ACTIVITY AND AGING IN ADULT MALES: INVESTIGATION OF ENTHESES AND CORTICAL BONE FROM THE SITE OF LISIEUX-MICHELET IN NORTHERN FRANCE

ACTIVITY AND AGING IN ADULT MALES: INVESTIGATION OF ENTHESES AND CORTICAL BONE FROM THE SITE OF LISIEUX-MICHELET IN NORTHERN FRANCE

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A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfillment of the Requirements

for the Degree

Master of Arts

McMaster University

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MASTER OF ARTS (2015)

Department of Anthropology

McMaster University

Hamilton, Ontario

TITLE: Activity and Aging in Adult Males: Investigation of Entheses and Cortical Bone from the Site of Lisieux-Michelet in Northern France

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NUMBER OF PAGES ix, 105

ACKNOWLEDGEMENTS

I would like to thank Cecile de Seréville-Niel and the other faculty and students from the anthropology department of the University of Caen for permitting me to use their collection and for being such kind and generous hosts during my stay in France. I would of course like to thank my thesis supervisor Dr. Megan Brickley and Dr. Tracy Prowse for allowing me to piggyback onto their project and for sitting on my thesis committee. A tearful thanks goes out to Dr. Ann Herring for withstanding the gauntlet of last minute questions and chapter drafts. Her sage advice and boundless patience saved me from the blind panic that preceded this thesis submission.

Last but not least, a million thanks go to my friends and family in Hamilton and beyond for carrying me through the trials and tribulations of grad school even when I was being fussy and difficult. You’re astounding and flawless human beings.

**ABSTRACT**

Cortical thickness and entheseal robusticity were used to measure the effects of activity and age in a group of 77 adult males from the site of Lisieux-Michelet in northern France. There was no known age at death for this population; age was determined using a series of osteological age estimation methods. Based on the currently available dates for this sample, the skeletal remains were primarily from the Late Roman Period (3rd-7th century AD).The adults were divided into three age categories based on these estimation results.

Trends in cortical and entheseal development were measured within and between age categories. Results showed that entheses increased with age while cortical thickness decreased. However, low correlation between these two factors suggests that while entheseal robusticity responds to age, it is highly influenced by physical activity. Activity levels also affect cortical thickness which causes variation within age groups.

A comparison of the Lisieux-Michelet entheseal and cortical measurements to both modern and archaeological populations indicated that these males engaged in physically demanding occupations. The degree of activity experienced by these individuals decreased during the middle adult years likely due to a shift to less physically demanding occupations. However, cortical and entheseal data suggest that the old adults from Lisieux-Michelet were not particularly frail and continued to be active even after the decrease in activity during the middle years.

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# **CHAPTER 1.0 INTRODUCTION**

One of the underlying goals of the examination of archaeological bone is to gain a better understanding of the daily activities of past populations. When contemporary textual sources are unavailable, evidence taken from skeletal remains can provide an important source of information regarding a population’s health and activity. Some methods that have been used in previous studies to obtain information regarding age and activity from archaeological bone are the examination of entheseal robusticity and cortical thickness. Both entheses (muscle attachment sites) and cortical thickness are noted to alter with age and mechanical strain exerted throughout an individual’s life (Bailey et al. 2010, Ma et al. 2009, Niinimäki et al. 2013, Rhodes and Knüsel 2005). These factors have previously been examined together in an occupation-specific study of professional archers using cortical measurements taken from the humerus rather than from the metacarpal (Stirland 1998). This study is the first to examine these factors together in relation to the general activity of a population. This current study examines entheseal robusticity and cortical thickness in a sample of adult male skeletal material from the site of Lisieux-Michelet in northern France in order to gain a better understanding of the daily life of this population.

This study focuses on non-elite adult males from the Late Roman Empire (3th-7th century AD) as non-elite males are often an understudied population in archaeological research. Male specific academic writings regarding health did not appear until the 20th century and focused mainly on sexual health overlooking general health and activity (De Krester 2010, Sorenson 2011). Age related bone loss in particular is mainly examined in females and is rarely studied in adult males even though males experience a similar, though less dramatic, cortical bone loss in adulthood (Mays 2001).

140 individuals were assessed from the site of Lisieux-Michelet to determine if their skeletal remains could be used in the current study. Of these 140 individuals, 77 adult males could provide the necessary data for this study. This sample was separated into young, middle, and old age categories and the cortical thickness and entheseal development of these adults were examined with a combination of macroscopic and radiographic techniques with the aim of measuring the degree to which these factors are influenced by age and activity. This study was conducted in tandem with Social-Cultural Determinants of Community Wellbeing in the Western Roman Empire: Analysis and Interpretation of Vitamin D Status project by Dr. Megan Brickley and Dr. Tracy Prowse of McMaster University. Of the 77 males in this sample, there is the possibility that ten of the individuals may have a later date. For the purposes of this study, the focus remained on the Roman period.

Cortical thickness is primarily influenced by age but variability within age groups can be caused by differing levels of activity. Previous studies of cortical thickness have noted that higher levels of physical activity adopted during youth and maintained through adulthood results in higher peak cortical bone thickness and reduced levels of bone loss later in life (Bailey et al. 2010, Ma et al. 2009, Niinimäki et al. 2013). Nutritional stress and low levels of physical activity in youth can also result in a lower peak bone mass and a reduced cortical thickness later in life.

Entheseal robusticity also develops in response to regular mechanical strain exerted by the muscles. Entheses are noted to increase in robusticity with age as their development is a result of cumulative activity over time (Weiss 2003). The fibrous entheses that compose the rotator cuff were examined in the Lisieux-Michelet sample; these entheses are related to large powerful muscles that have the potential to experience substantial strain during an individual’s life which would then be reflected in entheseal development. Although the large bones of lower limbs are often better preserved due to the thicker cortical bone present, upper limb entheses do not undergo the regular strain of weight bearing and might better reflect variance in activity.

The aims of this study are:

* To gain a more holistic perspective of the variance in activity and the effects of aging on adult male bone by examining entheseal development and cortical thickness within and between age categories.
* To compare the results of the Lisieux-Michelet sample to previously studied populations in order to make inferences about the relative levels of health and activity of this group.

Cortical thickness and entheseal development will be examined in order to determine whether there is any correlation between age and activity. The relative degree to which these factors relate to each other may reveal important data about the adult males of Lisieux-Michelet and the development of cortical bone and entheses.

# **CHAPTER 2.0 BACKGROUND**

## **2.1 Lisieux**

The skeletal material used in this study was taken from the site of Lisieux-Michelet, located in the city of Lisieux in the north of France (Figure 1). The city currently known as Lisieux has been a site of occupation since the 1st century AD although evidence of habitation was better established by the 3rd century (Paillard n.d.). The Roman town that was to become Lisieux was originally known as *Noviomagus* *Lexovii*. *Noviomagus* is a Latinized Celtic word meaning “new field” or “new market” used to refer to several Roman settlements. *Lexovii* refers to the Gallic people whose territory in which the city was located (Paillard n.d.).

During the 2nd century, this 60 hectare town was an important trade centre as it sat at the centre of many communication routes and was close to the sea (Paillard et al. 2006). A port was constructed at the confluence of the Orbiquet and the Touques rivers which assisted with trade and communication through this part of Gaulle. This site also supported a certain amount of industry as is evident through a progression of structures linked to metallurgy with associated slag pits as well as a series of well developments, cisterns, and waste pits associated with both domestic and artisanal use.

Large portions of *Noviomagus Lexovii* were destroyed by fire during the 3rd century as a result of invasions. This is supported archaeologically by a thick layer of ash as well as large pieces of charcoal and burned vestiges of buildings. The city was fortified after this and included an eight hectare *castrum* at the centre of the city which remained in use until the 15th century. The 4th century saw further expansions with the development of a suburb between the Orbiquet and the Touques rivers (Paillard n.d.).

Little is known about the medieval occupation of the city other than it ceased expanding and began to shrink in towards the *castrum*. It is likely that the town still suffered from invasions as the fortifications were still well maintained. During this period, the town retired the Roman name of *Noviomagus* and was referred to simply as *Lexovii* (Paillard n.d.)

### **2.1.1 The Site of Lisieux-Michelet**

The excavation of the site of Lisieux-Michelet was undertaken as a four year intervention program funded by the city of Lisieux, General Council of Calvados, Ministry of Culture. The program was set up preceding the road development of rue Joseph Guillonneau and the boulevard Duchesne-Fournet (Paillard n.d.).

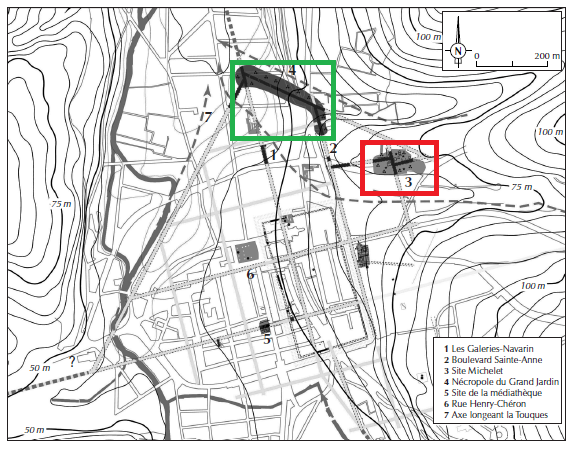


**Figure 1** Location of Lisieux (indicate by red dot) within France (Map France: http://www.map-france.com/Lisieux-14100/road-map-Lisieux.html)

The site of Lisiuex-Michelet is associated with a necropolis (Figure 2) which was discovered in the courtyard of a small seminary chapel during excavations related to pipeline development. Following this discovery, test pits were used to determine the full extent of the necropolis. Once this was established, a two year (1990 and1991) mitigation excavation was undertaken in order to recover the archaeological material from the southern end of the site. The following two years (1992 and1993) were spent collecting the archaeological material from the northern end of the site which was also being threatened by the development of new buildings in the area.

The excavation of the city of Lisieux-Michelet covered 8,400m² and reached a depth of 1.5m. A backhoe with a 1.2m reach was used to expedite the excavation of several of the buildings. However, the necropolis and all the inhumations were excavated manually (Paillard n.d.).

The early results from this site produced dates ranging from the protohistoric period of the 3rd century AD to the Carolingian period (8th-9th century AD). The necropolis in fact contains two chronologically separate periods of inhumation. The first period was from the 4th to the 5th century AD and accounts for the largest number of inhumations. The second period is represented by infrequent use of the necropolis from the 6th to the 9th century AD (Alduc-Le Bagousse and Blondiaux 2002, Paillard et al. 2006, Paillard n.d.). Skeletal preservation was assisted by a favourable soil pH and the fact that the site was covered by a paved courtyard for many years, which prevented soil disturbance and limited the amount of bone destruction due to pollution.



**Figure 2** Site of Lisieux-Michelet (indicated in red) and the necropolis (indicated in green) in the town of Lisieux (Paillard et al. 2006 Fig.1 p. 211)

### **2.1.2 Inhumations**

The superpositioning of the inhumations at Lisieux-Michelet helps distinguish the different periods of use. In some of the longer used areas of the necropolis, there were as many as ten layers of inhumations. The horizontal orientation of the bodies themselves are of less use in determining the chronology of the burials. The 43 earliest burials which are thought to be associated with foundation of the necropolis are oriented North-South. However, all the subsequent burials were oriented East-West during the 4th century AD (Paillard n.d.). It is possible that this change in burial orientation reflects the shift to Christianity in 312AD during the reign of Emperor Constantine (Lançon 2000). However, the first definite sign of Christian inhumations did not appear at Lisieux-Michelet until the inhumation of bishop Theudobaudis in the second half of the 6th century (Paillard n.d.)

Wood coffins are the most common type of inhumation at Lisieux-Michelet and are prevalent across all time periods. Wooden chambers large enough for two individuals were also present at this site but were only used in the 4th century. Inhumations surrounded by tiles appeared during the 5th to the 7th century and were indicative of Late Roman Empire or early Merovingian burials. The second half of the 7th century is the only period in which stone sarcophagi appear (Paillard n.d.).

The majority of the inhumations at Lisieux-Michelet are from the 4th or 5th century with 792 of the 970 recovered individuals dating to the 4th century alone. After the 5th century, use of the necropolis ceases for almost a century and then resumes near the end of the 6th century (Paillard n.d.).

Site disturbances at Lisieux-Michelet have made establishing a definite chronology difficult. Inhumations were primarily disturbed by the practice of exhuming older burials and subsequently reburying them in a different location in order to make space for new graves. While the inhumations were initially arranged into lines and rows, later burials were sometimes placed into available space between rows and older burial spaces were reused. The organic decay of coffin material can also cause individuals inhumed above to shift. Later disturbance to the site was the result of canal development in the 17th century to accommodate water pipes used for the public gardens north of the chapel (Paillard n.d.).

A formal final report on the excavation of Lisieux-Michelet and the associated necropolis had not yet been produced at the time of this study. In preparation for producing a final report, additional work, including radiocarbon dating, was being conducted to date the archaeological human remains at the site of Lisieux-Michelet. The dates currently attributed to the skeletal remains obtained from an unpublished report (Paillard n.d.) may be modified once the new research has been completed.

## **2.2 The Late Roman Empire**

The Late Roman Empire spanned the period between the latter half of the 3rd century AD to the early 7th century. This was a period of social upheaval with the adoption of Christianity, the disintegration of the Roman Empire in the West, and the emergence of barbarian kingdoms (Bury 1923, Mathisen 2003). A rift occurred between the eastern and western halves of the Roman Empire which lead to the establishment of the Byzantine Empire in the East during the Late Empire. The West, on the other hand, rejected the traditional social, political, and religious structure of the Roman Empire and adopted Christianity (Mathisen 2003).

There was a downturn in the Roman economy during the Late Empire which led to a decrease in the number of Roman elite. Most citizens existed at the subsistence level and even the lower class (plebs) had less social mobility. Membership in trade guilds became mandatory and citizens had few opportunities to move outside their current profession (Boren 1977). This social restriction represented only a fragment of the regular civil struggles and internal government corruption which, combined with the pressure of outside forces, eventually lead to the decline of the Roman Empire. This decline was most visible in the western empire which gradually decreased in size as barbarian kingdoms overtook parcels of land formerly under Roman influence (Jones 1964).

### **2.2.1 Male adulthood in the Roman Empire**

The male transition into adulthood in Roman society began around the age of 15 or 16 and ended around 25 to 30 years of age (Harlow and Laurence 2002). During this transitional period, males were defined as “youths” and were considered under Roman law to be capable of adult thinking but lacking the morality and restraint essential to adulthood. Some males were drafted into the military during this time as the characteristics of youth were seen as favourable for military service. The non-adult mind was considered more pliable and accustomed to taking orders than that of an adult and the exercises associated with military service were best carried out by a body that was un-hampered by age (Harlow and Laurence 2002). Males not engaged in military service would begin training in an occupation during this time.

During the late Roman Empire, the emphasis on military service was reduced after 440 AD when members of trade corporations could be exempt from military service and instead occupy local guard positions under the supervision of an urban prefect (Lançon 2000). During the period, the military was populated mainly by middle class males seeking better prospects while a smaller number of lower class youths made up mercenary bands (Boren 1977).

Once males reached adulthood, they had greater responsibilities in regards to both business and politics (Harlow and Laurence 2002). There were many occupations for adult males in the Late Empire, especially in the realm of trades. Although a village or smaller city like Lisieux would not have the range of specialized trades or the variety of merchants that might appear in a larger metropolis, men would likely find employment as potters, carpenters, smiths, weavers, leather makers, and similar occupations (Jones 1964, Lançon 2000). Casual labourers were numerous, especially in the building industry, and professional carriers were also often employed to transport local crops and wares into cities (Jones 1964).

Once an adult male reached a period of old age, they would withdraw from public life and were expected to take up more leisurely pursuits. Old age in the Roman Empire was not entirely defined by an individual’s chronological age but included consideration of their physical and mental capacity (Harlow and Laurence 2002). Romans perceived old age to be a disease and individuals who were visibly affected by it carried a considerable social handicap. Older individuals who were still physically fit and could contribute to society maintained good social standing while frail individuals were considered to be a burden. Especially among members of the elite, emphasis was placed on fighting off the effects of aging and maintaining good physical health (Cokayne 2003). Because of this, the onset of old age varied and could occur at any time from 40 years of age onwards, depending on the individual (Harlow and Laurence 2002).

The degree to which these attitudes and practices apply to the adult males from the site of Lisieux-Michelet is unknown. This site is located far from the center of Rome and the degree to which Roman culture and norms were upheld in this city cannot be established.

## **2.3 Entheses**

The term “enthesis” is used to describe the sites where muscles, capsules, and ligaments attach to bone (Mariotti et al. 2007, Villotte and Knüsel 2013). The development of robusticity at an enthesis is caused by the amount of time and the intensity of stress exerted by the muscle, capsule, or ligament on bone. Variation in entheseal development may in part be influenced by age, sex, and body size (Davis et al. 2013). The study of entheseal development in archaeological bone can help provide insight into muscle use and activity in past populations.

### **2.3.1 Entheseal morphology**

There are two types of entheses found in the human body that are defined by the type tissue present at the skeletal attachment point; fibrous and fibrocartilagenous (Benjamin et al. 2002). Fibrocartilagenous entheses are found at epiphyses and apophyses, are composed of a tendon or ligament, uncalcified and calcified fibrocartilage, and the subchondral bone to which they attach (Benjamin et al. 2002, Villotte and Knüsel 2013).

This study examines fibrous entheses as they are associated with some of the largest, strongest muscles in the body and yet are much less studied than their fibrocartilagenous counterparts (Benjamin et al. 2002). Fibrous entheses attach to the diaphysis of bone and are composed of a dense bundle of fibers connected directly to the periosteum and cover a much larger surface area than fibrocartilagenous entheses (Noldner and Edgar 2013). These entheses are found throughout the appendicular skeleton in areas with thick cortical bone which would suggest that they would preserve well in the archaeological record.

The nature of the connection between the ligament or tendon and the surface of bone affects how physical stress is dissipated at the entheses (Hawkey and Merbs 1995, Noldner and Edgar 2013). Fibrocartilagenous entheses appear as a smooth, well-delimited imprint at the site of attachment. Fibrous entheses disperse force across a wide area and create a rough, irregular mark on bone (Cardoso and Henderson 2010). This dispersion of force causes fibrous entheses to react less dynamically to mechanical loading than fibrocartilagenous entheses. The development of fibrous entheses is expressed through increased irregularity at the site of attachment which has made it difficult to measure the correlation between fibrous enthesis development and activity (Havelokova and Villotte 2007, Villotte and Knüsel 2013). The increased roughening of the cortical surface is difficult to score definitively and does not lend itself as well to measurement as the development of fibrocartilagenous entheses.

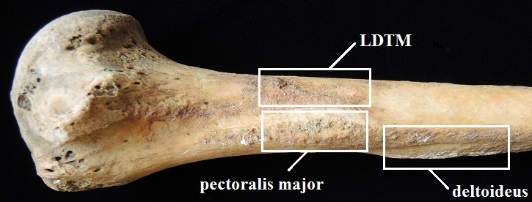
Sex is also thought to have some influence on entheseal robusticity (Cardoso and Henderson 2010, Hawkey and Merbs 1995, Mariotti et al. 2007), in part due to a combination of cultural factors such as division of labour where men frequently undertake heavy manual tasks causing greater robusticity (Hawkey and Merbs 1995, Noldner and Edgar 2013) and genetic components. Males are generally larger and have different fat distribution, body size, muscle mass, and overall morphology compared to women (Villotte and Knüssel 2013), which leads to them having larger entheses (Weiss 2010). This study focused solely on males in order to limit sex-related variability.

Age has been noted to be the greatest determinant of entheseal robusticity (Cardoso and Henderson 2010, Mariotti et al. 2007, Villotte et al. 2010, Weiss 2003). Entheseal robusticity can only increase over time as the development of an enthesis is determined by the duration and amount of activity-induced stress exerted on it by muscle use and is the result of cumulative muscle use over time (Noldner and Edgar 2013, Palmer et al. 2014). Unlike cortical thickness, entheseal robusticity does not decrease either with age or reduced levels of activity. This is most visible in lower limbs due to the regular physical stress of load bearing (Mariotti et al. 2007). The correlation between entheseal development and age can be mitigated by the different levels of physical stress exerted on the attachment site due to occupation and daily activities.

