Entheseal Changes in an Ancient Egyptian Skeletal Collection

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by
Sophie Minnig
San Francisco, California
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CERTIFICATION OF APPROVAL

I certify that I have read *Entheseal Changes in an Ancient Egyptian Skeletal Collection* by Sophie Minnig, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requests for the degree: Master of Arts in Anthropology at San Francisco State University.

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The purpose of this study is to examine the effects of age and sex on entheseal changes, as well as test for asymmetry in an ancient Egyptian skeletal collection. Entheseal changes refer to the morphological changes that occur on the bone surface where tendons and ligaments attach. Such morphological changes have been widely considered to reflect past activity patterns. However, recent bioarchaeological and biomedical research has shown biological factors such as age, sex, and body size to be significantly correlated with various types of entheseal change (Henderson et al. 2013, 2017; Wilczak 1998; Benjamin et al. 2008, 2009; Foster et al. 2014). This study utilizes the new Coimbra method (Henderson et al. 2013, 2015) to score and record entheseal changes at five fibrocartilaginous entheses: infra- and supra-spinatus, subscapularis insertion, common flexor origin, common extensor origin, and biceps *brachii* insertion. The results show bone formation tends to increase with age in males. Erosion tends to increase in females, particularly after age 50 with weaker age trends evident in males. Conversely, there was a slight tendency for fine porosity to be more frequent in individuals thirty years and younger. There was a lack of asymmetry observed within this sample, which argues against the notion that entheseal changes result from habitual mechanical stress. Within this relatively gracile population, there was significant sexual dimorphism in two humeral measurements: the vertical head diameter, and distal articular breadth. Further research is suggested to examine differences between socio-cultural classes, effects of pathological conditions, and to validate the reported impacts of biological factors like age and sex using a larger Egyptian sample.

I certify that the Abstract is a correct representation of the content of this thesis.

Cynthia Wilczak, Thesis Committee   Date

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CHAPTER 1

INTRODUCTION

Bioarchaeology as a discipline seeks to better understand human behavior and cultural practices through careful analyses of human skeletal remains. One manner in which this is done is through examination of the morphological variations that occur to the bone surface at tendon and ligament attachment sites (Hawkey and Merbs 1995; Henderson et al. 2013, 2016, 2017; Villotte 2006, 2013; Mariotti et al. 2007). Such morphological variations are referred to as 'entheseal changes.' The enthesis is the point on a bone where tendons and ligaments attach, and human skeletal remains display macroscopic variations on the bone surface at these attachment sites. Bioarchaeologists have typically examined entheseal changes as being indicative of, or directly related to, past activity patterns and occupations. While some features and variations of entheseal change may be caused by or related to those factors, it has more recently become clear that entheseal changes have a multifactorial etiology.

Bioarchaeological examinations of entheseal changes have expanded outside of a sole focus on activity patterns and occupations and are now looking at how both mechanical and biological factors – like age and sex– cause or affect entheseal changes. Recent advances in this realm of bioarchaeology have incorporated the concept of a multifactorial etiology into developments of new methodologies, terminology, and more precise classifications of entheses and entheseal changes. Doing so has required researchers to incorporate biomedical research on living populations that aims to answer the same questions: how do entheses form, and how and why do a variety of morphological changes occur at these attachment sites?

Biomedical research has greatly contributed towards answering the first question of how entheses form and develop (Benjamin and Ralphs 1998; Benjamin and McGonagle 2001, 2009; Benjamin et al. 2006; Benjamin et al. 2008). Obtaining a foundational set of knowledge about how different types of soft tissue attach to bone in different ways thereby creating the attachment site, or enthesis, helps bioarchaeologists develop the appropriate research questions. This is critical information in further understanding variations of entheseal changes, as seen in skeletal remains of past populations, and has greatly informed the ways in which bioarchaeologists record and characterize entheseal changes.

Early studies classified entheseal changes as markers of occupational stress (MOS). MOS is a broad categorization that implies a direct correlation and causation between morphological changes at the entheses and physical stressors related to specific occupations. Later efforts established a more specified subcategory of MOS known as musculoskeletal stress markers (MSM), a term coined by Hawkey and Merbs (1995). Kennedy (1983) was among the first to describe MOS, and the ways in which something such as handedness could be determined through classifying various changes observed on skeletal remains including changes at the entheses. Kelley and Angel (1987) conducted a similar study using entheseal changes to describe occupational stressors seen on the skeletons of individuals excavated from the First African Baptist Church in Philadelphia. This study looked at general variations in upper limb muscle attachment sizes, using "muscle crests," (Kelley and Angel 1987: 207) as their primary feature.

