4: Flattening complete-rim	Score=1: Smooth
LANK 447		
LANK 448		
LANK-243		Score=1: Smooth
LANK 2010-0012	Score=3-4: Flattening complete-rim	Score=1: Smooth
LANK 2010-0025	Score=3: Flattening Complete	
LANK 2010-0032		
LANK 2010-0050		Score=1: Smooth
LANK 2010-0055	Score=4-5: Rim-break down	Score=1-2: Smooth-rounded
LANK 2010-0061	Score=3-4: Flattening complete-rim	
LANK 2010-0077		
LANK 2010-0084	Score=3: Flattening Complete	Score=1: Smooth
LANK 2010-0093	Score=3: Flattening Complete	
LANK 2010-0108		Score=1: Smooth
LANK 2010-0134	Score=2: Flattening incomplete	Score=1: Smooth
LANK 2010-0212	Score=5: Break down	Score=2-3: Rounded-pointed
LANK 2010-0232		
LANK 2010-0259		Score=1: Smooth
LANK 2010-0271		
LANK 2010-0281	Score=4: Rim	
LANK 2010-0284	Score=5: Break down	Score=3: Pointed
LANK 2010-0317		
LANK 2010-0429	Score=4-5: Rim-break down	
LANK 2010-0435		Score=1: Smooth
LANK 2010-0441		
LANK 2010-0451	Score=3: Flattening Complete	Score=2: Rounded
LANK 2010-0479		
LANK 2010-0489		
LANK 2010-0522	Score=4: Rim	Score=2: Rounded
LANK 2010-0543		
LANK 2010-0554		
LANK 2010-0559		
LANK 2010-0566		Score=1: Smooth
LANK 2010-0579	Score=3: Flattening Complete	Score=3: Pointed
LANK 2010-0593		
LANK 2010-0616	Score=4: Rim	
LANK 2010-0623		

LANK 2010-0636		
LANK 2010-0642		
LANK 2010-0652		
LANK 2010-0661	Score=4: Rim	Score=2: Rounded
LANK 2010-0683	Score=4: Rim	
LANK 2010-0686		
LANK 2010-0702	Score=3: Flattening Complete	Score=1-2: Smooth-rounded
LANK 2010-0709		Score=1: Smooth
LANK 2010-0717		
LANK 2010-0776		
LANK 2010-0792		
LANK 2010-0806		
LANK 2010-0861		Score=2: Rounded
LANK 2010-0879		
LANK 2010-0908		
LANK 2010-0914		Score=1-2: Smooth-rounded
LANK 2010-0917	Score=1: Serrated	Score=1: Smooth
LANK 2010-0922		
LANK 2010-0932		Score=1: Smooth
LANK 2010-0938	Score=2: Flattening incomplete	Score=1: Smooth
LANK 2010-0971		
LANK 2010-1002		
LANK 2010-1022	Score=3: Flattening Complete	Score=1: Smooth
LANK 2010-1052		
LANK 2010-1082		
LANK 2010-1084		
LANK 2010-1091		
LANK 2010-1103		Score=2: Rounded
LANK 2010-1119		
LANK 2010-1134	Score=3-4: Flattening complete-rim	Score=1: Smooth
LANK 2010-1137	Score=3-4: Flattening complete-rim	Score=1: Smooth
LANK 2010-1156		
LANK 2010-1173	Score=5: Break down	
LANK 2010-1191		Score=1: Smooth
LANK 2010-1209	Score=3-4: Flattening complete-rim	
LANK 2010-1214		
LANK 2010-1219		
LANK 2010-1223	Score=1-2: Serrated-flattening incomplete	Score=1: Smooth

LANK 2010-1227	Score=5: Break down	Score=3: Pointed
LANK 2010-1232		
LANK 2010-1247		
LANK 2010-1258		
LANK 2010-1274		
LANK 2010-1281		
LANK 2010-1284		
LANK 2010-1289	Score=2: Flattening incomplete	
LANK 2010-1341		
LANK 2010-1361		
LANK 2010-1369		
LANK 2010-1393	Score=3-4: Flattening complete-rim	
LANK 2010-1416		Score=1: Smooth
LANK 2010-1474		
LANK 2010-1481	Score=3: Flattening Complete	Score=1: Smooth
LANK 2010-1512	Score=1: Serrated	Score=1: Smooth
LANK 2010-1517	Score=4-5: Rim-break down	
LANK 2010-1522		
LANK 2010-1532		
LANK 2010-1552		
LANK 2010-1557		
LANK 2010-1598		Score=3: Pointed
LANK 2010-1608		
LANK 2010-1621		
LANK 2010-1637		
LANK 2010-1640		
LANK 2010-1697	Score=3: Flattening Complete	Score=2: Rounded
LANK 2010-1738		
LANK 2010-1793		Score=1: Smooth
LANK 2010-1802	Score=3-4: Flattening complete-rim	
LANK 2010-1852	Score=3: Flattening Complete	Score=1-2: Smooth-rounded
LANK 2010-1882	Score=5: Break down	Score=3: Pointed
LANK 2010-1894		Score=1: Smooth
ADNR 318		
ADNR 319		Score=1: Smooth
ANDR 306		
ANDR 311	Score=5: Break down	Score=1: Smooth
ANDR 312	Score=3-4: Flattening complete-rim	Score=1: Smooth
ANDR 320		Score=1: Smooth

ANDR 324	Score=3-4: Flattening complete-rim	Score=1: Smooth
ANDR 331	Score=2: Flattening incomplete	Score=1: Smooth
ANDR 333		
ANDR 334		
ANDR 338		Score=1: Smooth
ANDR 339		Score=1: Smooth
HYS 001		Score=1: Smooth
HYS 002		Score=2: Rounded
HYS 007	Score=1: Serrated	Score=1: Smooth
HYS 012A		Score=2: Rounded
HYS 012B	Score=4-5: Rim-break down	Score=2: Rounded
HYS 013		
HYS 016	Score=4: Rim	Score=2: Rounded
HYS 017	Score=4: Rim	Score=1: Smooth
HYS 025	Score=1: Serrated	Score=1: Smooth
HYS 027	Score=1: Serrated	Score=1: Smooth