The duration and magnitude of physical stress can have differential effects on entheseal development; repetitive and regular strain with greater mechanical loading will produce a more robust enthesis than infrequent, lighter loading (Benjamin and McGonagle 2009, Cardoso and Henderson 2010, Villotte et al. 2010). Previous studies have noted that individuals who engage in strenuous manual labour have more robust muscle attachment sites than those who engage in lighter, less physically demanding work (Villotte et al. 2010). Given the contextual information available on burial type (Paillard n.d.), the male population of Lisieux-Michelet was likely composed primarily of manual labourers and craftsmen. This would be reflected in higher robusticity scores and relative entheseal development similar to other populations that engaged in comparable levels of labour as varying degrees of entheseal development can be indicative of the relative levels of physical activity within and between populations.

**2.3.2 Muscles examined in the study of Lisieux-Michelet males**

The study of adult males examined the fibrous entheses that make up the rotator cuff. These include the entheses associated with the deltoideus (deltoid), pectoralis major (pectoral), and the latissimus dorsii/teres major (LDTM) (Figure 3).



**Figure 3** Entheses of the rotator cuff (right humerus)

#### **2.3.2.1 Function of the deltoid**

The deltoid is a large muscle linked to basic shoulder abduction when the shoulder is internally rotated and transverse abduction when the shoulder is externally rotated. The abduction is produced with any motion that reaches the upper arm away from the body.

#### **2.3.2.2 Function of the latissimus dorsii/teres major**

The latissimus dorsii is a large muscle but has its main attachments at the inferior thoracic and lumbar vertebrae, sacrum, and iliac crest; the attachment on the humerus is relatively small. This muscle works antagonistically to the deltoid and in tandem with multiple other muscles. The teres major is a small but dense muscle that supports the motion of the latissimis dorsii. This muscle engages in motions that are supported by multiple other muscles, its enthesis would be under a lesser degree of strain than the deltoid or the pectoral which would create less robusticity.

#### **2.3.2.3 Function of the pectoral**

The pectoral muscle has a large point of connection with the humerus. This muscle is associated with a wide range of motions including the flexion, adduction, and medial rotation. However, the pectoral is also associated with much more passive activities such as expansion during deep breathing and holding the humerus next to the body. While the development of the other observed entheses are dependent to some degree on occupation and the level of physical activity an individual experiences during their life span, the pectoral will constantly undergo mild physical strain.

### **2.3.2 Archaeological examinations of entheses**

Previous studies of archaeological collections have examined entheseal development in relation to both activity and age. This research has been done on a variety of global populations and has been used to examine the effects of both occupation and generalized activity on entheseal development. The degree to which these studies were able to observe the link between lifestyle and entheseal development varies. However, all these studies note that age is consistently the greatest determinant of entheseal robusticity (Cardoso and Henderson 2010, Chapman 1997, Palmer et al 2014, Stirland 1998, Weiss 2003).

An examination of the entheses of professional archers from 1545 AD England noted that all activities are carried out by a group of muscles rather than by a single muscle, which indicates that muscles need to be evaluated in groups rather than in isolation in order to be related to an activity (Stirland 1998). This is supported in later studies of 19th century Dutch rural villagers (Palmer et al. 2014) and a multiple occupational study from 19th-20th century Portugal (Cardoso and Henderson 2010). Cardoso and Henderson (2010) examined entheseal development in relation to the occupation listed on the individual’s registered death and they discovered that there were no trends in entheseal development specific to the listed occupations. This lack of concordance between entheseal development and occupation likely occurs because muscles groups are associated with a variety of activities, both occupational and non-occupational, and this prevents the identification of clear, occupation-related trends.

The study of young and middle adult Dutch rural villagers by Palmer et al. (2014) also looked at groups of muscles, but instead of linking them to a specific occupation, the authors used relative entheseal development to examine the overall activities of a population. This is perhaps the best use of entheseal analysis in archaeological samples because it allows for the comparison of muscle use and development between populations. For example, these data can be used to map changes in muscles use in chronologically or geographically disparate agricultural populations which, in turn, can allow for inferences regarding differences in agricultural practices. Trends in muscle use can help create broad statements regarding activity between and within populations which studies can use as a base for cultural, occupational, and chronological examinations.

Chapman’s (1997) study of sedentary agriculturalists from 1200-1838 AD and mapped trends in muscle development before and after the Spanish occupation of Pecos Pueblo. Historical records noted that the Spanish occupation lead to a greater emphasis on maize production and processing, which the author noted was reflected in an increase in robusticity at entheses associated with these activities (Chapman 1997). Similar to the study of Dutch rural villagers, this study mapped a general change in entheseal development following a social shift associated with Spanish occupation that placed more emphasis on certain occupations than others.

## **2.4 Cortical bone**

Cortical bone thickness in anatomically modern skeletons has become an area of interest for the study of the influences of nutritional stress, activity, and aging on bone (Mays, 2001, Niinimäki et al. 2013, Tveit et al. 2013). Cortical bone increases during adolescence and decreases in later years. Variability in the gain and loss of cortical bone can be influenced by the frequency and degree of mechanical strain on bone, but age is noted as being the best determinant of cortical thickness. Males experience a hormone related decrease in cortical bone similar to age-related osteoporosis in females, but it is both less dramatic and not as well understood (Mays 2001, Niinimäki et al. 2013).

### **2.4.1 Cortical bone and age**

In adolescence, cortical bone mass is increased through the apposition of bone to both the endosteal and periosteal surfaces (Mays 2006). While severe dietary restrictions can increase osteoporosis in adults (Ortner 2003), poor nutrition is more likely to affect skeletal health in adolescence leading to a decrease in peak cortical bone mass (Mays 2001, 2006). This peak bone mass is achieved during the first 30 years of life and begins to decrease from that point on (Niinimäki et al. 2013). A shift in sex hormones occurs in males between the ages of 30-40 years (Argawal and Sharma 2013) which leads to cortical bone loss through the expansion of medullary cavity and trabecularization of cortical bone (Warden et al. 2014). Some extraneous factors have been noted to influence the severity of bone loss in men, including calcium deficiency and a sedentary lifestyle (Nguyen and Eisman 1999), which can cause an increase in age related bone loss and lead to variation in cortical thickness and loss within age groups. Vitamin D deficiency can also result in loss of cortical thickness. However, the individuals included in this sample did not present with any osteological evidence of this deficiency.

### **2.4.2 Cortical bone and activity**

Activity is also noted to influence both peak bone mass and age related bone loss. Multiple clinical studies have attempted to better understand how activity impacts cortical bone. Many note that activity during childhood and young adulthood leads to lasting benefits in bone structure (Bailey et al. 2010, Tveit et al. 2013, Warden et al. 2014). Although the cortical benefits of activity obtained during youth are gradually lost during old age, this can be mitigated though physical activity during adult years.

A study of same-sex twin adults who had a known discordance in physical activity was conducted to observe the influence of activity on bone while controlling for genetic variation as much as possible (Ma et al. 2009). This study noted that the most active of the twin pair had significantly thicker cortical bone and higher trabecular density than the less active twin, due physical activity during adulthood (Ma et al. 2009). This clearly supports the fact that bone thickness can increase or decrease with mechanical stimulation. This phenomenon, described by mechanostat theory, indicates that bone is adapted to a normal amount of stress and any stress that is greater or lesser than this amount will lead to an adaptive response in bone (Niinimäki et al. 2013).

A clinical study of baseball pitchers noted that players who continued throwing into their later adult years maintained better bone mass than those who did not (Warden et al. 2014). Preferential side use was also visible in these individuals through thicker cortical bone in their throwing arm, due to higher mechanical loading. It was also noted that after an individual stopped pitching, there was a rapid decrease in cortical thickness. The higher activity levels experienced by these athletes led to cortical benefits in both greater cortical thickness and a decrease in cortical bone loss. However, the greater the number of years that passed after an individual stopped pitching, the greater the loss of these cortical benefits (Warden et al. 2014).

Disuse of a body part and sedentary lifestyle, either through injury leading to decreased mobility or a decline in activity levels with time, are also noted to lead to increased bone loss. Upper limbs are especially sensitive to cortical loss through disuse as they lack the mechanical strain the lower limbs receive through weight bearing (Giannotti et al. 2013).

In general terms, the earlier the onset of physical activity and the more consistently it is maintained, the greater benefit to both bone strength and thickness in later years. Cortical bone thickness benefits most from short periods of activity with high rates of loading (Robling et al. 2002, Rhodes and Knüsel 2005). Dynamic bouts of activity prevent bone from desensitising to strain and lead to greater cortical benefits (Robling et al. 2002).

## **2.5 Current study of adult males from Lisieux-Michelet**

There are no contemporary sources describing the daily activities of the adult males from Lisieux-Michelet. Therefore, relative levels of activity and the effects of aging on the non-elite, adult male populace were examined using complementary methodologies: entheseal robusticity and cortical thickness. These data were compared to other previously studied populations in order to make inferences on the relative cortical health and muscle use in the Lisieux-Michelet sample. The cortical data were compared to a modern sample from Finland, which was mainly composed of industrial workers and manual labourers (Virtama and Helelä 1969) as well as to a group of wealthier 19th century males from Spitalfields, England (Mays 2001) in order to compare trends in bone loss. The entheseal robusticity measurements from this sample were compared to those taken from Dutch rural villagers, Neolithic farmers, and Natufian hunter-gatherers in order to compare tendencies in muscle use and make inferences about the levels of activity of the Lisieux-Michelet males.

Entheseal robusticity is also beneficial in explaining trends in cortical thickness within the Lisieux-Michelet sample and vice versa. A low increase in entheseal robusticity and a marked decrease in cortical bone between age groups would suggest an overall decrease in activity during this period. The combination of entheseal and cortical data is especially beneficial when comparing the age groups from the Lisieux-Michelet sample to other populations as entheseal development can help explain the variation in cortical thickness and rates of cortical bone loss relative to other studies in regards to the relative activity of this population.

# **CHAPTER 3.0 MATERIALS AND METHODS**

## **3.1 Materials**

The skeletal remains used in this study are drawn from the site of Lisieux-Michelet. Lisieux-Michelet was a necropolis associated with the Late Roman Empire city of *Noviomagus Lexovii* (Figure 2) which was excavated as part of a mitigation dig preceding the development of rue Joseph Guillonneau and the boulevard Duchesne-Fournet (Paillard et al. 2006). The skeletal remains were exhumed in the city of Lisieux located in the department of Calvados, France. Over 1,150 human remains were excavated from this site over the period of four years (1990, 1991,1992 and 1993). By the end of the 5th century, use of the necropolis dwindled and it contained virtually no burials until a brief resurgence during the 7th century (Paillard et al. 2006). These remains were stored at the University of Caen from the time of excavation until the time this thesis research was initiated during the summer of 2014.

### **3.1.1 Criteria for inclusion in the study**

The sample used in this study included only adult males whose skeletal remains had at least one humerus and one metacarpal in suitable condition for analysis.

* The shaft of the metacarpal could not have been fractured by post mortem damage and the end had to be intact so the midpoint could be measured for metacarpal radiogrammetry.
* The humerus had to have at least one of the entheses of the rotator cuff (deltoid, latissimus dorsi/teres major, pectoral).

The individuals assessed in this study were selected using the database provided by the University of Caen. The database included the estimated sex and age of the individual as well as a list of which bones were retrieved from the excavation.

The initial analysis of the recovered material done by the University of Caen was used as a reference for the sex of the individual. The individuals distinguished as male were reassessed using the age and sex methods chosen for this study; the results of this assessment agreed with the previous sex estimates provided by the University of Caen. Only individuals who were scored as “male” or “probable male” based on this reassessment were included in the current study.

This study aimed to examine only non-elite individuals present at the site of Lisieux-Michelet. It was previously noted that some individuals had grave goods of a quality that would indicate a more elite status (Paillard et al. 2006). The grave goods and type of inhumation were examined for each of the individuals used in this sample. All of them were buried in wooden coffins with either very simple or no grave goods which would suggest that these were non-elite individuals

Due to time constraints, some adult males could not be assessed; others were either held in private collections or at museums and were not available for study at the University of Caen. Other individuals were assessed but deemed unusable due to insufficient preservation (Table 1).

|  |  |  |  |
| --- | --- | --- | --- |
| **Adult Males from the Lisieux-Michelet Collection** | | | |
| **Total number** | Unassessed individuals | Assessed but unusable | Assessed and usable |
| 229 | 89 | 63 | 77 |

**Table 1** Breakdown of adult males assessed and unassessed in the Lisieux-Michelet sample

Based on information contained in an unpublished site report (Paillard n.d.) ten individuals in this sample may date to a period later than the Late Roman Empire (Appendix 1). To evaluate the impact of these ten individuals on the results, these individuals were removed from the sample and the results re-calculated (Appendix 4). The standard deviation decreased but the overall results were unaffected. As these possible non-Roman individuals did not alter the results, and given that the dating of the site may be revised in the future, the ten individuals were kept in the sample.

## **3.2 Sex estimation methods**

The possible sex of the individuals used in this study was assessed using both cranial and pelvic traits (Table 2) as outlined in Buikstra and Ubelaker (1994). Due to the generally fragmentary nature of cranial preservation, cranial traits were taken from either the right or left side depending on which was present; where possible, both sides were assessed. The pelvic traits were assessed on the left innominate. If this was unavailable, the right innominate was used.

|  |  |
| --- | --- |
| **Innominate** | **Cranium** |
| Ventral arc | Nuchal crest |
| Subpubic concavity | Mastoid process |
| Ischiopubic ramus ridge | Supraorbital margin |
| Greater sciatic notch | Glabella |
| Preauricular sulcus | Mental eminence |

**Table 2** Sex estimation traits based on Buikstra and Ubelaker (1994)

Based on the appearance of these traits, the individuals from Lisieux-Michelet were placed in five categories: female, probable female, ambiguous, probable male, or male. If the cranial and pelvic traits produced different sex estimates, the estimate provided by the pelvic assessment was used (Appendix 1.2) as the pelvis is considered a more reliable indicator of sex (Buikstra and Ubelaker 2004).

## **3.3 Age estimation methods**

Multiple macroscopic approaches were used to estimate the age of these individuals in order to account for the differential levels of preservation and degree of skeletal recovery. Using these macroscopic techniques, the males chosen for this sample were divided into three categories: young adult (20-34), middle adult (35-49), and old adult (50 and older) following Buikstra and Ubelaker’s age classification system (1994). As noted in Section 2.2.1 page 9, males in the Roman Empire began their transition into adulthood around the age of 15. Individuals under the age of 20 were not included in this sample due to the high degrees of variation in cortical thickness that result from bone development before this age. By examining only adults who were close to achieving peak cortical mass or who had already achieved it, this study could limit this source of variation in the young adult age category.

### **3.3.1 Epiphyseal fusion**

Epiphyseal fusion is only an effective method of age estimation for adolescents or young adults. The timing of epiphyseal fusion followed in this analysis is based on the epiphyseal fusion methodology by Cardoso (2008 a,b). Unlike the other methods used in this study that rely on cranial or pelvis traits, epiphyseal fusion can be used across the skeleton, which facilitates age estimation in less complete individuals. The epiphyses selected for in the Social-Cultural Determinants of Community Wellbeing in the Western Roman Empire: Analysis and Interpretation of Vitamin D Status project were also used for this study (Table 3). The epiphyseal fusion observations recorded in this study were used in conjunction with other aging methods to identify individuals who fell within the earlier portion of the young adult age category.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Bone** | Femur | Tibia | Humerus | Radius | Pelvis | Clavicle |
| **Epiphyses** | proximal epiphysis | proximal epiphysis | proximal epiphysis | proximal epiphysis | iliac crest | sternal epiphysis |
| greater  trochanter | distal epiphysis | distal epiphysis | distal epiphysis | ischial epiphysis |  |
| lesser trochanter |  | medial epicondyle |  |  |  |
| distal epiphysis |  |  |  |  |  |

**Table 3** List of bones and epiphyses used for the epiphyseal fusion age estimation method.

### **3.3.2 Dental wear analysis**

Dental wear analysis was used to assess the age of the individuals in this sample. This method was applied whenever there were molars present by visually comparing the teeth to Brothwell’s (1981) dental wear scoring chart. This method was effective for all three of the age categories but was less effective for individuals with excessive antemortem or post depositional tooth loss.

This method, however, was problematic for individuals who might fall into the older adult category. The likelihood of antemortem tooth loss increases with age, which limits the observability of dental wear (Mays 2014). Dental wear analysis was only used to assign an age category to individuals who had two molars that were in occlusion; non-articulating molars were deemed unreliable as the wear would produce a younger age estimate if the molar did not have another tooth to wear against. Individuals with advanced antemortem tooth loss who were scored as old adults by the dental wear aging method were examined against pelvic ages in order to confirm that they were in fact old adults.

### **3.3.3 Pubic symphysis analysis**

The Suchey-Brooks methodology (Brooks and Suchey 1990) is one of two pelvic scoring methods used in this study. For the sake of expediency, only one pubic symphysis was scored per individual; the left side was primarily selected but if the left side was absent, the right was used.

### **3.3.4 Transition analysis of the auricular surface**

Transition analysis was used to score the features of the auricular surface of the innominate based on the methodology developed by Boldsen et al. (2002). This technique produces both point estimates and age intervals which are based on auricular morphology in previously known population age at death distributions. The age interval provides a 95% confidence interval while the point estimate represents the maximum likelihood estimate (Milner and Bolden 2012). As many of the pelvic bones in the Lisieux-Michelet collection were glued together, they had to be separated using acetone to expose the auricular surface. After the auricular surface was washed with acetone, tweezers were used to remove the remaining adhesive so that the traits of the characteristics of the auricular surface could be examined. The removal of the adhesive was non-destructive and did not affect aging estimates. However, many of the auricular surfaces analysed for aging were damaged and incomplete, which may have in part contributed to the wide age ranges in the Lisieux-Michelet sample.

### **3.3.4 Conflicts in aging methods**

It was noted that the age estimates provided by the three methods used in this study often produce discordant results (Appendix 1.1). In these situations, the methods were ranked based on their consistency of the age indicator and the size of the age intervals provided. Still fusing epiphyses were used to assign individuals to the young adult age category. When epiphyses were fused or not present, dental wear analysis was given priority.

If dental wear was not viable as an aging method, pubic symphysis analysis was used and finally, transition analysis when all other methods were unavailable. The other methods were considered more accurate than transition analysis as the point estimates produced by this method have low accuracy. Milner and Boldsen note that transition analysis is beneficial in providing a general sense of the age at death distribution within an archaeological sample but suffers from inaccuracy and imprecision especially in the case of individuals whose age at death falls between 40 and 70 years of age (2012).

These aging methods often produce age ranges that overlap two or more of the adult age categories used in this study. In these instances, the most likely age estimate was determined by comparing the age range each method provided and estimating which age into which the individual was most likely to fall. For instance, if an individual presented with dental aging that spanned both the young and middle adult age category, but the pubic symphysis score suggested it was middle adult, the individual’s age would be recorded as middle adult.

## **3.5 Entheseal scoring methodology**

There are several different methodologies used to examine changes that occur at an enthesis that are all based around a visual reference system and ordinal scoring. One of the earliest methodologies used to examine entheses in archaeological bone was developed by Hawkey and Merbs (1995) which measured robusticity, stress, and ossification on a three point scale (faint, moderate, and severe). This method used the same criteria for every enthesis regardless of morphology. The entheseal characteristics that were scored in this methodology were somewhat arbitrary as they did not reflect the mechanics of entheseal development or account for variations in entheseal morphology; this resulted in high interobserver error (Davis et al. 2013).

Ordinal methods like the one developed by Hawkey and Merbs make it difficult to account for individuals who fall between scoring categories. The range of subtle variations that can occur in entheseal development might be better accounted for with a ratio scale. However, the qualitative nature of entheseal development does not lend itself well to ratio measurement (Mariotti et al. 2004).

A later method developed by Villotte (2006) attempted to take this variation into account by including modern anatomical and histological information regarding entheseal morphology in the ordinal scoring system. This methodology differentiates between fibrocartilagenous and fibrous entheses as the morphological variation and differences in mechanical properties alter the appearance and development at the site of attachment (Villotte 2006, Villotte and Knüsel 2013). The scoring system separates entheses into four categories including three fibrcartilagenous groups and one for fibrous entheses (Villotte 2006). Each category is scored using a different ordinal system that is attuned to different entheseal features present in each category. This method is well developed to assess the morphology of fibrocartilagenous entheses but is not as strong at assessing fibrous entheses (Havelkova and Villotte 2007).

This study employed the method used to analyse the robusticity and enthesopathies present at the muscle attachment sites of the rotator cuff was developed by Mariotti et al. (2004, 2007). The humeri were assessed macroscopically and photographed for future reference. The entheseal robusticity of the deltoid, pectoral, and LDTM attachment sites was given a score using Mariotti et al.’s (2004, 2007) five point system and this was recorded on a fillable PDF (Appendix 2.1).

The entheseal scoring method used in this study was developed by Mariotti et al. (2004, 2007). The method employs a five point ordinal scoring system that can be reduced to a three point system in order to reduce user error. The first three scores (1a, 1b, 1c) all correspond to mild robusticity and deal with subtle variations in entheseal development and thus can easily be combined into one score. This scoring system uses the same five or three point scale for all the postcranial entheses examined by the authors, but it accounts for morphological variation in these entheses by providing detailed descriptions of what type of development corresponds with each score as well as high definition photographs of each stage of entheseal development. These photos highlight the differences in development at each individual attachment site (Mariotti et al. 2004, 2007).

The post cranial entheses used in Mariotti et al.’s (2004, 2007) method of entheseal analysis include the three muscle attachment sites used in this study: pectoral, deltoid, and latissimus dorsii/teres major (LDTM). This system does not have a differentiation in scoring systems based on whether an enthesis is fibrous or fibrocartilagenous. However, all the entheses used in the study of the Lisieux-Michelet males are fibrous and this differentiation is not necessary.

The entheseal robusticity was scored using both the three and five point scale. The five point system presented with higher inter and intraobserver error but the three point system was not as sensitive to variability in entheseal development (Appendix 5) which is why the five point system was used in this sample.

### **3.5.1 Inter and intraobserver error**

The proposed standardized methodology for entheseal scoring proposed by Mariotti et al. (2004, 2007) was selected for this study based on the simplicity and expediency of the scoring method and its applicability to fibrous entheses. Earlier methods used for entheseal scoring are noted to improperly represent the mechanics of muscle activity on bone and suffer heavily from intra- and inter-observer error (Davis et al. 2013). The method developed by Mariotti et al. (2004, 2007) was tested on the muscle insertion sites used in this study. The reproducibility of the results produced by this method were tested by Mariotti and colleagues and were found to have intra- and inter-observer rates between 5% -28% (Davis et al. 2013; Mariotti et al. 2004, 2007). The entheseal scoring method developed by Villotte (2006) has slightly lower intra- and inter-observer rates of 5%-15%. However, this method primarily focuses on fibrocartilagenous entheses while the current study examines fibrous entheses. Based on the background research conducted for this study, there are no published evaluations of "acceptable" levels of observer error for entheseal scoring methodologies. None of the papers consulted for this thesis discuss the problem of acceptable levels of error. This is clearly an important question that warrants future research.

Inter-observer error for this study was tested using ten pairs of humeri from the Lisieux-Michelet collection and four different observers. One observer was the author of this study while the other three were osteologists who had no previous experience using Mariotti et al.’s (2007) methodology for entheseal scoring. The intra-observer error was tested using fifteen individuals from the Lisieux-Michelet collection that were scored by the same observer on two separate occasions. The collected observer data were transferred onto a table in order to compare the observer disagreement for each enthesis (Appendix 3).

## **3.6 Metacarpal radiogrammetry**

Metacarpal radiogrammetry is a technique to measure cortical bone and identify thinning related to osteoporosis. Using radiographs, the width of the medullary cavity (M) is taken and subtracted from the overall width of metacarpal (T) to determine cortical thickness in accordance to the methods laid out in Ives and Brickley (2004). The cortical index (CI) can be calculated using the equation:

CI=

This calculation provides the percentage of the metacarpal that is composed by cortical bone.

Metacarpal radiogrammetry was first used to monitor cortical bone in a clinical setting in the 1960s. This method is also useful in archaeological studies of bone as it is relatively simple and non-destructive (Ives and Brickley 2004, 2005). The second metacarpal is useful for this technique as it is the largest bone in the hand and is easily positioned on radiographs to mimic the orientation of the bone in a living individual (Ives and Brickley 2004). The metacarpal cortical index is an effective indicator of cortical thickness in the hip, spine, forearm, and the total body bone mineral content which makes it valuable for monitoring overall bone loss in archaeological skeletal material (Mays 2006).

Cortical thickness was assessed using metacarpal radiogrammetry as outlined by Ives and Brickley (2004). The metacarpals were radiographed at the Centre Sadi Carnot using a MULTIX DR (serial number R034179). Both right and left metacarpals were radiographed unless one was missing or damaged. The metacarpals were marked with lead numbers to identify bones from each individual.

The measurements for metacarpal radiogrammetry were taken using Mastercraft electrical calipers with digital display. The measurements were taken using millimeters with two decimal places. The radiographs were placed on a light box and covered with an acetate sheet to prevent damage from the calipers.

## **3.7 Bilateral Asymmetry**

Although bilateral asymmetry was not the focus of this study, it was taken into account as it may affect both cortical thickness and entheseal robusticity. The maximum length of the humerus was taken using the standards set out by Buikstra and Ubelaker (1994), which is measured from the most superior point on the head of the humerus to the most inferior point of the trochlea. Other researchers have also taken the maximum diameter at the midshaft as well as the epichondylar width (Blackburn 2011, Steele and Mays 1995). However, the sample of humeri from Lisiuex-Michelet suffered extensive cortical wear and width measurements would be unreliable in many cases.

## **3.8 Recording methodology**

In order to maintain consistent data, information from the individuals was recorded on fillable PDF forms. Permission was received to use the forms for recording age and sex which were designed by Dr. Megan Brickley and Dr. Tracy Prowse for their study of vitamin D deficiency (Appendix 2.2). Fillable forms were also designed to collect data on the entheses and the measurements used to account for bilateral asymmetry (Appendix 2.1). These forms were designed to expedite recording and to be easily transferred into an Excel table for analysis. This was especially useful in order to compare the results from the multiple methods of sex estimation.

## **3.9 Statistical Methodology**

The descriptive statistics and correlation between the factors observed in this study were calculated using IMB SPSS Statistics 22. Pearson’s correlation, which measures the linear relationship between two ratio values, was used to calculate the relationship between humeral length and cortical thickness as both these variables are measured on a ratio scale. The strength of the correlation between two values is expressed in both an r value and a p-value (Table 4, 5). Spearman’s correlation, which measures the nonparametric relationship between two variables, was used to calculate the relationships involving entheseal robusticity in order to account for the combination of ratio and ordinal measurements. The method also produces a p-value as well as an r5 value.

|  |  |
| --- | --- |
| **r or r5 value** | **Strength of correlation** |
| 0.00-0.19 | very weak |
| 0.20-0.39 | weak |
| 0.40-0.59 | moderate |
| 0.60-0.79 | strong |
| 0.80-1.00 | very strong |

**Table 4** Strength of correlation as represented by Spearman’s and Pearson’s correlation

|  |  |
| --- | --- |
| **p-value** | **Strength of correlation** |
| +1 | Perfect positive relationship |
| -1 | Perfect negative relationship |
| ≤0.05 | Significant correlation |
| 0 | Complete absence of correlation |

**Table 5** Strength of correlation as defined by p-values

# **CHAPTER 4.0 RESULTS**

## **4.1 Introduction**

The descriptive statistics presented in this chapter separate the variables of this study (entheseal robusticity, cortical thickness, and humeral length) by side and age category. These variables are then put together in a correlation analysis which combines side, age category, and variables to check for significant relationships between the studied elements.

## **4.2 Observer error for entheseal scoring**

The calculation of inter- and intra-observer error helps assess the validity of a scoring method by testing the reproducibility of its results. If a methodology produces high levels of error, it implies that the methodology is inconsistent and the results are unreliable. The inter-observer testing of the methodology developed by Mariotti et al. reported error rates of 5-28% (2004, 2007). Mariotti et al. (2004) noted that reducing this system from a five point scoring system to a three point system reduces the amount of error caused by the minor variations between the first three scores (1a, b, c). Inter and intra-observer agreement for the Lisieux-Michelet was assessed with both the five point and three point scoring system. The observer error was calculated separately for each enthesis as well as the total error for each test.

The inter- and intra-observer error rates for this study were higher than the observer error rates noted by Mariotti et al. (2007). Even when reduced to the three point scoring system, the observer error rates still fell at the high end of the previously noted levels of error. This discrepancy is probably due to different levels of experience with this scoring methodology. The authors that developed this methodology likely produced lower rates of error because they had greater experience with this methodology and the entheseal traits that were scored relative to the observers who scored the Lisieux-Michelet material.

### **4.2.1 Inter-observer error for entheseal scoring**

Inter-observer error was tested using ten pairs of humeri (a total of 20 humeri). The results were tabulated and compared to each other to note observer disagreement for each entheses (Appendix 3.1, 3.2). The initial results showed 39% observer error when scoring entheseal robusticity of the ten pairs of humeri (Table 6). Scoring disagreement for the pectoral and LDTM was similar and there was a higher observer error noted on the scoring of the deltoid.

|  |  |
| --- | --- |
| **Enthesis** | **Percent error** |
| Deltoid | 45% |
| LDTM | 33% |
| Pectoral | 39% |
| **Total error** | **39%** |

**Table 6** Inter-observer error assessed with the five point scoring system

Using the three point scoring method, the overall inter-observer error for the same sample of humeri was reduced by 20% (Table 7). The observer error for the pectoral was highest in the second assessment while the inter-observer error for the deltoid was reduced by 29% and presented the lowest level of observer disagreement. This suggests that the more robust stages of entheseal development for the deltoid are easy to differentiate while the early stages are not.

|  |  |
| --- | --- |
| **Enthesis** | **Percent error** |
| Deltoid | 16% |
| LDTM | 18% |
| Pectoral | 24% |
| **Total error** | **19%** |

**Table 7** Inter-observer error assessed with the three point scoring system

### **4.2.2 Intra-observer error for entheseal scoring**

Intra-observer error was tested using two separate samples. The first sample consisted of five pairs of humeri and was conducted at the beginning of the study with an intra-observer disagreement of 43% (Table 8). The second intra-observer test used ten different pairs of humeri and was conducted near the end of the study. This test resulted in an intra-observer disagreement of 37%. In both tests the assessment of the pectoral enthesis had the lowest level of intra-observer disagreement at 30%.

The intra-observer error was reassessed using the three point scale. The error for the first test was reduced to 20% and the error of the second test was reduced to 17% (Table 9). The enthesis of the LDTM had the least intra-observer error in both tests with an intra-observer disagreement of 10%.

|  |  |  |
| --- | --- | --- |
| **Enthesis** | **Test 1** | **Test 2** |
| Deltoid | 50% | 50% |
| LDTM | 50% | 30% |
| Pectoral | 30% | 30% |
| **Total error** | **43%** | **37%** |

**Table 8** Intra-observer error assessed with the five point scoring system

|  |  |  |
| --- | --- | --- |
| **Enthesis** | **Test 1** | **Test 2** |
| Deltoid | 30% | 20% |
| LDTM | 10% | 10% |
| Pectoral | 20% | 20% |
| **Total error** | **20%** | **17%** |

**Table 9** Intra-observer error assessed with the three point scoring system

## **4.3 Descriptive statistics**

The data from this study were input into IMB SPSS Statistics 22 in order to determine the mean, mode, and standard deviation of the collected data. Entheseal robusticity, humeral length, and the cortical index were separated by age group to produce descriptive statistics.

### **4.3.1 Metacarpal radiogrammetry**

Table 10 summarizes the radiogrammetric measurements used to produce the cortical index. There is no consistent relationship between age and the total width of the metacarpal. However, all other mean measurements link consistently to age; medullary width increases with age while cortical thickness and index decrease. The minimum, maximum, and median of the cortical index also decrease consistently with age for

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Total width (mm)** | | | | **Medullary width**  **(mm)** | | | | **Cortical thickness**  **(mm)** | | | | **Cortical Index** | | | |
|  | **Left** | | **Right** | | **Left** | | **Right** | | **Left** | | **Right** | | **Left** | | **Right** | |
| **Age Group** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** |
| Young adult | 8.72 | 0.94 | 8.24 | 0.77 | 4.08 | 0.79 | 3.52 | 0.95 | 4.64 | 0.61 | 4.59 | 0.59 | 53.5 | 6.21 | 55.8 | 6.18 |
| Middle Adult | 8.57 | 0.81 | 8.16 | 0.85 | 4.26 | 0.81 | 3.31 | 1.59 | 4.31 | 0.64 | 4.28 | 0.60 | 50.4 | 7.21 | 52.9 | 7.08 |
| Old adult | 8.64 | 0.83 | 8.32 | 0.65 | 4.36 | 0.76 | 4.07 | 0.74 | 4.29 | 0.64 | 4.24 | 0.76 | 49.7 | 6.66 | 51.1 | 8.35 |
| Undetermined | 8.46 | 0.00 | - | - | 3.83 | 0.00 | - | - | 4.63 | 0.00 | - | - | 54.8 | 0.00 | - | - |

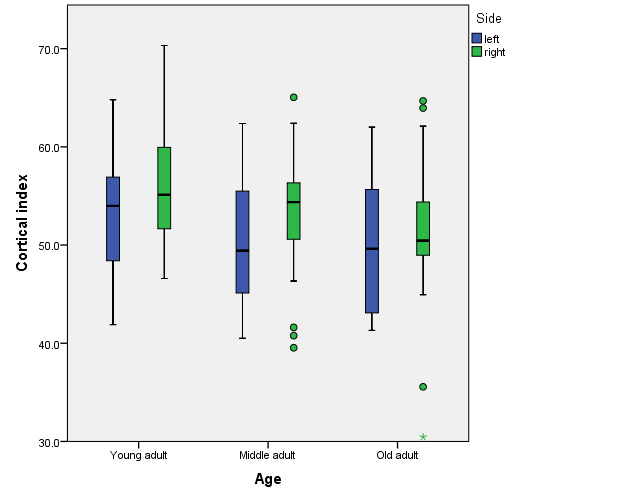
**Table 10** Comparison of metacarpal radiogrammetric measurements in relation to estimated age at death

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Age group** | **Side** | **Number** | **Minimum** | **Maximum** | **Mean** | **Median** | **Standard deviation** |
| Young | Left | 21 | 41.9 | 64.8 | 53.5 | 54.0 | 6.21 |
| Right | 26 | 46.6 | 70.3 | 55.8 | 55.1 | 6.18 |
| Middle | Left | 15 | 40.5 | 62.4 | 50.4 | 49.4 | 7.21 |
| Right | 18 | 39.5 | 65.0 | 52.9 | 54.2 | 7.08 |
| Old | Left | 23 | 41.3 | 62.0 | 49.7 | 49.6 | 6.66 |
| Right | 20 | 30.5 | 64.7 | 51.1 | 50.5 | 8.34 |
| Undetermined | Left | 1 | 54.8 | 54.8 | 54.8 | 54.8 | - |
| Right | - | - | - | - | - | - |

**Table 11** Cortical index frequencies from the Lisieux-Michelet sample

both the right and left side (Table 11). The mean and median cortical index are higher for the right side than the left across all age groups.

The old adult age group has the greatest similarity in mean and median cortical index results for the right and left sides. Both the middle and old adult age categories present with outliers while the young adult category does not. The mean, median, and maximum are consistently higher for the right side but the minimum for middle and older adults is higher on the left side. Figure 4 also shows that the cortical index of the right side is consistently higher than the left in all of the age groups. The cortical index for the right side of the middle and old age groups also has the highest number of outliers.



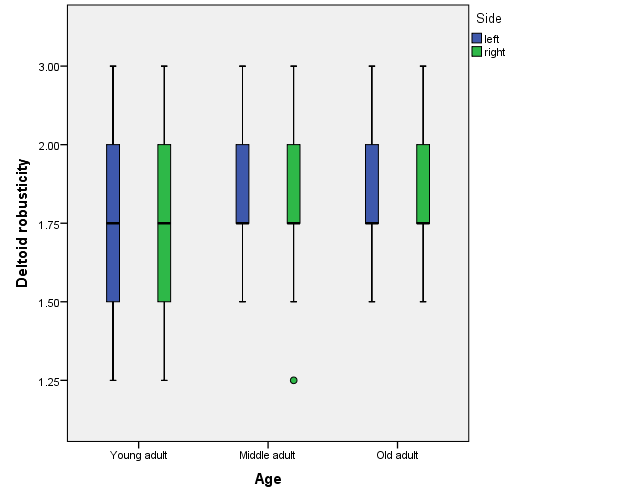
**Figure 4** Cortical index results in relation to age category. Asterisks denote extreme outliers.

### **4.3.2 Entheseal robusticity**

The ordinal categories in the scoring system developed by Mariotti et al. (2007) that contained letters (1a, 1b, 1c) were converted into numbers (1.25, 1.5, 1.75) so they could be assessed using SPSS. Figures 5, 6, and 7 show the robusticity distributions for the deltoid, LDTM, and pectoral respectively. The mean and median of the right side are generally slightly higher than the left except for five instances highlighted in green (Table 12). The mean and median of the pectoral are consistently higher for the right side. They are generally higher on the left side as well except for the young adult age group. The upper quartile range is also highest for the pectoral (Figure 7). The standard deviation of the right side is lowest for the LDTM in each age group.

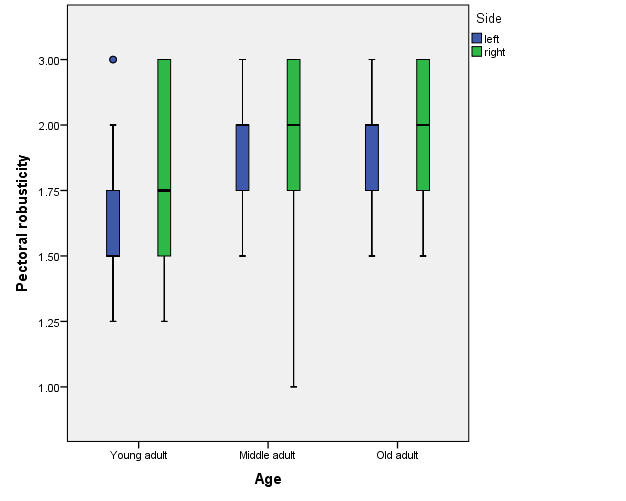
|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Age group** | **Enthesis** | **Number of observable entheses** | | **Mean** | | **Median** | | **Standard deviation** | |
| Left | Right | Left | Right | Left | Right | Left | Right |
| Young | Deltoid | 27 | 24 | 1.75 | 1.76 | 1.75 | 1.75 | 0.45 | 0.37 |
| LDTM | 25 | 21 | 1.65 | 1.63 | 1.63 | 1.50 | 0.38 | 0.42 |
| Pectoral | 24 | 25 | 1.74 | 1.98 | 1.50 | 1.75 | 0.43 | 0.62 |
| Middle | Deltoid | 15 | 19 | 2.02 | 1.86 | 1.75 | 1.75 | 0.53 | 0.35 |
| LDTM | 19 | 19 | 1.82 | 1.86 | 1.75 | 1.75 | 0.36 | 0.47 |
| Pectoral | 18 | 20 | 2.03 | 2.34 | 2.00 | 2.00 | 0.48 | 0.63 |
| Old | Deltoid | 23 | 24 | 1.99 | 2.04 | 1.75 | 1.88 | 0.51 | 0.53 |
| LDTM | 23 | 23 | 2.09 | 1.91 | 2.00 | 1.75 | 0.51 | 0.49 |
| Pectoral | 22 | 22 | 2.10 | 2.25 | 2.00 | 2.00 | 0.53 | 0.68 |

**Table 12** Entheseal robusticity calculated to account for differential limb use. Instances where mean or median is greater on the left side rather than the right are highlighted in green.



**Figure 5** Deltoid robusticity in relation to age category

**Figure 6** LDTM robusticity in relation to age category



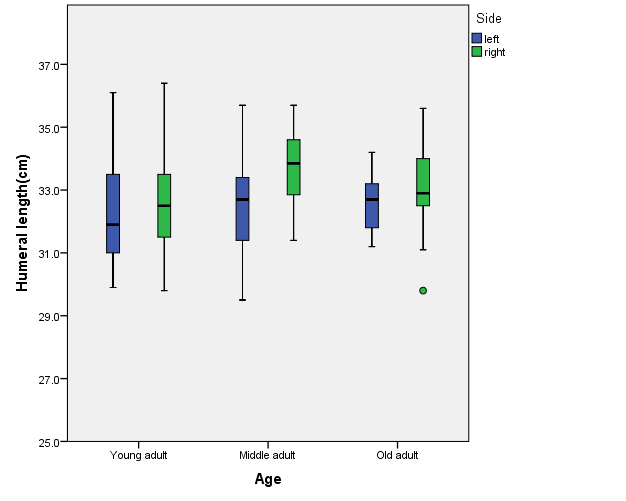
**Figure 7** Pectoral robusticity in relation to age category

### **4.3.3 Humeral length**

The humeral length measurements from the Lisieux-Michelet sample do not increase or decrease consistently in relation to age (Table 13). The mean and median on the right side are generally slightly higher than those on the left suggesting slight preferential use of the right side. However, the overlap between the measurements of the right and left side (Figure 8) that is present in humeral length as well as the cortical and entheseal measurements demonstrates that there are no significant bilateral differences for the Lisieux-Michelet sample.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Age group** | **Side** | **Number of measurable humeri** | **Mean** | **Median** | **Standard deviation** |
| Young | Left | 22 | 32.4 | 32.0 | 1.76 |
| Right | 23 | 32.6 | 32.6 | 1.61 |
| Middle | Left | 15 | 32.2 | 32.7 | 1.72 |
| Right | 10 | 33.5 | 33.7 | 1.30 |
| Old | Left | 14 | 32.6 | 32.9 | 1.00 |
| Right | 18 | 33.3 | 33.0 | 1.58 |

**Table 13** Humeral length measurements from the Lisieux-Michelet sample (length measured in cm)



**Figure 8** Humeral length in relation to age category

## **4.4 Correlation**

Spearman’s correlation coefficient was used to measure any correlation involving entheseal robusticity as this factor is measured using an ordinal scale and all other factors used in this study are measured using ratio values. The correlation between the cortical index and humeral length was calculated with Pearson’s correlation as both these variables produce ratio values. Positive r or r5 values represent a relationship where the increase or decrease of one variable is correlated to the same response in the other variable; for example, a decrease in cortical index is correlated with a decrease in humeral length. Negative r or r5 values indicate that there is a correlation between the increase of one variable and the decrease of the other. Both methods also measure the linear relationships between two variables using a p-value that produces a score between +1 and -1. A perfect positive relationship is indicated by a score of +1 while a perfect negative relationship is indicated by -1. If there is a complete absence of correlation between the two variables, the score will be 0. A significant correlation is indicated by a p-value of ≤0.05 (Table 5).

### **4.4.1 Correlation of entheseal robusticity and cortical index**

The correlation between entheseal robusticity and cortical index is very weak to weak, with consistently non-significant p-values (Table 14). The level of correlation is consistently the least significant for both p and r5 value in the young adult age group.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Age group** | **Deltoid** | | **LDTM** | | **Pectoral** | |
|  | rs | p | rs | p | rs | p |
| Young | -0.002 | 0.989 | -0.020 | 0.901 | 0.110 | 0.489 |
| Middle | -0.312 | 0.093 | -0.214 | 0.232 | -0.217 | 0.225 |
| Old | -0.055 | 0.744 | -0.034 | 0.840 | -0.266 | 0.122 |
| Age Independent | -0.136 | 0.154 | -0.193 | 0.044 | -0.167 | 0.081 |

**Table 14** Correlation of entheseal robusticity and cortical index using Spearman’s correlation coefficient (rs)

### **4.4.2 Correlation of cortical index and humeral length**

The correlation between the cortical index and humeral length as represented by the r value is very weak in all age groups and the p-value is non-significant. The majority of the correlations in this assessment are positive with the exception of the young adult age group (Table 15).

|  |  |  |
| --- | --- | --- |
| **Age group** | **Correlation** | |
|  | r | P |
| Young | -0.050 | 0.767 |
| Middle | 0.185 | 0.409 |
| Old | 0.088 | 0.683 |
| Age independent | 0.025 | 0.821 |

**Table 15** Correlation of cortical index and humeral length using Pearson’s correlation coefficient (r)

### **4.4.3 Correlation of entheseal robusticity and humeral length**

The correlation between entheseal robusticity and humeral length has very weak to moderate significance (Table 16). A significant p-value (p≤ 0.05), which indicates a moderate correlation, is noted for one enthesis in each age category. The pectoral presents with a moderate negative correlation for young adults, the deltoid in the middle adult category has a moderate positive correlation, and the LDTM in the old adult category has a moderate negative correlation. The correlation between humeral length and entheseal robusticity is generally negative except for the deltoid and pectoral of the middle adult group.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Age group** | **Deltoid** | | **LDTM** | | **Pectoral** | |
|  | r5 | p | r5 | p | r5 | p |
| Young | -0.144 | 0.369 | -0.189 | 0.248 | -0.333 | 0.038 |
| Middle | 0.397 | 0.045 | -0.370 | 0.057 | 0.306 | 0.120 |
| Old | -0.320 | 0.111 | -0.488 | 0.011 | -0.174 | 0.427 |
| Age Independent | -0.016 | 0.879 | -0.195 | 0.061 | -0.048 | 0.652 |

**Table 16** Correlation of entheseal robusticity and humeral length using Spearman’s correlation coefficient (rs). Correlations with significant p-value are highlighted in green.

# **CHAPTER 5.0 DISCUSSION**

## **5.1 Trends found in Lisieux-Michelet compared to other studied populations**

Examining trends in cortical thickness and entheses can reveal both age and activity related patterns within the population of Lisieux-Michelet. Although cortical thickness is influenced most consistently by age, the activity related variation within age groups can be explained by entheseal data which is primarily influenced by activity.

When examined on its own, the data from Lisieux-Michelet provides limited insight into the levels of activity experienced by the adult males of this sample. However, when these data are compared to the findings for other populations, both archaeological and modern, the trends in cortical thickness for Lisieux-Michelet are more informative about activity levels. Although many of the studies used for comparison to the Lisieux-Michelet findings employed different age categories, and the ordinal entheseal scoring methods differ between studies, it is still possible to compare general cortical and entheseal trends between populations.

### **5.1.1 Trends in cortical thickness**

Previous studies of cortical thickness in archaeological bone have noted that young adults have much higher cortical thickness than older adults (Mays 2001, Mays 2006, Niinimäki et al. 2013).This holds true for the Lisieux-Michelet sample as the young adult age category has the highest cortical thickness and cortical index. Peak bone mass is achieved during the first 30 years of life (Niinimäki et al. 2013), which would lead to much higher cortical thickness in this age group compared to the others. The young adult age category also has the lowest amount of cortical variation. Variation in the group could be due to differing levels of cortical development; some individuals may have reached peak bone mass while others are still developing. It is likely that activity and past nutritional history are important sources of the variation found within this age category, although the lack of low outliers in the young age category suggests that nutritional deficiencies were not a major problem in this population. The levels of activity present in this age group would also influence variability in the older age groups, as differential levels of activity would influence variation in peak bone thickness as well the rate of age related bone loss.

The outliers present in the old adult group (Figure 4) are likely due to the presence of particularly frail or robust individuals in this category. It is unlikely that these low outliers were the oldest individuals in this sample as the osteological age estimates for these males do not suggest that these outliers are older than the other individuals in this age category. Exostoses present on the posterior surface are generally indicative of older age, and have been termed an “old age” trait (Milner and Boldsen 2012: 107). The posterior portion of the auricular surface required to score this old age trait was missing and could not be scored for all the low outliers. In fact, the pubic symphysis analysis of one of the two low outliers suggested that this individual fell at the younger end of the old age category. It is possible that the exceptionally low cortical measurements for these individuals was not linked to old age, but resulted from prolonged immobility leading to increased cortical loss or from other factors, such as reduced activity in adolescence or the lasting effects of poor childhood nutrition.

The Lisieux sample was compared to a population of 18th-19th century British site of Spitalfields (Mays 2001) and a modern study of Finnish labourers (Virtama and Helelä 1969). The cortical thickness of Lisieux-Michelet was higher than the Spitalfields sample but lower than the Finnish group across all age groups. The Spitalfields sample is slightly biased towards wealthier individuals and includes individuals who engaged in non-manual occupations (Mays 2001) which may be why the Lisieux-Michelet sample exhibits higher levels of cortical thickness across all ages. The sample from Lisieux-Michelet may have included individuals from non-manual occupations but the adult males from this sample were likely mainly manual labours. The higher levels of physical activity from these occupations would produce higher levels in cortical thickness than the Spitalfields group and a slower decrease in cortical thickness over time. This might also be in part due to nutritional factors but Mays notes that the diet of the Spitalfields males was likely not deficient in calcium (2001). Diet may have contributed to the cortical differences between the Lisieux-Michelet and Spitalfields samples but different levels of physical activity were probably influential in creating the disparities in cortical thickness between these populations.

The thicker cortical bone noted in the modern Finnish population might be in part due to the fact that, unlike the individuals from the Lisieux-Michelet and Spitalfields samples, the cortical thickness measurements from the modern population were taken from living individuals. This might be a possible source of disagreement between the samples as still living individuals would not experience the circumstances or stresses that led to the death of the adult males from the archaeological populations.

### **5.1.2 Trends in entheseal robusticity**

Previous studies of entheseal development have stated that entheseal robusticity is influenced to some degree by morphology, activity, and age. The entheses of the Lisieux-Michelet sample were examined in regards to the general level of development within the sample rather than in relation to a specific occupation or activity. This study of the Lisieux-Michelet sample examines entheseal development produced by both occupational and non-occupational activities. This allows for the comparison of relative levels of entheseal development between Lisieux-Michelet and other populations. The robusticity of entheses is influenced by repetitive and regular mechanical strain (Benjamin and McGonagle 2009, Cardoso and Henderson 2010) and this process of mechanical loading over a longer period of time would produce a more robust enthesis thus resulting in increased entheseal robusticity with age.

The entheses examined in this study of Lisieux-Michelet males show some similar trends in muscle development when compared to populations of adult males from a study of 19th century Dutch rural villagers (Palmer et al. 2014), Natufian hunter-gatherers (13,000-11,000 BC), and Neolithic farmers (8,000-6,000 BC) (Eshed et al. 2004). Similar to Lisieux-Michelet, these studies note that the pectoral produces higher robusticity scores than the other muscles of the rotator cuff. This is likely due in part to the constant, mild strain the muscle undergoes in relation to the passive activity of holding the arm next to the body (see Section 2.3.1.1 page 13). All these studies also noted that the LDTM enthesis demonstrated relatively low development compared to other entheses despite the strenuous manual labour undertaken by these groups (Eshed et al. 2004, Palmer et al. 2014).

The entheseal trends from Lisieux-Michelet were most similar to the 19th century Dutch rural villagers. The deltoid entheses observed in the Lisieux-Michelet males presented with relatively low scores across all age categories and reach a plateau in middle adulthood. Palmer et al. (2014) also noted low development of the deltoid in their study of 19th century Dutch villagers similar to that of the Lisieux-Michelet sample. The deltoid had the second lowest score of robusticity when compared to the latissimus dorsii/teres major, brachioradialis, and pectoral. The study of the Natufian hunter-gatherers and Neolithic farmers presented with greater deltoid robusticity; the Neolithic farmers had especially high deltoid scores. Although they may have engaged in different trades, the working conditions of the Dutch farmers and Roman labourers would likely have been more similar to each other than to the Neolithic or Natufian populations due to the technologies available. The Neolithic and Dutch sample both represent farming groups but due to the cultural differences between this early farming group and the later European sample, the level of physical strain and duration of heavy manual labour over an individual’s life span may have been more similar between the Dutch sample and Lisieux-Michelet.

### **5.1.3 Changes between the young to middle adult category**

The young adult age category has the lowest entheseal robusticity scores for the deltoid, latissimus dorsii/teres major (LDTM), and pectoral. Entheseal development at this earlier stage in life would be more limited as mechanical stress has not had as long to act on the entheses. The greatest inter-group increase in robusticity is seen between the young and middle adult age categories which is likely due to differences in the combination of activity and age related bone development between these ages. The entheses in the young age group may have had regular mechanical stress applied to them as younger individuals are usually active. It is likely that the adult male population of Lisieux-Michelet was primarily composed of manual labourers which would result in regular physical strain beginning in early adulthood. The increased robusticity in the middle adult age category is likely reflective of this physical strain enacted on entheses over a greater period of time. The less marked increase in robusticity between the middle and old adult age categories is likely due to the fact that there was likely an occupation-related decrease in activity between these two age categories.

The decrease in cortical thickness between the young and middle age categories likely reflects a decrease in activity that occurs in the middle adult group. A modern study notes that while activity promotes bone health in later years, there is a marked osteological remodeling following a cessation or significant decrease in physical activity, leading to a widening of the medullary cavity (Warden et al. 2014). The greater bone loss between the young and old adult age categories from Lisieux-Michelet might be in part due to this process. In a study of adult males involved in trade occupations, Mays (2001) notes that after an individual obtains a certain level of experience in their occupation, they may shift from heavy manual labour to a less physical, more supervisory position. This transition to less physical strenuous work may have also occurred in the Lisieux-Michelet sample and this would have exacerbated the osteological loss associated with the hormonal shift that occurs with aging.

### **5.1.4 Changes between the middle and old category**

The decrease in cortical bone between the middle and old adult age categories of Lisieux-Michelet is very similar to the decrease present in the sample of modern Finnish labourers. Although the modern population would obviously have access to different technologies and have different types of occupation related activity than people from the Late Roman Empire, similar levels of activity exerted on bone could produce similar rates of cortical loss noted in these populations. It has previously been noted that sustained activity in older age was an important mechanism in maintaining cortical thickness (Warden et al. 2014). The similar rates of cortical decrease in later adult years would suggest that these populations of manual labourers experienced activity-induced benefits in reduced cortical thickness loss and maintained cortical thickness through similar levels of activity in old age. This would also suggest that old adults from Lisieux-Michelet may have experienced decreased levels of physical activity that resulted in lower cortical loss in later years. This may be in part due to the economic limitations present in the Late Roman Period that would have encouraged individuals to maintain a level of involvement in their profession into the later years of adulthood.

Decreased levels of physical exertion would be more apparent in the entheses of the upper limb which are not affected by weight bearing strain like those found in the lower limbs (Mariotti et al. 2007). This decrease in mechanical loading of the humeral entheses would explain the limited increase in robusticity between the middle and old adult age categories. This is especially apparent in the deltoid which has almost no development between the middle and old age categories despite being a large, multifunctional muscle. There is also little noticeable increase in the pectoral; however, this is more due the fact that once the robusticity of the pectoral enthesis reaches the highest category of the ordinal scoring method, there is no means by which to observe any further development at this enthesis. Entheseal development has been noted to decrease with old age due to a decreased osteological response to activity after the age of 50-60 years of age (Milella et al. 2012) although there does not seem to be a loss in robusticity related to increased age in the Lisieux-Michelet sample. Unlike the deltoid, the enthesis of the LDTM does show an increase in robusticity between the middle and old adult categories. The continued age related increase of the LDTM combined with the plateau of the deltoid enthesis supports the idea that while the older adult males of Lisieux-Michelet may have abandoned heavier labour which would exert strain on large muscles like the deltoid, they still maintained a level of physical activity which engaged the LDTM and its associated muscles.

## **5.2 Relationship between variables examined**

There were generally very weak correlations between the various sources of data examined in the Lisieux-Michelet sample. Although development of the cortical thickness, entheseal robusticity, and humeral length are all influenced by age and activity, the weak correlations noted in this study suggest they are influenced by these factors to very differing degrees.

### **5.2.1 Metacarpal index and entheseal robusticity**

It was expected at the beginning of this study that a significant correlation would be present between the cortical index and entheseal robusticity as changes in both cortical index and entheseal robusticity are highly dependent on age. However, the Lisieux-Michelet sample produced a very weak correlation (r5 value= 0.00-0.19) between the cortical index and the entheses, which were mainly negative except for the positive correlation noted for pectoral robusticity in the young adult category. The very weak correlation between the cortical index and entheseal robusticity is likely due to the fact that cortical bone will continually decrease in thickness with age while entheseal robusticity does not react as consistently and may plateau over time. While the expected changes are occurring, the measurement of their robusticity is mediated by aspects of the development of the entheses observed.

Entheseal robusticity does increase with age but it is noted, especially in the deltoid, that robusticity plateaus after a certain point and due to current ordinal methods of measurement for fibrous entheses, any increase in robusticity after a certain point cannot be measured. The decrease in cortical index related to age is taken in ratio measurements rather than an ordinal scale and is more representative of the constant change in cortical index as it relates to age. Because of these different rates of increase and decrease in relation to age, the possibility of a significant relationship is greatly reduced.

Entheseal robusticity and cortical index are also affected differently by activity. Entheses respond to specific patterns of activity which differentially influence the loading at particular muscle attachment sites, whereas cortical index is influenced by overall levels of activity rather than specific types of motion. This causes different levels of activity induced variation and reduces the correlation between these two factors.

A previous study by Stirland examined the relationship between cortical thickness of the humerus using radiographs and muscle attachment sites in a group of archers from the Mary Rose (1998). This study separated the individuals into two age categories, young (under 30) and mature (over 30). Stirland focused primarily on the relationship between cortical and entheseal development in relation to activity and occupation. This study faced similar issues as the Lisieux-Michelet study due to the different ways in which entheseal and cortical development are measured (Stirland 1998). The current study of the Lisieux-Michelet males confirms that cortical thickness and entheseal robusticity are not significantly correlated. However, this study also suggests that these factors can be complimentary as entheseal development can reflect the levels of physical exertion that influence variation in the degrees of cortical thickness and loss in a population.

### **5.2.2 Entheseal robusticity and humeral length**

The moderate correlation between humeral length and entheseal robusticity found in this study is most likely incidental and the result of a small sample size, rather than demonstrating a significant relationship between humeral length and entheseal development. Entheseal robusticity is prone to a large amount of variation as the mechanics influencing development are not fully understood and thus the stages of entheseal development cannot be completely explained. Although activity over time influences greater entheseal robusticity and can lead to slight differences in humeral length, limb length is largely determined by genetics (Blackburn 2011, Drapeau 2008). Genetics have been noted to play a role in entheseal morphology. However, this would not necessarily lead to a strong correlation as genetics do not affect humeral length and entheseal robusticity in the same way; an individual with long limbs will not necessarily have larger muscles. The different sources of variation that affect entheseal robusticity and humeral length create confounding issues in the analysis of these variables. Future studies could examine these factors in a larger sample to determine whether this is in fact a valid rather than incidental correlation.

### **5.2.3 Metacarpal index and humeral length**

Metacarpal index and humeral length are primarily influenced by different factors which results in a very weak correlation. Humeral length is mainly dependant on body size with slight activity related variation observed between the right and left sides. The metacarpal index is mainly determined by age but the intragroup variation can be determined by activity. The influence of activity on humeral length and cortical thickness may have contributed to the very weak positive correlation seen in middle and old adults but does not create a significant link between these two factors. Taller individuals, individuals with longer humeri, are not necessarily healthier or more active than their shorter counterparts; thus, thicker cortical bone would not necessarily be found in correlation with longer humeral length.

## **5.3 Study limitations and possible sources of error**

Some elements that may have limited this study or skewed the interpretation of the collected data arise from a lack of contemporary documentation of the site of Lisieux-Michelet and bone preservation. Like many provincial Roman sites, there is a paucity of contemporary textual sources that mention the site of Lisieux-Michelet; much of the information on the settlement in the Late Roman period (approximately the 4th-6th century AD) was inferred from archaeological study. As such, there is no information regarding the occupation of the individuals that compose the sample used in this study, and age at death had to be estimated using osteological techniques that have limitations (Buikstra and Konigsberg 1987, Milner 2012).

As is often the case with archaeological bone, some skeletal elements from this collection suffered post-depositional wear. The pelvis has a particularly complex and delicate structure and has frequently been noted to be damaged in archaeological skeletal remains (Mays 1992, Waldron 1987). Cortical damage also led to the exclusion of some individuals from this study as relatively high cortical preservation was required for the assessment of entheseal development. For the complete criteria for inclusion in this study, please see Section 3.1.1 page 18.

The Suchey-Brooks and transition analysis aging methods used in this study relied on the interpretation of features of the pelvis. Some individuals were aged based on traits scored on the auricular surface as many individuals also did not have a pair of articulating molars for dental wear analysis due to post-deposition tooth loss (Appendix 1.1) which may have led to some ambiguity in the age groups. The young and old adult age categories were formed with relative levels of certainty as both these categories have characteristics that clearly define them. However, the middle adult age category was likely most affected by issues in aging skeletal material as it can be difficult to distinguish from individuals from the older end of the young adult category and the younger range of the old adult category.

# **CHAPTER 6.0 CONCLUSION**

The cortical and entheseal data examined in this study of the Lisieux-Michelet males shows similar patterns of development to both modern and archaeological European populations that engaged in heavy manual labour. The relative entheseal development of the rotator cuff muscles most closely resembles measurements taken from a group of Dutch rural farmers, suggesting similar levels of physical activity experienced by these populations. The cortical data in this study reflected trends noted in both adult males from Spitalfield, England and a modern populations in Finland.

The decrease in cortical bone thickness between the young and middle adult age categories is noted for both the Lisieux-Michelet and the Spitalfield males but is absent from the modern population of Finnish labourers. This suggests that the hormone related decrease in cortical thickness is exacerbated by a shift to less physically demanding labour in the Roman males. These data are supported by a plateau in the entheseal development of the deltoid.

Despite this decrease in physical activity in the middle adults, the Lisieux-Michelet males seem to maintain a certain level of physical exertion even into old adulthood. The less pronounced cortical decrease between the middle and old adult age groups, similar to that of modern labourers, suggests that cortical bone loss is mitigated by both physical activity in younger years and in old age. This is also indicated by the age related increase in entheseal robusticity of the LDTM. Although the large deltoid muscles see less use in later years, the continued development of the LDTM suggests some degree of physical activity.

The higher levels of cortical index in the young adult category and the continued decrease of cortical bone through the age categories used, confirms that age is the greatest influencing factor for cortical thickness. Variation within age categories is likely the result of activity and to a lesser degree, genetics and the effects of childhood nutrition.

These data indicate that the adult males of Lisieux-Michelet were generally an active population engaged in a variety of manual labours. Cortical loss and decrease in entheseal development suggests a shift in later adulthood to either more supervisory work or a limited involvement in the work force. However, it is likely even in older age, the males from the Roman Empire did not suffer greatly from frailty and remained physically active.

Both the measurement of cortical thickness and entheseal development were beneficial in measuring the relative levels of activity and the influence of age on the sample from Lisieux-Michelet. The data examined in this study allowed for some degree of inter-population comparison between the current study and other archaeological and modern groups. There were notable limitations due to differing methods of analysis between studies. Different categorizations of age limited the comparison of cortical index between populations and differing methods of entheseal analysis used hampered direct comparison of entheseal robusticity. However, it was still possible to note the relative level of development between different entheses and pick out similarities between chronologically disparate samples.

While greater standardization of entheseal and cortical thickness analysis practices would allow for more specific comparison of different samples, these factors are still beneficial for measuring age related trends and relative levels of activity between groups. These two factors can be complimentary in the analysis of age and activity related trends within a population; the metacarpal index best reflects the effects of age on bone but the variation noted in cortical analysis can be explained by activity related trends noted in enthseal robusticity. Entheseal development and cortical thickness provide useful and accessible baseline of general activity patterns in a past population that can be used to compare archaeological samples and make inferences about the lives of past populations.

# **BIBLIOGRAPHY**

Agrawal NK, Sharma B. 2013. Prevalence of osteoporosis in otherwise healthy Indian males aged 50 years and above. Archives of Osteoporosis 8(1-2): 1-7

Alduc-Le Bagousse A, Blondiaux J. 2002. Maternal death and perinatal pathology at Lisieux (Calvados, France) during the first millennium. Bulletins et Mémoires de la Société d’Anthropologie de Paris 14(2-3): 295-309

Auerbach BM, Ruff CB. 2006. Limb bone bilateral asymmetry: variability and commonality among modern humans. Journal of Human Evolution 50(2): 203-218

Bailey CA, Kukuljan S, Daly RM. 2010. Effects of lifetime loading history on cortical bone density and its distribution in middle-aged and older men. Bone 47(3): 673-680

Benjamin M, Kumai T, Boszczyk BM, Boszczyk AA, Ralphs JR. 2002. The skeletal attachment of tendons—tendon ‘entheses’. Comparative Biochemistry and Physiology Part A 133(4): 931-945

Benjamin M, McGonagle D. 2009. Entheses: tendon and ligament attachment sites. Scandinavian Journal of Medicine & Science in Sports 19(4): 520-527

Benjamin M, Toumi H, Ralphs JR, Bydder G, Best TM, Milz S. 2006. Where tendons and ligaments meet bone: attachment sites (‘entheses’) in relation to exercise and/or mechanical load. Journal of Anatomy 208(4): 471-490

Blackburn A. 2011. Bilateral asymmetry of the humerus during growth and development. American Journal of Physical Anthropology 145(4): 639-646

Boldsen J, Milner GR, Konigsberg LW, Wood JW. 2002. Transition analysis: a new

method for estimating age from skeletons. In RD Hoppa & JW Vaupel (Eds.), Paleodemography: age distributions from skeletal samples (pp. 73-106). Cambridge University Press: Cambridge England

Boren HC. 1977. Roman Society: A Social, Economic, and Cultural History. Heath and Company: Lexington

Brooks S, Suchey JM. 1990. Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. Human Evolution 5(3): 227-238

Brothwell DR. 1981. Digging up Bones. Cornell University Press: New York

Buikstra J, Ubelaker D (eds.). 1994. Standards for Data Collection from Human Skeletal Remains. Proceedings of a Seminar at the Field Museum of Natural History. Arkansas Archaeological Survey Research Series 44: Arkansas

Bury JB. 1923. History of the Later Roman Empire: from the Death of Theodosius I to the Death of Justinian. MacMillan: London

Cardoso FA. 2008a. Epiphyseal union at the innominate and lower limb in a modern Portuguese skeletal sample, and age estimation in adolescent and young adult male and female skeletons. American Journal of Physical Anthropology 135(2): 161-170

Cardoso FA. 2008b. Age estimation of adolescent and young adult male and female skeletons II, epiphyseal union at the upper limb and scapular girdle in a modern Portuguese skeletal sample. American Journal of Physical Anthropology 137(1): 97-105

Cardoso FA, Henderson CY. 2010. Enthesopathy formation in the humerus: data from known age-at-death and known occupation skeletal collection. American Journal of Physical Anthropology 141(4): 550-560

Chapman NEM. 1997. Evidence of Spanish influence on activity induced musculoskeletal stress markers at Pecos Pueblos. International Journal of Osteoarchaeology 7(5): 497-506

Cokayne, Karen. 2003. Experiencing Old Age in Ancient Rome. Routledge: New York

Crubézy E, Goulet J, Bruzek J, Jelinek J, Rougé D, Ludes B. 2002. Epidemiology of osteoarthritis and enthesopathies in a European population dating back 7700 years. Joint Bone Spine 69(6): 580-588

Davis CB, Shuler KA, Danforth ME, Herndon KE. 2013. Patterns of interobserver error in the scoring of entheseal changes. International Journal of Osteoarchaeology 23(2): 147-151

De Rooy DPC, Kalvesten J, Huizinga TWJ, van der Helm-van Mil AHM. Loss of metacarpal bone density predicts RA development in recent-onset arthritis. Rheumatology 51(6): 1037-1041

De Krester D. 2010. Determinants of male health: the interaction of biological and social factors. Asian Journal of Andrology 12(3): 291-297

Drapeau M. 2008. Enthesis bilateral asymmetry in humans and African apes. HOMO-Journal of Comparative Human Biology 59(2): 93-109

Eshed V, Gopher A, Galili E, Hershkovitz I. 2004. Musculoskeletal stress markers in Natufian Hunter-Gatherers and Neolithic Farmers in the Levant: the upper limb. American Journal of Physical Anthropology 123(4): 303-315

Giannotti S, Bottai V, Dell’Osso G, DePaola G, Bugelli G, Pini E, Guido G. 2013. Disuse osteoporosis of the upper limb: assessment of thirty patients. Clinical Cases in Mineral and Bone Metabolism 10(2): 129-132

Harlow M, Laurence R. 2002. Growing Up and Growing Old in Ancient Rome. Routledge: New York

Havelkova P, Villotte S. 2007. Enthesopathies: test of the reproducibility of the new scoring system based on current medical data. Slovenská antropológia 10(1): 51-57

Hawkey DE, Merbs CF. 1995. Activity induced musculoskeletal stress markers (MSM) and subsistence strategy changes among ancient Hudson Bay Eskimos. International Journal of Osteoarchaeology 5(1): 324-338

Henderson CY. 2013. Do diseases cause entheseal changes at fibrous entheses? International Journal of Paleopathology 3(1): 64-69

Jones AHM. 1964. The Later Roman Empire 284-602. Billing and Sons: London

Ives R, Brickley M. 2004. A procedural guide to metacarpal radiogrammetry in archaeology. International Journal of Osteoarchaeology 14(1): 7-17

Ives R, Brickley M. 2005. Metacarpal radiogrammetry: a useful indicator of bone loss throughout the skeleton? Journal of Archaeological Science 32(10): 1552-1559

Lançon B. 2000. Rome in Late Antiquity. Routlege: New York

Ma H, Leskinen T, Alen M, Cheng S, Sipilä S, Heinonen A, Kaprio J, Suominen H, Kujala UM. 2009. Long-term leisure time physical activity and properties of bone: a twin study. Journal of Bone and Mineral Research 24(8): 1427-1433

Mariotti V, Facchini F, Belcastro MG. 2004. Enthesopathies: proposal of a standardized scoring method and applications. Collegium Antropologicum 28(1): 145-159

Mariotti V, Facchini F, Belcastro MG. 2007. The study of entheses: proposal of a standardised scoring method for twenty-three entheses of the postcranial skeleton. Collegium Antropologicum 31(1): 291-313

Mathisen. 2003. People, Personal Expression, and Social Relations in Late Antiquity, Volume I. University of Michigan Press: Ann Arbor

Mays S. 1996. Age-dependent cortical bone loss in a medieval population. International Journal of Osteoarchaeology 6(2):144-154

Mays S. 2001. Effects of age and occupation on cortical bone in a group of 18th-19th century British men. American Journal of Physical Anthropology 116(1): 34-44

Mays S. 2006. Age related cortical bone loss in women from a 3rd-4th century AD population from England. American Journal of Physical Anthropology 129(1): 518-528

Mays S. 2014. Resorption of mandibular alveolar bone following loss of molar teeth and its relationship to age at death in a human skeletal population. American Journal of Physical Anthropology 153(4): 643-652

Milella M, Belcastro MG, Zollikofer CPE, Mariotti V. 2012. The effect of age, sex, and physical activity on entheseal morphology in a contemporary Italian skeletal collection. American Journal of Physical Anthropology 148(3): 379-388

Milner GR, Boldsen JL. 2012. Transition analysis: a validation study with known-age modern American skeletons. American Journal of Physical Anthropology 148(1): 98-110

Niinimäki S, Söderling S, Junno JA, Finnilä M, Niskanen M. 2013. Cortical bone thickness can adapt locally to muscular loading while changing with age. HOMO-Journal of Comparative Human Biology 64(6): 474-490

Noldner LK, Edgar HJH. 2013. Technical note: 3D representation and analysis of enthesis morphology. American Journal of Physical Anthropology 152(3): 417-424

Ortner NJ. 2003. Identification of Pathological Conditions in Human Skeletal Remains. Elsevier: Oxford

Palmer JLA, Hoogland MHL, Waters-Rist AL. 2014. Activity reconstruction of post-medieval Dutch rural villagers from upper limb osteoarthritis and entheseal changes. International Journal of Archaeology 133(3): 931-945

Paillard D. unpublished report. Ancienne école Michelet-Jules Ferry Lisieux (Calvados) : Document final de Synthèse 1990-1993. Archaeology department, University of Caen, France

Paillard D, Buchet L, Alduc-Le Bagousse. 2006. Nombre d’inhumés, nombre d’habitants. Estimations archéologiques et anthropologiques Lisieux (Calvados), IVe siècle de notre ère. La paléodémographie. Mémoire d’Os, Mémoire d’Hommes 8: 209-223

Rhodes J, Knüsel C. 2005. Activity-related skeletal change in medieval humeri: cross-sectional and architectural alterations. American Journal of Physical Anthropology 128(3): 536-546

Robling AG, Hinant FM, Burr DB, Turner CH. 2002. Improved bone structure and strength after long-term mechanical loading is greatest if loading is separated into short bouts. Journal of Bone and Mineral Research 17(8): 1545-1554

Sorenson SB. 2011. Gender disparities in injury mortality: consistent, persistent, and larger than you’d think. American Journal of Public Health 101(2): 353-358

Steele J, Mays S. 1995. Handedness and directional asymmetry in the long bones of the human upper limb. International Journal of Osteoarchaeology 5(1): 39-49

Stirland AJ. 1998. Musculoskeletal evidence for activity: problems of evaluation. International Journal of Osteoarchaeology 8(5): 354-362

Tveit M, Rosengren BE, Nilsson JA, Ahlborg, Karlsson MK. 2013. Bone mass following physical activity in young years: a mean 39-year prospective controlled study in men. Osteoporosis International 24(4): 1389-1397

Villotte SV. 2006. Connaissances médicales actuelles, cotation des enthésopathies: nouvelle méthode. Bulletins et Mémoires de la Société d’Anthropologie de Paris 18(1-2): 65-85

Villotte SV, Castex D, Couallier V, Dutour O, Knüsel CJ, Henry-Gambier D. 2010. Enthesopathies as occupational stress markers: evidence from the upper limb. American Journal of Physical Anthropology 142(2): 224-234

Villotte SV, Knüsel C. 2013. Understanding entheseal changes: definition and life course changes. International Journal of Osteoarchaeology 23(2): 135-146

Virtama P, Helela T. 1969. Radiographic measurements of cortical bone. Variation in a normal population between 1 and 90 years of age. Acta Radiologica 293(Supplemental): 1-268

Warden SJ, Roosa SMM, Kersh ME, Hurd AL, Fleisig GS, Pandy MG, Fuchs RK. 2014. Physical activity when young provides lifelong benefits to cortical bone size and strength in men. Proceedings of the National Academy of Sciences of the United States of America 111(14): 5337-5347

Weiss E. 2003. Understanding muscle markers: aggregation and construct validity. American Journal of Physical Anthropology 121(3): 230-240

# **Appendix 1: Data tables**

## **Appendix 1.1 Male ages**

|  |  |
| --- | --- |
| **Data table key** | |
| **Y** | Young adult |
| **M** | Middle adult |
| **O** | Old adult |
| **-** | Indicates a trait that was absent or could not be scored |
|  | Indicates possibly non-Roman individual |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Skeleton number | Unfused Epiphyses | Dental Wear | Suchey Brooks | Transition Analysis | Assigned Age Category |
| 2 | - | - | - | 26.1 (26.1-47.7) | Y |
| 3 |  | - | 23-57 | 73.9 (28.6-90.6) | M |
| 11 |  | - | - | 42 (19.8-79.4) | M |
| 53 |  | - | - | 83.8 (65.6-110.0) | O |
| 73 | - | 17-25 | - | 30.9 (30.9-70.2) | Y |
| 74 |  | 25-35 | - | 69.3 (28.6-90.6) | M |
| 92 |  | 25-35 | 23-57 | 70.3 (28.3-89.2) | M |
| 112 | - | - | 15-23 | 43.8 (19.9-84.7) | Y |
| 125 |  | 45+ | 23-66 | 81.3 (60.7-93.6) | O |
| 128 |  | - | 23-57 | 78.3 (51.6-92.3) | O |
| 132 |  | - | - | 75.9 (26.6-88.8) | O |
| 151 |  | 45+ | - | 81.8 (61.6-93.8) | O |
| 152 | - | 25-35 | 19-34 | 75.5 (38.2-91.1) | Y |
| 153 | 17-21 | 17-25 | 15-23 | 30.1 (30.1-58.7) | Y |
| 154 | 19-25 | 17-25 | - | 15.0 (15.0-31.0) | Y |
| 156 | - | 17-25 | - | 27.1 (27.1-50.3) | Y |
| 163 | - | 17-25 | 21-46 | 70.6 (30.1-89.3) | Y |
| 168 |  | - | 27-66 | 40.5 (40.5-86.6) | M |
| 182 | - | 25-35 | - | - | Y |
| 188 |  | 33-45 | 23-57 | 77.7 (48.1-92) | M |
| 189 |  | - | - | 77.1 (42.8-91.9) | O |
| 193A |  | - | 23-57 | 37.3 (15.5-78.9) | M |
| 217 |  | 25-35 | 21-46 | 39.3 (39.3-82.5) | M |
| 237 |  | 33-45 | 23-57 | 43.0 (17.6-83.2) | M |
| 239 |  | 33-45 | - | 78.1 (48.5-92.2) | M |
| 242 |  | 45+ | - | 82.4 (62.1-110.0) | O |
| 244 | 16-21 | 17-25 | - | 15.0 (15.0-36.3) | Y |
| 249A | 16-21 | 25-35 | 15-23 | 31.0 (31.0-70.2) | Y |
| 259 | - | 25-35 | 21-46 | 77.6 (41.8-92.3) | M |
| 284 | - | 17-25 | - | 43.1 (18.8-84.7) | Y |
| 289 |  | - | 23-57 | 66.3 (27.9-87.9) | O |
| 295 |  | 33-45 | 23-57 | - | M |
| 317 |  | - | 21-46 | 71.5 (31.2-89.8) | M |
| 322 | 16-21 | 17-25 | - | 15.0 (15.0-33.0) | Y |
| 329 |  | 45+ |  | 75.6 (36.0-91.3) | O |
| 333 |  | - | - | 80.5 (57.9-93.3) | O |
| 334 |  | - | 27-66 | 74.7 (42.0-90.6) | O |
| 337 | - | 17-25 | - | 26.8 (26.8-50.7) | Y |
| 342 |  | - | 19-34 | 78.7 (49.6-92.6) | Y |
| 375 |  | 33-45 | 19-34 | 30.7 (30.7-69.9) | M |
| 392 | - | 17-25 | 23-57 | 43.6 (17.1-83.9) | Y |
| 406 |  | 45+ | 27-66 | 77.0 (47.2-91.4) | O |
| 420A |  | 25-35 | 23-57 | 76.4 (47.5-91.2) | Y |
| 427 |  | - | - | 76.3 (28.8-91.9) | O |
| 428 |  | - | - | 73.7 (35.5-90.3) | O |
| 471 |  | - | 23-57 | 75.0 (32.2-91.2) | O |
| 491 |  |  | - | 77.3 (43.0-92.0) | O |
| 527 |  | 45+ | 27-66 | 78.8 (30.8-110.0) | O |
| 539 |  | 25-35 | 23-57 | 81.2 (58.1-110.0) | Y |
| 553 |  | 25-35 | - | 76.7 (37.3-91.9) | M |
| 554 | - | 17-25 | 23-57 | 48.8 (18.5-86.8) | Y |
| 566 | - | 15-25 | 21-46 | 78.2 (54.4-91.8) | Y |
| 577 |  | - | 27-66 | 75.9 (45.4-91.1) | M |
| 579 |  | 33-45+ | 23-57 | 77.8 (47.9-92.1) | M |
| 582 |  | - | 27-66 | 70.4 (32.2-89.1) | M |
| 592 |  | 45+ | - | 82.4 (62.3-110.0) | O |
| 597 |  | 17-25 | 21-46 | 36.2 (16.0-76.7) | Y |
| 611 |  | - | 23-57 | 80.6 (56.4-110.0) | O |
| 615 |  |  | - | - | Undetermined |
| 620 |  | - | 23-57 | 40 (17.1-85.2) | M |
| 639 |  |  | - | 29.9 (29.9-58.9) | Y |
| 649 |  |  | - | 72.6 (32.2-89.9) | O |
| 654 |  | 45+ | 27-66 | 74.9 (43.2-90.6) | O |
| 668 |  | 17-25 | 23-66 | 75.5 (43.0-91.0) | Y |
| 670 |  | 33-45+ | 21-46 | 77.6 (47.8-91.9) | M |
| 699 |  |  | - | 73.4 (35.7-90.4) | O |
| 705 |  | 25-35 | 21-46 | 28.4 (28.4-52.4) | Y |
| 714 |  | - | 27-66 | 79.2 (56.3-92.3) | O |
| 767 |  | - | 27-66 | 84.3 (67.7-110.0) | O |
| 772 |  | - | 23-57 | 63.7 (20.2-88.7) | Y |
| 808 |  | 25-35 | - | 43.7 (18.9-85.4) | Y |
| 828 |  | - | - | 77.0 (42.5-91.8) | O |
| 842 |  | - | 23-57 | 73.3 (34.4-90.2) | M |
| 876 |  | - | 27-66 | 74.0 (74.0-91.1) | O |
| 903 |  | - | - | 77.1 (47.8-91.5) | O |
| 919 | 19-25 | 17-25 | 15-23 | 16.5 (16.5-31.0) | Y |
| 939 |  | - | 19-34 | 73 (73.0-90.5) | Y |

## **Appendix 1.2 Traits used for sex estimation**

|  |  |
| --- | --- |
| **Data table key** | |
| **x** | Indicates which trait or combination of traits were used to determine sex |

|  |  |  |  |
| --- | --- | --- | --- |
| Skeleton number | Cranial traits only | Pelvic traits only | Both cranial and pelvic traits |
| 2 |  |  | x |
| 3 |  | x |  |
| 11 |  |  | x |
| 53 | x |  |  |
| 73 |  |  | x |
| 74 |  |  | x |
| 92 |  |  | x |
| 112 |  |  | x |
| 125 |  |  | x |
| 128 |  |  | x |
| 132 | x |  |  |
| 151 |  |  | x |
| 152 |  |  | x |
| 153 |  | x |  |
| 154 |  |  | x |
| 156 | x |  |  |
| 163 |  |  | x |
| 168 |  | x |  |
| 182 | x |  |  |
| 188 |  |  | x |
| 189 |  |  | x |
| 193A |  | x |  |
| 217 |  |  | x |
| 237 |  |  | x |
| 239 |  | x |  |
| 242 |  |  | x |
| 244 |  |  | x |
| 249A |  |  | x |
| 259 | x |  |  |
| 284 |  |  | x |
| 289 |  | x |  |
| 295 |  |  | x |
| 317 |  | x |  |
| 322 |  |  | x |
| 329 |  |  | x |
| 333 |  |  | x |
| 334 |  |  | x |
| 337 |  | x |  |
| 342 |  |  | x |
| 375 |  | x |  |
| 392 |  |  | x |
| 406 |  |  | x |
| 420A |  |  | x |
| 427 | x |  |  |
| 428 | x |  |  |
| 471 |  | x |  |
| 491 |  |  | x |
| 527 |  | x |  |
| 539 |  |  | x |
| 553 |  |  | x |
| 554 |  |  | x |
| 566 |  | x |  |
| 577 |  |  | x |
| 579 |  |  | x |
| 582 |  |  | x |
| 592 |  |  | x |
| 597 |  |  | x |
| 611 | x |  |  |
| 615 |  | x |  |
| 620 |  |  | x |
| 639 |  |  | x |
| 649 | x |  |  |
| 654 |  |  | x |
| 668 |  |  | x |
| 670 |  |  | x |
| 699 | x |  |  |
| 705 |  |  | x |
| 714 |  |  | x |
| 767 |  |  | x |
| 772 |  | x |  |
| 808 |  |  | x |
| 828 |  |  | x |
| 842 |  |  | x |
| 876 |  | x |  |
| 903 |  |  | x |
| 919 |  | x |  |
| 939 |  |  | x |

## **Appendix 1.3 Young adult entheseal scoring**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Individual | Deltoid  (left) | Deltoid  (right) | LDTM  (left) | LDTM  (right) | Pectoral  (left) | Pectoral  (right) |
| 2 | 1.75 | 1.75 | 1.25 | 1.25 | 1.75 | 1.75 |
| 73 | 2 | 2 | 2 | 2 | 1.75 | 1.75 |
| 112 | 1.25 | 1.5 | 1.5 | 1.25 | - | 1.5 |
| 152 | 1.25 | - | 1.5 | - | - | - |
| 153 | 1.75 | 1.25 | - | - | 2 | 2 |
| 154 | 1.25 | 1.25 | 1.25 | 1.25 | 1.5 | 1.5 |
| 156 | 1.5 | 1.5 | 1.25 | 1.25 | 1.25 | 1.25 |
| 163 | 1.25 | 1.5 | - | - | - | 1.5 |
| 182 | 1.75 | 2 | 2 | 1.75 | 1.5 | 3 |
| 244 | 1.25 | 1.25 | 1.25 | 1.25 | 1.5 | 1.75 |
| 249A | 1.5 | - | 1.5 | - | 1.5 | - |
| 284 | 2 | 1.75 | 1.25 | 1.25 | 1.5 | 3 |
| 322 | 1.5 | 1.5 | 1.75 | 1.5 | 1.5 | 1.5 |
| 337 | 1.75 | 1.75 | 1.25 | 1.25 | 1.75 | 1.5 |
| 342 | 1.75 | 2 | 2 | 2 | 3 | 3 |
| 392 | 1.75 | 2 | 1.75 | - | 1.75 | 2 |
| 420A | 1.75 | 1.75 | 1.75 | 1.75 | 3 | 2 |
| 539 | 2 | 1.75 | 1.75 | - | 1.5 | 1.75 |
| 554 | 2 | 2 | 1.5 | 2 | 1.5 | 1.75 |
| 566 | 1.25 | 1.5 | 1.75 | 1.75 | 1.5 | 1.75 |
| 597 | 1.5 | 1.5 | 1.5 | 1.5 | 2 | 1.25 |
| 639 | 2 | 3 | 1.75 | 1.75 | 1.75 | 3 |
| 668 | 3 | 2 | 1.75 | 1.5 | 1.75 | 1.75 |
| 705 | 1.75 | 2 | 1.5 | 1.5 | 1.75 | 3 |
| 772 | - | 1.75 | - | 3 | - | 3 |
| 808 | 2 | - | 3 | - | 1.5 | - |
| 919 | 3 | 2 | 1.75 | 2 | 1.75 | 1.75 |
| 939 | 1.75 | - | 1.75 | 1.5 | 1.5 | 1.5 |

## **Appendix 1.4 Middle adult enthseal scoring**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Individual | Deltoid  (left) | Deltoid  (right) | LDTM  (left) | LDTM  (right) | Pectoral  (left) | Pectoral  (right) |
| 3 | 1.75 | 2 | 1.25 | 1.25 | 1.75 | 2 |
| 11 | 1.75 | 1.75 | 2 | 3 | 2 | 3 |
| 74 | - | 1.75 | - | 1.5 | - | 1.5 |
| 92 | 1.75 | 1.75 | 2 | 2 | 2 | 1.75 |
| 168 | - | - | 3 | 1.75 | 2 | 1.75 |
| 188 | - | 2 | 1.75 | 1.5 | 3 | 3 |
| 193A | 2 | 2 | 1.5 | 1.75 | 2 | 2 |
| 217 | 1.75 | 2 | 1.75 | 1.75 | 2 | 3 |
| 237 | 1.75 | 1.75 | 1.5 | 3 | 1.5 | 2 |
| 239 | 3 | 2 | 1.75 | 2 | 1.75 | 3 |
| 259 | 1.5 | 1.25 | 1.5 | 1.25 | 1.5 | 1.5 |
| 295 | 2 | 1.75 | 1.75 | 2 | 3 | 3 |
| 317 | 1.75 | 1.75 | 1.5 | 1.5 | 2 | 3 |
| 375 | 3 | 2 | 1.75 | - | 1.75 | 2 |
| 553 | - | 1.5 | 2 | 2 | - | 2 |
| 577 | 2 | 3 | 2 | 1.75 | 1.75 | 3 |
| 579 | 1.75 | 1.5 | 1.75 | 1.5 | 1.75 | 1.5 |
| 582 | - | 1.75 | - | 1.75 | - | 3 |
| 620 | - | - | 2 | - | 3 | - |
| 670 | 1.5 | 1.75 | 2 | 2 | 2 | 3 |
| 842 | 3 | 2 | 1.75 | 2 | 1.75 | 1.75 |

## **Appendix 1.5 Old adult entheseal scoring**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Individual | Deltoid  (left) | Deltoid  (right) | LDTM  (left) | LDTM  (right) | Pectoral  (left) | Pectoral  (right) |
| 53 | - | 1.75 | - | 2 | - | 1.75 |
| 125 | 1.75 | 1.75 | 2 | 1.75 | - | 1.5 |
| 128 | 2 | 2 | 2 | 3 | 2 | 2 |
| 132 | 2 | - | 1.75 | - | 2 | - |
| 151 | 2 | 2 | 1.75 | 1.5 | 2 | 3 |
| 189 | 1.5 | 1.75 | 1.75 | - | 1.5 | - |
| 242 | 3 | 3 | 1.75 | 1.5 | 1.5 | 1.5 |
| 289 | 1.75 | 2 | 2 | 2 | 3 | 3 |
| 329 | 3 | 3 | 1.75 | 1.75 | 3 | 3 |
| 333 | - | 3 | 1.75 | 2 | 2 | 3 |
| 334 | 2 | 2 | - | 3 | - | 3 |
| 406 | 2 | 1.75 | 2 | - | 2 | 1.75 |
| 427 | 3 | 3 | 1.75 | 2 | 1.75 | 2 |
| 428 | 2 | 2 | - | 1.25 | - | 1 |
| 471 | 3 | 3 | 2 | 1.5 | 3 | 3 |
| 491 | 1.75 | 2 | 3 | 2 | 1.5 | 1.75 |
| 527 | 1.5 | 1.5 | 2 | 1.75 | 3 | 3 |
| 592 | 1.75 | 1.5 | 1.5 | 1.5 | 1.5 | - |
| 611 | 1.5 | 1.75 | 3 | 1.75 | 3 | 2 |
| 649 | - | 1.5 | 1.75 | 2 | 2 | 3 |
| 654 | 1.75 | 2 | 3 | 3 | 2 | 1.75 |
| 699 | 1.75 | - | 3 | - | 2 | - |
| 714 | - | - | - | 2 | - | 3 |
| 767 | 1.5 | 1.5 | 2 | 1.5 | 1.75 | 1.5 |
| 828 | 1.75 | 1.75 | 1.5 | 1.5 | 1.75 | 2 |
| 876 | 2 | 1.75 | 2 | 2 | 2 | 2 |
| 903 | 1.5 | 1.75 | 3 | 1.75 | 2 | - |

## **Appendix 1.6** **Young adult metacarpal index**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |
| --- | --- | --- |
| Individual | Index (left) | Index (right) |
| 2 | 64.8 | 70.3 |
| 73 | - | 53.7 |
| 112 | 34.4 | 46.7 |
| 152 | 64.3 | 56.9 |
| 153 | 45.7 | 48.5 |
| 154 | 56.9 | 59.9 |
| 156 | 56.8 | 61.8 |
| 163 | 55.9 | 53.0 |
| 182 | 41.9 | 52.3 |
| 244 | - | 46.6 |
| 249A | 48.4 | - |
| 284 | 46.7 | 53.2 |
| 322 | - | 49.1 |
| 337 | 44.9 | 54.8 |
| 342 | 59.4 | 66.6 |
| 392 | - | - |
| 420A | 54.0 | 54.0 |
| 539 | 50.7 | 50.7 |
| 554 | 49.0 | 49.0 |
| 566 | 55.2 | 55.2 |
| 597 | 58.2 | 58.2 |
| 639 | 53.8 | 55.4 |
| 668 | 56.8 | 63.7 |
| 705 | 58.4 | 55.1 |
| 772 | - | 56.2 |
| 808 | 53.3 | 51.3 |
| 919 | - | 47.2 |
| 939 | - | 55.1 |

## **Appendix 1.7** **Middle adult metacarpal index**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |
| --- | --- | --- |
| Individual | Index (left) | Index (right) |
| 3 | 57.5 | 50.9 |
| 11 | 47.2 | 53.2 |
| 74 | - | 41.6 |
| 92 | 45.6 | 50.2 |
| 168 | 49.4 | 53.8 |
| 188 | - | 54.5 |
| 193A | 41.2 | 53.7 |
| 217 | 40.5 | 39.5 |
| 237 | - | 57.1 |
| 239 | 43.2 | 40.8 |
| 259 | 62.4 | 62.4 |
| 295 | - | 56.1 |
| 317 | 53.9 | 55.6 |
| 375 | 45.7 | - |
| 553 | - | 46.3 |
| 577 | 51.8 | - |
| 579 | 54.4 | 65.0 |
| 582 | - | 56.6 |
| 620 | 62.3 | 55.4 |
| 670 | 44.6 | - |
| 842 | 56.6 | 59.9 |

## **Appendix 1.8 Old adult metacarpal index**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |
| --- | --- | --- |
| Individual | Index (left) | Index (right) |
| 53 | - | 30.5 |
| 125 | 51.3 | - |
| 128 | 42.9 | 50.5 |
| 132 | 43.1 | - |
| 151 | 51.5 | 55.3 |
| 189 | 48.8 | 64.0 |
| 242 | 41.9 | - |
| 289 | 41.3 | - |
| 329 | 49.4 | - |
| 333 | 49.8 | 49.5 |
| 334 | 51.2 | 50.5 |
| 406 | 45.5 | 45.5 |
| 427 | - | 50.3 |
| 428 | - | 54.4 |
| 471 | 44.1 | 50.3 |
| 491 | 62.0 | 64.7 |
| 527 | 42.9 | 59.5 |
| 592 | 57.6 | 53.5 |
| 611 | 41.7 | - |
| 649 | 56.7 | 50.1 |
| 654 | 61.3 | 62.1 |
| 699 | 58.8 | 44.9 |
| 714 | - | 35.6 |
| 767 | 50.9 | 51.4 |
| 828 | - | - |
| 876 | 55.7 | 48.8 |
| 903 | 44.8 | 50.5 |

## **Appendix 1.9 Young adult humeral length measurements**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |
| --- | --- | --- |
| Individual | Length (left)  (cm) | Length (right) (cm) |
| 2 | 33.0 | - |
| 73 | 31.1 | 31.5 |
| 112 | 34.4 | 34.7 |
| 152 | 30.8 | 31.7 |
| 153 | - | 32.4 |
| 154 | 34.1 | 34.5 |
| 156 | - | 32.9 |
| 163 | 36.1 | - |
| 182 | 30.5 | 31.6 |
| 244 | 30.6 | 30.9 |
| 249A | 32.0 | - |
| 284 | 31.9 | 33.0 |
| 322 | 31.8 | 32.6 |
| 337 | 31.0 | 32.0 |
| 342 | 31.7 | 32.4 |
| 392 | 33.7 | 34.5 |
| 420A | 29.9 | 30.6 |
| 539 | 35.7 | 36.4 |
| 554 | 34.4 | 34.4 |
| 566 | 33.0 | 33.5 |
| 597 | - | - |
| 639 | 32.0 | 32.7 |
| 668 | 30.3 | 31.0 |
| 705 | - | 29.8 |
| 772 | - | 30.3 |
| 808 | - | - |
| 919 | 33.5 | 33.6 |
| 939 | 31.6 | 32.7 |

## **Appendix 1.10 Middle adult humeral length measurements**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |
| --- | --- | --- |
| Individual | Length (left)  (cm) | Length (right)  (cm) |
| 3 | 32.7 | 33.5 |
| 11 | 29.5 | - |
| 74 | - | 31.4 |
| 92 | 31.3 | 32.0 |
| 168 | - | - |
| 188 | 35.7 | 35.7 |
| 193A | 33.4 | 33.7 |
| 217 | 32.7 | 33.7 |
| 237 | 31.4 | 32.2 |
| 239 | - | - |
| 259 | 33.2 | - |
| 295 | 32.6 | - |
| 317 | 33.4 | 34.7 |
| 375 | - | - |
| 553 | 33.5 | 34.1 |
| 577 | 32.9 | - |
| 579 | 29.8 | - |
| 582 | - | 34.0 |
| 620 | 31.4 | - |
| 670 | 29.5 | - |
| 842 | - | - |

## **Appendix 1.11 Old adult humeral length measurements**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |
| --- | --- | --- |
| Individual | Length (left)  (cm) | Length (right)  (cm) |
| 53 | - | - |
| 125 | 34.2 | 34.6 |
| 128 | 31.8 | 32.1 |
| 132 | 31.5 | 32.7 |
| 151 | - | 35.5 |
| 189 | - | 29.8 |
| 242 | 32.2 | 32.5 |
| 289 | - | 31.1 |
| 329 | - | - |
| 333 | - | - |
| 334 | 31.8 | 32.6 |
| 406 | - | - |
| 427 | 33.1 | 33.7 |
| 428 | 33.1 | 34.9 |
| 471 | - | 34.0 |
| 491 | 33.2 | - |
| 527 | 33.1 | 33.7 |
| 592 | 34.2 | 35.6 |
| 611 | - | - |
| 649 | 32.7 | 32.7 |
| 654 | 31.4 | - |
| 699 | 33.5 | - |
| 714 | 31.2 | 32.1 |
| 767 | - | 35.6 |
| 828 | - | - |
| 876 | - | 32.9 |
| 903 | - | 33.0 |

## **Appendix 1.12 Young adult metacarpal measurements (left)**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Individual | Length (mm) | Width(mm) | Medullary Cavity (mm) | Cortical thickness (mm) | Index (thickness/width) |
| 2 | 65.12 | 8.70 | 3.06 | 5.64 | 64.80 |
| 73 | - | - | - | - | - |
| 112 | 66.24 | 9.17 | 4.80 | 4.37 | 47.63 |
| 152 | 61.82 | 7.95 | 2.84 | 5.11 | 64.29 |
| 153 | 62.59 | 8.82 | 4.79 | 4.03 | 45.66 |
| 154 | 58.33 | 8.98 | 3.87 | 5.11 | 56.91 |
| 156 | 63.66 | 7.25 | 3.13 | 4.12 | 56.83 |
| 163 | 66.79 | 10.11 | 4.46 | 5.65 | 55.87 |
| 182 | 55.06 | 8.95 | 5.20 | 3.75 | 41.89 |
| 244 | - | - | - | - | - |
| 249A | 60.22 | 7.42 | 3.83 | 3.59 | 48.40 |
| 284 | 64.71 | 8.88 | 4.74 | 4.14 | 46.66 |
| 322 | - | - | - | - | - |
| 337 | 56.87 | 9.20 | 5.07 | 4.13 | 44.91 |
| 342 | 64.11 | 8.88 | 3.60 | 5.28 | 59.44 |
| 392 | - | - | - | - | - |
| 420A | 63.90 | 9.27 | 4.26 | 5.00 | 53.99 |
| 539 | 63.37 | 9.69 | 4.78 | 4.91 | 50.68 |
| 554 | 63.93 | 10.56 | 5.39 | 5.17 | 49.00 |
| 566 | 64.42 | 8.69 | 3.89 | 4.79 | 55.17 |
| 597 | 60.72 | 8.21 | 3.43 | 4.78 | 58.20 |
| 639 | 63.93 | 8.57 | 3.96 | 4.61 | 53.78 |
| 668 | 60.56 | 8.55 | 3.70 | 4.86 | 56.79 |
| 705 | 45.82 | 6.36 | 2.65 | 3.71 | 58.37 |
| 772 | - | - | - | - | - |
| 808 | 59.56 | 8.94 | 4.17 | 4.77 | 53.32 |
| 919 | - | - | - | - | - |
| 939 | - | - | - | - | - |

## **Appendix 1.13 Young adult metacarpal measurements (right)**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Individual | Length (mm) | Width (mm) | Medullary Cavity (mm) | Cortical thickness (mm) | Index (thickness/width) |
| 2 | 65.45 | 7.11 | 2.11 | 5.00 | 70.32 |
| 73 | 56.76 | 8.41 | 3.89 | 4.51 | 53.69 |
| 112 | 66.61 | 8.05 | 4.29 | 3.76 | 46.72 |
| 152 | 60.97 | 7.63 | 3.29 | 4.34 | 56.92 |
| 153 | 62.58 | 8.17 | 4.21 | 3.96 | 48.47 |
| 154 | 59.10 | 9.23 | 3.70 | 5.53 | 59.94 |
| 156 | 63.19 | 7.19 | 2.75 | 4.45 | 61.83 |
| 163 | 64.34 | 8.49 | 3.99 | 4.50 | 53.03 |
| 182 | 59.08 | 7.64 | 3.64 | 4.00 | 52.33 |
| 244 | 56.50 | 7.76 | 4.14 | 3.62 | 46.60 |
| 249A | - | - | - | - | - |
| 284 | 67.37 | 8.76 | 4.11 | 4.66 | 53.16 |
| 322 | 59.93 | 8.66 | 4.41 | 4.25 | 49.09 |
| 337 | 57.70 | 8.61 | 3.89 | 4.71 | 54.75 |
| 342 | 64.93 | 8.14 | 2.72 | 5.43 | 66.61 |
| 392 | - | - | - | - | - |
| 420A | 62.54 | 8.24 | 3.02 | 5.21 | 63.30 |
| 539 | 62.83 | 8.29 | 3.58 | 4.71 | 56.85 |
| 554 | 66.11 | 9.25 | 3.83 | 5.43 | 58.63 |
| 566 | 64.22 | 8.36 | 4.04 | 4.32 | 51.66 |
| 597 | 60.72 | 8.40 | 3.22 | 5.17 | 61.64 |
| 639 | 63.40 | 9.94 | 4.44 | 5.50 | 55.38 |
| 668 | 60.30 | 7.79 | 2.82 | 4.96 | 63.73 |
| 705 | 46.30 | 6.61 | 2.97 | 3.64 | 55.08 |
| 772 | 55.05 | 7.97 | 3.49 | 4.48 | 56.24 |
| 808 | 58.04 | 9.87 | 4.80 | 5.07 | 51.34 |
| 919 | 56.35 | 8.16 | 4.31 | 3.85 | 47.17 |
| 939 | 55.97 | 7.62 | 3.42 | 4.20 | 55.15 |

## **Appendix 1.14 Middle adult metacarpal measurements (left)**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Individual | Length (mm) | Width (mm) | Medullary Cavity (mm) | Cortical thickness (mm) | Index (thickness/width) |
| 3 | 63.94 | 9.85 | 4.18 | 5.66 | 57.51 |
| 11 | 52.84 | 8.61 | 4.54 | 4.07 | 47.24 |
| 74 | - | - | - | - | - |
| 92 | 60.23 | 8.45 | 4.59 | 3.85 | 45.63 |
| 168 | 65.89 | 9.37 | 4.74 | 4.63 | 49.44 |
| 188 | - | - | - | - | - |
| 193A | 59.49 | 7.76 | 4.57 | 3.19 | 41.16 |
| 217 | 63.57 | 9.74 | 5.79 | 3.95 | 40.51 |
| 237 | - | - | - | - | - |
| 239 | 61.42 | 8.13 | 4.62 | 3.51 | 43.18 |
| 259 | 69.12 | 8.21 | 3.09 | 5.12 | 62.38 |
| 295 | - | - | - | - | - |
| 317 | 67.28 | 8.20 | 3.78 | 4.42 | 53.95 |
| 375 | 65.97 | 9.12 | 4.95 | 4.17 | 45.73 |
| 553 | - | - | - | - | - |
| 577 | 58.44 | 9.20 | 4.44 | 4.77 | 51.79 |
| 579 | 60.26 | 7.59 | 3.46 | 4.13 | 54.43 |
| 582 | - | - | - | - | - |
| 620 | 59.16 | 8.01 | 3.02 | 4.99 | 62.27 |
| 670 | 59.86 | 9.17 | 5.08 | 4.09 | 44.60 |
| 842 | 56.76 | 7.15 | 3.11 | 4.05 | 56.56 |

## **Appendix 1.15 Middle adult metacarpal measurements (right)**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Individual | Length (mm) | Width (mm) | Medullary Cavity (mm) | Cortical thickness (mm) | Index (thickness/width) |
| 3 | 62.70 | 8.50 | 4.17 | 4.33 | 50.93 |
| 11 | 53.17 | 6.94 | 3.25 | 3.70 | 53.23 |
| 74 | 63.77 | 8.66 | 5.06 | 3.60 | 41.62 |
| 92 | 60.40 | 8.12 | 4.04 | 4.08 | 50.24 |
| 168 | 66.90 | 8.95 | 4.13 | 4.82 | 53.83 |
| 188 | 69.48 | 9.02 | 4.11 | 4.91 | 54.47 |
| 193A | 60.65 | 7.18 | 3.33 | 3.85 | 53.68 |
| 217 | 64.10 | 9.21 | 5.57 | 3.64 | 39.54 |
| 237 | 61.09 | 7.35 | 3.15 | 4.20 | 57.09 |
| 239 | 62.40 | 8.16 | 4.83 | 3.33 | 40.78 |
| 259 | 69.75 | 8.14 | 3.06 | 5.08 | 62.40 |
| 295 | 65.13 | 8.66 | 3.80 | 4.86 | 56.10 |
| 317 | 66.40 | 7.48 | 3.33 | 4.16 | 55.56 |
| 375 | - | - | - | - | - |
| 553 | 62.70 | 9.54 | 5.12 | 4.42 | 46.33 |
| 577 | - | - | - | - | - |
| 579 | 60.07 | 7.85 | 2.75 | 5.11 | 65.04 |
| 582 | 64.93 | 9.15 | 3.97 | 5.17 | 56.57 |
| 620 | 58.95 | 7.31 | 3.26 | 4.05 | 55.42 |
| 670 | - | - | - | - | - |
| 842 | 54.85 | 6.80 | 2.73 | 4.07 | 59.88 |

## **Appendix 1.16 Old adult metacarpal measurements (left)**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Individual | Length (mm) | Width (mm) | Medullary Cavity (mm) | Cortical thickness (mm) | Index (thickness/width) |
| 53 | - | - | - | - | - |
| 125 | 64.43 | 7.85 | 3.83 | 4.03 | 51.26 |
| 128 | 64.28 | 8.95 | 5.11 | 3.84 | 42.92 |
| 132 | 64.63 | 8.03 | 4.57 | 3.46 | 43.09 |
| 151 | 69.30 | 8.36 | 4.05 | 4.30 | 51.50 |
| 189 | 54.86 | 8.45 | 4.33 | 4.12 | 48.75 |
| 242 | 65.22 | 8.16 | 4.74 | 3.42 | 41.91 |
| 289 | 55.62 | 8.43 | 4.95 | 3.48 | 41.31 |
| 329 | 62.40 | 10.98 | 5.56 | 5.43 | 49.40 |
| 333 | 61.86 | 8.74 | 4.38 | 4.36 | 49.85 |
| 334 | 63.08 | 9.58 | 4.67 | 4.91 | 51.24 |
| 406 | 58.12 | 8.41 | 4.58 | 3.83 | 45.53 |
| 427 | - | - | - | - | - |
| 428 | - | - | - | - | - |
| 471 | 65.23 | 7.91 | 4.42 | 3.48 | 44.07 |
| 491 | 62.16 | 8.41 | 3.19 | 5.21 | 62.01 |
| 527 | 65.72 | 9.25 | 5.28 | 3.97 | 42.94 |
| 592 | 67.58 | 9.50 | 4.03 | 5.48 | 57.64 |
| 611 | 66.30 | 9.46 | 5.52 | 3.95 | 41.70 |
| 615 | 61.82 | 8.46 | 3.83 | 4.63 | 54.76 |
| 649 | 64.63 | 8.33 | 3.60 | 4.73 | 56.74 |
| 654 | 65.02 | 8.22 | 3.18 | 5.04 | 61.32 |
| 699 | 53.56 | 8.02 | 3.30 | 4.72 | 58.81 |
| 714 | - | - | - | - | - |
| 767 | 50.96 | 7.73 | 3.79 | 3.93 | 50.91 |
| 828 | - | - | - | - | - |
| 876 | 58.16 | 7.55 | 3.35 | 4.20 | 55.66 |
| 903 | 66.09 | 9.78 | 5.40 | 4.38 | 44.80 |

## **Appendix 1.17** **Old adult metacarpal measurements (right)**

|  |  |
| --- | --- |
| **Data table key** | |
| **-** | Indicates a trait that was absent or could not be scored |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Individual | Length (mm) | Width (mm) | Medullary Cavity (mm) | Cortical thickness (mm) | Index (thickness/width) |
| 53 | 63.74 | 7.97 | 5.54 | 2.43 | 30.46 |
| 125 | - | - | - | - | - |
| 128 | 63.64 | 8.32 | 4.12 | 4.20 | 50.48 |
| 132 | - | - | - | - | - |
| 151 | 68.30 | 8.36 | 3.74 | 4.62 | 55.29 |
| 189 | 56.22 | 7.62 | 2.75 | 4.87 | 63.95 |
| 242 | - | - | - | - | - |
| 289 | - | - | - | - | - |
| 329 | - | - | - | - | - |
| 333 | 61.43 | 8.13 | 4.11 | 4.03 | 49.51 |
| 334 | 62.21 | 8.69 | 4.30 | 4.38 | 50.46 |
| 406 | 58.12 | 8.41 | 4.58 | 3.83 | 45.53 |
| 427 | 64.90 | 8.53 | 4.24 | 4.29 | 50.31 |
| 428 | 58.33 | 9.06 | 4.13 | 4.92 | 54.37 |
| 471 | 63.40 | 7.67 | 3.81 | 3.85 | 50.26 |
| 491 | 63.68 | 7.51 | 2.65 | 4.86 | 64.67 |
| 527 | 64.36 | 8.76 | 3.55 | 5.21 | 59.49 |
| 592 | 66.38 | 8.74 | 4.07 | 4.67 | 53.47 |
| 611 | - | - | - | - | - |
| 615 | - | - | - | - | - |
| 649 | 63.39 | 8.28 | 4.13 | 4.14 | 50.08 |
| 654 | 64.13 | 8.78 | 3.33 | 5.45 | 62.11 |
| 699 | 54.74 | 8.29 | 4.56 | 3.72 | 44.93 |
| 714 | 56.50 | 8.39 | 5.40 | 2.98 | 35.56 |
| 767 | 50.29 | 7.29 | 3.54 | 3.75 | 51.44 |
| 828 | - | - | - | - | - |
| 876 | 57.48 | 7.49 | 3.86 | 3.63 | 48.41 |
| 903 | 65.59 | 10.14 | 5.02 | 5.12 | 50.52 |

# **Appendix 2: Recording forms**

## **Appendix 2.1 Muscle attachment sites recording form**

Date  
Specimen Number  
Observer  
Age-at-Death

**Muscle Attachment Sites**

**Muscle attachment site assessment** (from Mariotti et al. 2004, 2007)

|  |  |  |  |
| --- | --- | --- | --- |
| **Left Humerus** | | | |
|  | **Robusticity** | **Proliferative Enthesopathy** | **Erosive Enthesopathy** |
| **Deltoideus** |  |  |  |
| **Latisimus dorsi/ Teres Major** |  |  |  |
| **Pectoralis major** |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| **Right Humerus** | | | |
|  | **Robusticity** | **Proliferative Enthesopathy** | **Erosive Enthesopathy** |
| **Deltoideus** |  |  |  |
| **Latisimus dorsi/ Teres Major** |  |  |  |
| **Pectoralis major** |  |  |  |

|  |
| --- |
| Robusticity scoring: - =could not be assessed; 0= not present; 1a = slight impression; 1b = low development; 1c = medium development; 2 = high development; 3 = very high development |
| Proliferative scoring: - = could not be assessed; 0= not present; 1= minimal exocytosis (1mm); 2 = clear exocytosis (1-4mm); 3= substantial exocytosis (>4mm) |
| Erosive scoring: - = could not be assessed; 0= not present; 1= presence of fine porosity (<1mm); 2= diffuse porosity or small erosion; 3= multiple areas of erosion or one deep erosive area (>4mm) |

|  |  |
| --- | --- |
| **Humeral Length(cm)** | |
| Left |  |
| Right |  |

|  |
| --- |
| Notes: |

**Appendix 2.2: Age and sex recording form**

**Age Estimation – Juvenile**

**Dental Development** (following Gustafson and Koch 1974)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Deciduous Dentition** | | | | | | | | | | |
| **Maxilla** | | | | |  | **Mandible** | | | | |
|  | **Left** | **Right** | **Unsided 1** | **Unsided 2** |  |  | **Left** | **Right** | **Unsided 1** | **Unsided 2** |
| m2 |  |  |  |  |  | m2 |  |  |  |  |
| m1 |  |  |  |  |  | m1 |  |  |  |  |
| c |  |  |  |  |  | c |  |  |  |  |
| i2 |  |  |  |  |  | i2 |  |  |  |  |
| i1 |  |  |  |  |  | i1 |  |  |  |  |
|  | | | | | | | | | | |
| **Permanent Dentition** | | | | | | | | | | |
| **Maxilla** | | | | |  | **Mandible** | | | | |
|  | **Left** | **Right** | **Unsided 1** | **Unsided 2** |  |  | **Left** | **Right** | **Unsided 1** | **Unsided 2** |
| M2 |  |  |  |  |  | M2 |  |  |  |  |
| M1 |  |  |  |  |  | M1 |  |  |  |  |
| PM2 |  |  |  |  |  | PM2 |  |  |  |  |
| PM1 |  |  |  |  |  | PM1 |  |  |  |  |
| C |  |  |  |  |  | C |  |  |  |  |
| I2 |  |  |  |  |  | I2 |  |  |  |  |
| I1 |  |  |  |  |  | I1 |  |  |  |  |
|  |  | | | | | | | |  |  |
| 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 | | | | | | | | | | |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Long Bone Length**  (in mm) | | |  |  | **Epiphyseal Fusion** (following Cardoso 2008 a, b) - Fusion should be scored on **left** bone only. If left is not present right should be scored. | | | | | |
|  | **Left** | **Right** |  |  | 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 | | | | | |
| **Femur** |  |  |  |  |
| **Tibia** |  |  |  |  |
| **Fibula** |  |  |  |  |
| **Humerus** |  |  |  |  |
| **Radius** |  |  |  |  |
| **Ulna** |  |  |  |  |  | **Side** | **Epiphysis 1** | **Epiphysis 2** | **Epiphysis 3** | **Epiphysis 4** |
|  |  |  |  |  | **Femur** |  |  |  |  |  |
|  |  |  |  |  | **Tibia** |  |  |  |  |  |
| **Notes:** | | | |  | **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 – Juvenile Age**

|  |  |  |  |
| --- | --- | --- | --- |
| 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** | | |  | **Mandible** | | |
|  | **Left** | **Right** |  |  | **Left** | **Right** |
| M3 |  |  |  | M3 |  |  |
| M2 |  |  |  | M2 |  |  |
| M1 |  |  |  | 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 O. For those 16+ years the features of the skull/mandible and pelvis set out in Buikstra and Ubelaker (1994) will be used.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Pelvis** | | |  | **Skull** | | |
|  | **Left** | **Right** |  |  | **Left** | **Right** |
| Ventral Arc (1-3) \* |  |  |  | Nuchal Crest (1-5) \* |  | |
| Subpubic Concavity (1-3) \* |  |  |  | Mastoid Process (1-5) \* |  |  |
| Ischiopubic Ramus Ridge (1-3) \* |  |  |  | Supraorbital Margin (1-5) \* |  |  |
| Greater Sciatic Notch (1-5) \* |  |  |  | Glabella (1-5) \* |  | |
| Preauricular Sulcus (1-4) \* |  |  |  | Mental Eminence (1-5) \* |  | |
|  | | |  |  |  | |
| **Estimated Sex** |  | |  | **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 BOsen 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:** | | | | | | | | |

1Record 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 BOsen et al. 2002

\* Superior and Inferior Posterior Iliac Crest

**Summary Information – Adult Age and Sex**

|  |  |
| --- | --- |
| Age1 |  |
| Sex2 |  |
|  | |
| 1Y adult (20-34), M adult (35-49), O adult (50+)  2After Buikstra and Ubelaker (1994: 21): undetermined; female; probable female; ambiguous; probable male; male | |

# **Appendix 3: Observer error**

## **Appendix 3.1 Inter-observer error with five point scale (cells shaded in red indicate observer disagreement)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Deltoid (left) | | | | | Deltoid (right) | | | | |
|  | Observer | | | |  | Observer | | | |
| Sk# | Obs 1 | Obs 2 | Obs 3 | Obs 4 | **Sk#** | Obs 1 | Obs 2 | Obs 3 | Obs 4 |
| 189 | 1c | 1c | 1c | 1b | **189** | 1b | 1c | 1b | 1c |
| 237 | 1c | 2 | 2 | 1c | **237** | 1b | 1c | 1c | 1c |
| 259 | 1b | 1c | 1b | 1b | **259** | 1a | 1b | 1a | 1a |
| 284 | 1b | 1c | 3 | 2 | **284** | 1a | 1c | 1c | 1c |
| 289 | 1c | 2 | 1c | 1c | **289** | 2 | 2 | 3 | 2 |
| 322 | 1a | 1b | 1b | 1b | **322** | 1a | 1c | 1a | 1b |
| 406 | 1b | 2 | 1c | 2 | **406** | 1b | 2 | 1b | 1c |
| 714 | 1a | 2 | 1c | - | **714** | 1a | 2 | 1c | - |
| 903 | 1c | 2 | 1c | 1b | **903** | 1b | 2 | 1b | 1c |
| 939 | 2 | 2 | 3 | 1c | **939** | 1 | 2 | 2 | - |
| LDTM (left) | | | | | **LDTM (right)** | | | | |
|  | Observer | | | |  | Observer | | | |
| Sk# | Obs 1 | Obs 2 | Obs 3 | Obs 4 | **Sk#** | Obs 1 | Obs 2 | Obs 3 | Obs 4 |
| 189 | 1b | 1c | 1b | 1c | **189** | - | - | - | - |
| 237 | 1b | 2 | 1c | 1b | **237** | 2 | 1b | 1b | 3 |
| 259 | 1a | 1b | 1a | 1b | **259** | 1a | 1b | 1a | 1a |
| 284 | 2 | 1a | 1a | 1a | **284** | 2 | 1a | 1a | 1a |
| 289 | 2 | 1c | 1c | 2 | **289** | 3 | 1c | 2 | 2 |
| 322 | 1b | 1b | 3 | 1c | **322** | 1b | 1b | 1b | 1b |
| 406 | 2 | 2 | 2 | 2 | **406** | 2 | 1c | 1c | 1c |
| 714 | 2 | 2 | 2 | - | **714** | 2 | 2 | 2 | 2 |
| 903 | 1b | 2 | 3 | 3 | **903** | 1a | 1b | 1b | 1c |
| 939 | 1b | 1c | 1b | 1c | **939** | 1b | 1c | 1b | 1b |
| Pectoral (left) | | | | | **Pectoral (right)** | | | | |
| Observer | | | | | Observer | | | | |
| Sk# | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 1 |
| 189 | 1b | 1c | 2 | 1b | **189** | - | - | - | - |
| 237 | 1c | 1c | 1c | 1b | **237** | 2 | 2 | 1c | 2 |
| 259 | 1a | 1c | 1b | 1b | **259** | 1a | 2 | 2 | 1b |
| 284 | 1a | 1c | 1b | 1b | **284** | 1a | 2 | 3 | 3 |
| 289 | 2 | 3 | 2 | 3 | **289** | 2 | 2 | 2 | 3 |
| 322 | 1a | 1b | 1b | 1b | **322** | 1a | 1c | 1b | 1b |
| 406 | 1c | 3 | 2 | 2 | **406** | 1c | 3 | 2 | 1c |
| 714 | 2 | 3 | 3 | - | **714** | 3 | 3 | 3 | 3 |
| 903 | 2 | 2 | 1c | 2 | **903** | 1c | 2 | 1b | 1c |
| 939 | 1b | 2 | 2 | 1b | **939** | 1b | 2 | 1c | 1b |

## **Appendix 3.2 Inter-observer error with three point scale (cells shaded in red indicate observer disagreement)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Deltoid (left) | | | | | Deltoid (right) | | | | |
|  | Observer | | | |  | Observer | | | |
| Sk# | Obs 1 | Obs 2 | Obs 3 | Obs 4 | **Sk#** | Obs 1 | Obs 2 | Obs 3 | Obs 4 |
| 189 | 1 | 1 | 1 | 1 | **189** | 1 | 1 | 1 | 1 |
| 237 | 1 | 2 | 2 | 1 | **237** | 1 | 1 | 1 | 1 |
| 259 | 1 | 1 | 1 | 1 | **259** | 1 | 1 | 1 | 1 |
| 284 | 1 | 1 | 3 | 2 | **284** | 1 | 1 | 1 | 1 |
| 289 | 1 | 2 | 1 | 1 | **289** | 2 | 2 | 3 | 2 |
| 322 | 1 | 1 | 1 | 1 | **322** | 1 | 1 | 1 | 1 |
| 406 | 1 | 2 | 1 | 2 | **406** | 1 | 2 | 1 | 1 |
| 714 | 1 | 2 | 1 | - | **714** | 1 | 2 | 1 | - |
| 903 | 1 | 2 | 1 | 1 | **903** | 1 | 2 | 1 | 1 |
| 939 | 2 | 2 | 3 | 1 | **939** | 1 | 2 | 2 | - |
| LDTM (left) | | | | | **LDTM (right)** | | | | |
|  | Observer | | | |  | Observer | | | |
| Sk# | Obs 1 | Obs 2 | Obs 3 | Obs 4 | **Sk#** | Obs 1 | Obs 2 | Obs 3 | Obs 4 |
| 189 | 1 | 1 | 1 | 1 | **189** | - | - | - | - |
| 237 | 1 | 2 | 1 | 1 | **237** | 2 | 1 | 1 | 3 |
| 259 | 1 | 1 | 1 | 1 | **259** | 1 | 1 | 1 | 1 |
| 284 | 2 | 1 | 1 | 1 | **284** | 2 | 1 | 1 | 1 |
| 289 | 2 | 1 | 1 | 2 | **289** | 3 | 1 | 2 | 2 |
| 322 | 1 | 1 | 3 | 1 | **322** | 1 | 1 | 1 | 1 |
| 406 | 2 | 2 | 2 | 2 | **406** | 2 | 1 | 1 | 1 |
| 714 | 2 | 2 | 2 | - | **714** | 2 | 2 | 2 | 2 |
| 903 | 1 | 2 | 3 | 3 | **903** | 1 | 1 | 1 | 1 |
| 939 | 1 | 1 | 1 | 1 | **939** | 1 | 1 | 1 | 1 |
| Pectoral (left) | | | | | **Pectoral (right)** | | | | |
| Observer | | | | | Observer | | | | |
| Sk# | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 1 |
| 189 | 1 | 1 | 2 | 1 | **189** | - | - | - | - |
| 237 | 1 | 1 | 1 | 1 | **237** | 2 | 2 | 1 | 2 |
| 259 | 1 | 1 | 1 | 1 | **259** | 1 | 2 | 2 | 1 |
| 284 | 1 | 1 | 1 | 1 | **284** | 1 | 2 | 3 | 3 |
| 289 | 2 | 3 | 2 | 3 | **289** | 2 | 2 | 2 | 3 |
| 322 | 1 | 1 | 1 | 1 | **322** | 1 | 1 | 1 | 1 |
| 406 | 1 | 3 | 2 | 2 | **406** | 1 | 3 | 2 | 1 |
| 714 | 2 | 3 | 3 | - | **714** | 3 | 3 | 3 | 3 |
| 903 | 2 | 2 | 1 | 2 | **903** | 1 | 2 | 1 | 1 |
| 939 | 1 | 2 | 2 | 1 | **939** | 1 | 2 | 1 | 1 |

## **Appendix 3.3 Intra-observer error with five point scale (cells shaded in red indicate observer disagreement)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test 1 | | | | | |
| Deltoid (left) | | | **Deltoid (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 2 | 1c | 1c | **2** | 1a | 1a |
| 3 | 1c | 1c | **3** | 1a | 1c |
| 527 | 1b | 1c | **527** | 2 | 2 |
| 539 | 2 | 1c | **539** | 1c | 1a |
| 705 | 1c | 2 | **705** | 1b | 1b |
| LDTM (left) | | | **LDTM (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 2 | 1c | 1c | **2** | 1b | 1b |
| 3 | 2 | 2 | **3** | 1a | 1c |
| 527 | 1b | 1c | **527** | 1c | 3 |
| 539 | 1c | 2 | **539** | - | 1c |
| 705 | 2 | 2 | **705** | 1b | 1c |
| Pectoral (left) | | | **Pectoral (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 2 | 1c | 1b | **2** | 1c | 1c |
| 3 | 1c | 2 | **3** | 2 | 2 |
| 527 | 3 | 3 | **527** | 3 | 3 |
| 539 | 1b | 1b | **539** | 1c | 1c |
| 705 | 1c | 1b | **705** | 3 | 3 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test 2 | | | | | |
| Deltoid (left) | | | **Deltoid (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 189 | 1b | 1b | **189** | 1c | 1c |
| 237 | 1c | 1b | **237** | 1c | 1c |
| 259 | 1b | 1c | **259** | 1a | 1b |
| 284 | 2 | 3 | **284** | 1c | 1b |
| 289 | 1c | 1a | **289** | 2 | 2 |
| 322 | 1b | 1a | **322** | 1b | 1b |
| 406 | 2 | 2 | **406** | 1c | 1c |
| 714 | - | 1a | **714** | - | 1a |
| 903 | 1b | 1b | **903** | 1c | 1c |
| 939 | 1c | 1c | **939** | - | 2 |
| LDTM (left) | | | **LDTM (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 189 | 1c | 1c | **189** | - | - |
| 237 | 1b | 1c | **237** | 3 | 3 |
| 259 | 1b | 1b | **259** | 1a | 1b |
| 284 | 1a | 1b | **284** | 1a | 1a |
| 289 | 2 | 2 | **289** | 2 | 2 |
| 322 | 1c | 1c | **322** | 1b | 1b |
| 406 | 2 | 3 | **406** | 1c | 1b |
| 714 | - | - | **714** | 2 | 1c |
| 903 | 3 | 3 | **903** | 1c | 1c |
| 939 | 1c | 1c | **939** | 1b | 1b |
| Pectoral (left) | | | **Pectoral (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 189 | 1b | 1b | **189** | - | - |
| 237 | 1b | 1c | **237** | 2 | 3 |
| 259 | 1b | 1b | **259** | 1b | 1b |
| 284 | 1b | 1b | **284** | 3 | 2 |
| 289 | 3 | 2 | **289** | 3 | 3 |
| 322 | 1b | 1b | **322** | 1b | 1b |
| 406 | 2 | 1c | **406** | 1c | 1b |
| 714 | - | 3 | **714** | 3 | 3 |
| 903 | 2 | 2 | **903** | 1c | 1c |
| 939 | 1b | 1b | **939** | 1b | 1b |

## **Appendix 3.4 Intra-observer error with three point scale (cells shaded in red indicate observer disagreement)**

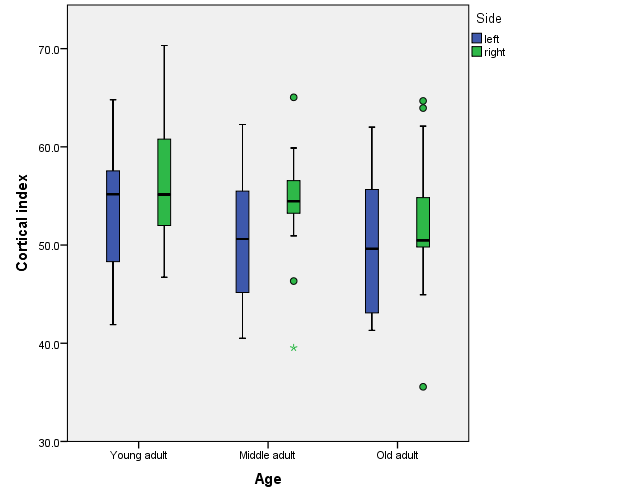
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test 1 | | | | | |
| Deltoid (left) | | | **Deltoid (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 2 | 1 | 1 | **2** | 1 | 1 |
| 3 | 1 | 1 | **3** | 2 | 2 |
| 527 | 1 | 1 | **527** | 1 | 1 |
| 539 | 2 | 1 | **539** | 1 | 2 |
| 705 | 1 | 2 | **705** | 2 | 2 |
| LDTM (left) | | | **LDTM (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 2 | 1 | 1 | **2** | 1 | 1 |
| 3 | 1 | 1 | **3** | 1 | 1 |
| 527 | 2 | 2 | **527** | 1 | 3 |
| 539 | 1 | 1 | **539** | - | 1 |
| 705 | 1 | 1 | **705** | 1 | 1 |
| Pectoral (left) | | | **Pectoral (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 2 | 1 | 1 | **2** | 1 | 1 |
| 3 | 1 | 2 | **3** | 2 | 2 |
| 527 | 3 | 3 | **527** | 3 | 3 |
| 539 | 1 | 1 | **539** | 1 | 1 |
| 705 | 1 | 1 | **705** | 3 | 3 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test 1 | | | | | |
| Deltoid (left) | | | **Deltoid (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 189 | 1 | 1 | **189** | 1 | 1 |
| 237 | 1 | 1 | **237** | 1 | 1 |
| 259 | 1 | 1 | **259** | 1 | 1 |
| 284 | 2 | 3 | **284** | 1 | 1 |
| 289 | 1 | 1 | **289** | 2 | 2 |
| 322 | 1 | 1 | **322** | 1 | 1 |
| 406 | 2 | 2 | **406** | 1 | 1 |
| 714 | - | 1 | **714** | - | 1 |
| 903 | 1 | 1 | **903** | 1 | 1 |
| 939 | 1 | 1 | **939** |  |  |
| LDTM (left) | | | **LDTM (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 189 | 1 | 1 | **189** | - | - |
| 237 | 1 | 1 | **237** | 3 | 3 |
| 259 | 1 | 1 | **259** | 1 | 1 |
| 284 | 1 | 1 | **284** | 1 | 1 |
| 289 | 2 | 2 | **289** | 2 | 2 |
| 322 | 1 | 1 | **322** | 1 | 1 |
| 406 | 2 | 3 | **406** | 1 | 1 |
| 714 | - | - | **714** | 2 | 1 |
| 903 | 3 | 3 | **903** | 1 | 1 |
| 939 | 1 | 1 | **939** | 1 | 1 |
| Pectoral (left) | | | **Pectoral (right)** | | |
| Sk# | Obs 1 | Obs 2 | **Sk#** | Obs 1 | Obs 2 |
| 189 | 1 | 1 | **189** | - | - |
| 237 | 1 | 1 | **237** | 2 | 3 |
| 259 | 1 | 1 | **259** | 1 | 1 |
| 284 | 1 | 1 | **284** | 3 | 2 |
| 289 | 3 | 2 | **289** | 3 | 3 |
| 322 | 1 | 1 | **322** | 1 | 1 |
| 406 | 2 | 1 | **406** | 1 | 1 |
| 714 | - | 3 | **714** | 3 | 3 |
| 903 | 2 | 2 | **903** | 1 | 1 |
| 939 | 1 | 1 | **939** | 1 | 1 |

# **Appendix 4: Results excluding possible non-Roman individuals**

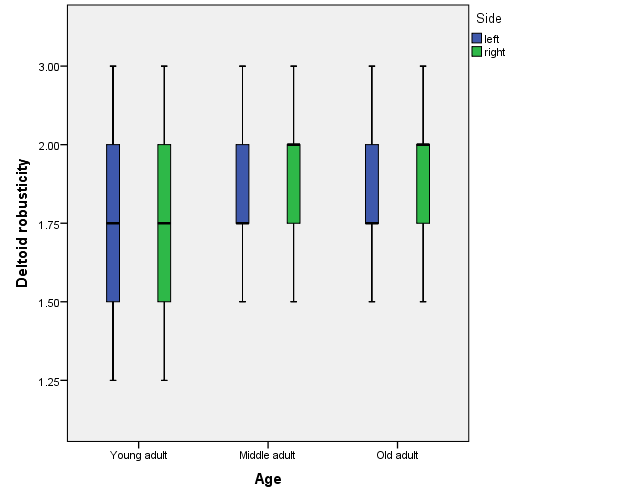
## **Appendix 4.1 Cortical index data excluding possible non-Roman individuals**

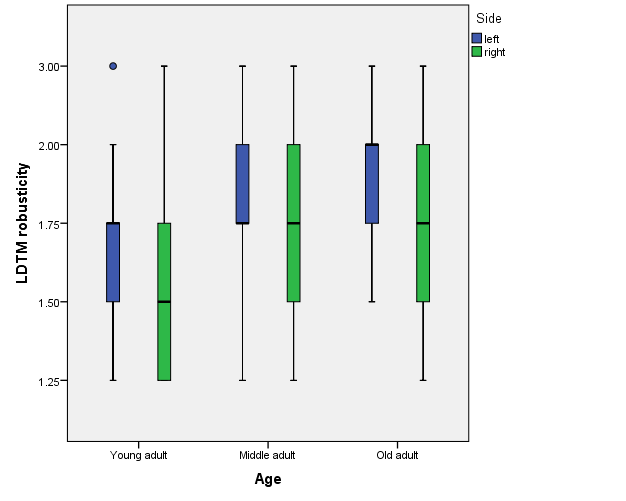
|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Age group** | **Side** | **Number** | **Minimum** | **Maximum** | **Mean** | **Median** | **Standard deviation** |
| Young | Left | 19 | 41.9 | 64.8 | 53.9 | 55.2 | 6.4 |
| Right | 23 | 46.7 | 70.3 | 56.2 | 55.1 | 6.3 |
| Middle | Left | 12 | 40.5 | 62.3 | 50.4 | 50.6 | 6.8 |
| Right | 13 | 39.5 | 65.0 | 54.0 | 54.5 | 6.2 |
| Old | Left | 22 | 41.3 | 62.0 | 49.7 | 49.6 | 6.7 |
| Right | 19 | 35.6 | 64.7 | 52.2 | 50.5 | 7.0 |
| Undetermined | Left | 1 | 54.8 | 54.8 | 54.8 | 54.8 | - |
| Right | - | - | - | - | - | - |

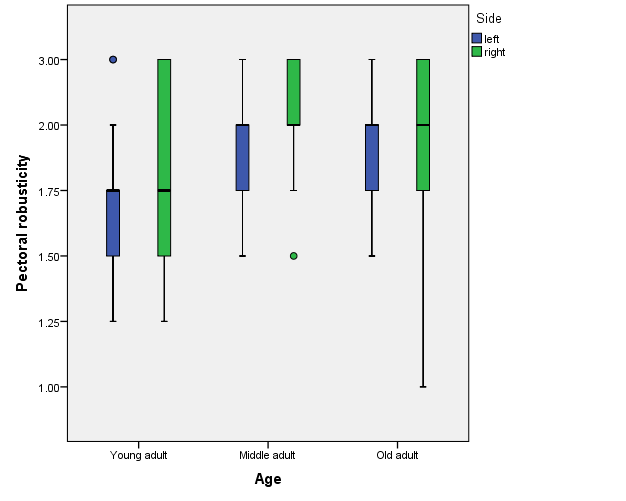


## **Appendix 4.2 Entheseal robusticity data excluding possible non-Roman individuals**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Age group** | **Enthesis** | **Number of observable entheses** | | **Mean** | | **Median** | | **Standard deviation** | |
| Left | Right | Left | Right | Left | Right | Left | Right |
| Young | Deltoid | 23 | 21 | 1.76 | 1.77 | 1.75 | 1.77 | 0.47 | 0.38 |
| LDTM | 21 | 19 | 1.65 | 1.63 | 1.75 | 1.63 | 0.39 | 0.43 |
| Pectoral | 20 | 22 | 1.78 | 2.01 | 1.75 | 1.75 | 0.46 | 0.65 |
| Middle | Deltoid | 11 | 14 | 2.00 | 1.91 | 1.75 | 1.88 | 0.51 | 0.36 |
| LDTM | 15 | 14 | 1.83 | 1.89 | 1.75 | 1.75 | 0.40 | 0.52 |
| Pectoral | 14 | 15 | 2.02 | 2.40 | 2.00 | 2.00 | 0.44 | 0.60 |
| Old | Deltoid | 23 | 23 | 1.99 | 2.05 | 1.75 | 2.00 | 0.51 | 0.54 |
| LDTM | 23 | 22 | 2.09 | 1.91 | 2.00 | 1.75 | 0.51 | 0.50 |
| Pectoral | 22 | 21 | 2.10 | 2.27 | 2.00 | 2.00 | 0.53 | 0.68 |

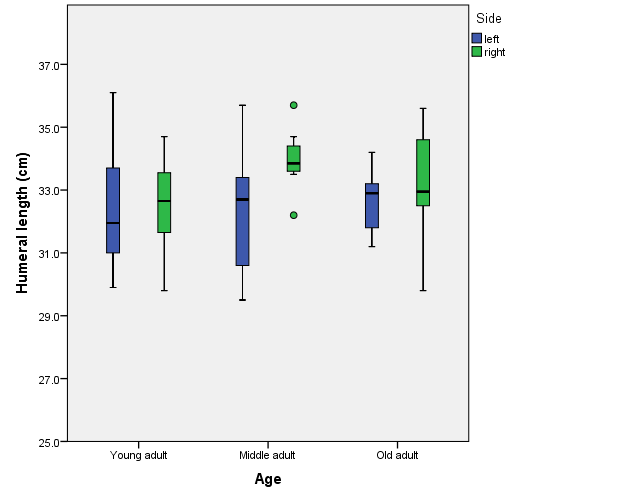






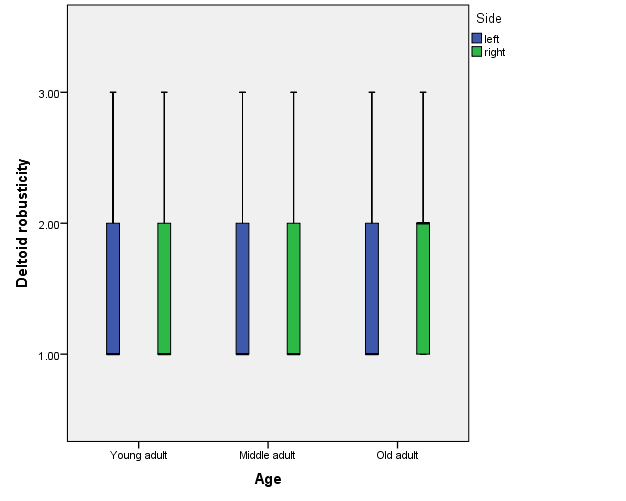
## **Appendix 4.3 Humeral length data excluding possible non-Roman individuals**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Age group** | **Side** | **Number of measurable humeri** | **Mean** | **Median** | **Standard deviation** |
| Young | Left | 22 | 32.4 | 32.0 | 1.8 |
| Right | 23 | 32.6 | 32.6 | 1.6 |
| Middle | Left | 15 | 32.2 | 32.7 | 1.7 |
| Right | 10 | 33.5 | 33.7 | 1.3 |
| Old | Left | 14 | 32.6 | 32.9 | 1.0 |
| Right | 18 | 33.3 | 33.0 | 1.6 |

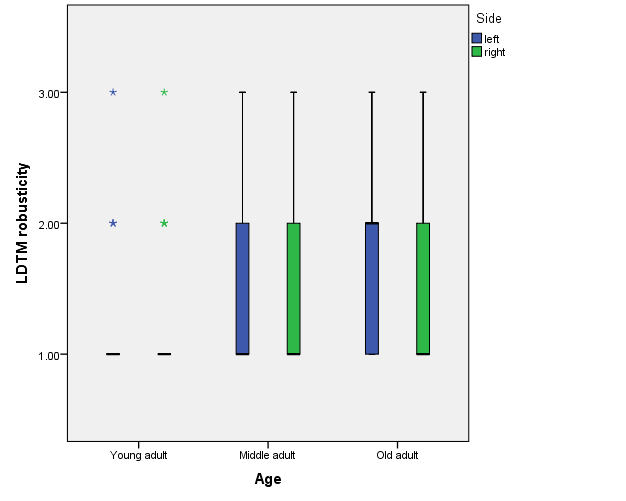


# **Appendix 5: Entheseal robusticity measured using the three point scale**

## **Appendix 5.1 Deltoid robusticity represented using the three point scale**



## **Appendix 5.2 LDTM robusticity represented using the three point scale**



## **Appendix 5.3 Pectoral robusticity represented using the three point scale**