Robusticity – which here often refers to variations in diaphyseal size of long bones, related to new bone formation at tendon and ligament attachment sites – was a critical component of many early studies looking at MOS and MSM. The use of muscle crests in Kelley and Angel's (1987) study, and the way in which they quantified changes based on size, is similar to Hawkey and Merbs' (1995) study, which focused largely on robusticity as a primary feature of change. Hawkey and Merbs (1995) applied a method that was initially developed by Hawkey (1988) to look at MSM in a Hudson Bay Eskimo population. They looked at three characteristics – one of which was robusticity – of muscle attachment sites that were separately scored on a scale of 0-3. The variation seen within this population was interpreted as being indicative of gendered division of labor, which continues to be a recurring area of interest for bioarchaeologists looking at MSM, or entheseal changes. Hawkey and Merbs (1995) attributed these morphological changes to a combination of habitual muscle strain known as microtrauma and possible overuse injuries known as macrotrauma. This research set a foundation for identification of more specific changes and further investigation into the multifactorial etiology of entheseal changes. Bioarchaeological inquiry on entheseal changes has shifted from considering general variations observed at muscle attachment sites, to recognizing more specific changes that could be examined as separate features.

Since the Hawkey and Merbs (1995) study, other methods have been developed to score and record entheseal changes. Mariotti and colleagues (2007) developed a scoring system that was based on Hawkey and Merbs (1995). They used a total of 23 different entheses and looked at variations in robusticity, enthesophytes, and enthesopathies. More recent studies and methods have sought to refine the ways in which entheseal changes classified are scored, and to look closely at more specific features with varying expressions of change. Villotte (2006) developed a method that distinguishes between the two different types of entheses, fibrous and fibrocartilaginous. The fibrous entheses occur on the diaphyses and metaphyses of bones and the fibrocartilaginous entheses occur at the epiphyses and apophyses of bones. This distinction between entheses types has been extensively covered in biomedical literature and is important because of the different ways soft tissue develops and attaches to bone at different entheses, and thereby responds to mechanical or biological factors differently (Benjamin and Ralphs 1998; Benjamin et al. 2002; Benjamin et al. 2008). Villotte (2006) further distinguished between two different zones of fibrocartilaginous entheses that are also separately observed in the Coimbra method. Dividing fibrocartilaginous entheses into two zones is a necessary distinction in that the properties of zone 1 are similar to that of fibrous entheses (Villotte 2013, Henderson et al. 2015; 2016).

In 2009 a group of bioarchaeologists met at the University of Coimbra in Portugal to review past MSM research and work towards developing a more effective methodology and set of terminology for future research. Three working groups were created at this meeting: methodology, terminology, and occupation. The methodology working group developed the first version of the Coimbra method, which was later revised during a second meeting in 2013 by altering some definitions and terminology to improve overall usability and rates of inter and intra-observer agreement (Henderson et al. 2013, 2015, 2016; Wilczak et al. 2017). The Coimbra method looks at a series of features specifically occurring at fibrocartilaginous entheses and was predominately focused on correlations between entheseal changes and biological factors such as age. The terminology working group concluded that the term entheseal changes was more appropriate than MSM in that MSM implies a mechanical, physical activity etiology, which may not necessarily be the case for all changes and variations observed at the entheses. The occupation working group worked towards developing a standard protocol for grouping occupations based on socio-cultural criteria and physical activity criteria.

This project aims at expanding upon findings from past entheseal change research that has used the Coimbra method to explore the association between entheseal changes and biological factors. An additional and important component of this project is the use of an ancient Egyptian skeletal collection, different from historic European populations that have typically been used in studies using the Coimbra method. The ancient Giza, Egypt skeletal collection housed at the Phoebe A. Hearst Museum at the University of California, Berkeley was chosen for this project. Thirty-three adult individuals will be utilized for this analysis, twenty-one of which are males and twelve of which are females. Five upper limb fibrocartilaginous entheses will be scored and recorded on each individual: infra- and supra-spinatus, subscapularis insertion, biceps brachii insertion, common flexor origin, and the common extensor origin. Age-at-death, sex, and body size proxies to determine a degree of sexual dimorphism will also be calculated. Statistical analysis using SPSS software will be utilized in running descriptive statistics as well as in testing for asymmetry and significance of sexual dimorphism.

The new Coimbra method will be applied in the recordation of entheseal changes (Henderson et al. 2015; 2013; 2010; Wilczak et al. 2017). Specifics of this method include a distinction between the two zones of fibrocartilaginous entheses: zone 1, or the margin of the enthesis, is defined as the most distant from the acute angle formed by the intersection of tendon and bone, and zone 2 is the remainder of the tendon attachment surface (Villotte 2013). A series of features on each zone of the enthesis are assessed and assigned a score of 0, 1, or 2 depending on the degree of expression except for textural change, which is scored as 0 or 1. For zone 1, the features that are scored are bone formation and erosion. For zone 2, the features that are scored are textural change, bone formation, erosion, fine porosity, macro-porosity, and cavitation. This researcher has undergone proper training on using the Coimbra method from one of the original developers, Dr. Cynthia Wilczak.

Sex will be determined using several reliable methods for sex estimation in human skeletal remains. The Phenice (1969) method will be the primary method utilized and is understood as the most reliable method for sex estimation. This method looks at three features on the sub-pubic region of the os coxae that, if present, are female specific traits. Other single feature scoring methods that look at the pre-auricular sulcus and greater sciatic notch of the os coxae and cranial features will also be employed to ensure accuracy (Walker et al. 1988; Buikstra and Ubelaker 1994).

Assessment of age-at-death is done through examination of epiphyseal closure, cranial suture closure, and normal changes to the auricular surface and pubic symphyseal surface. Several researchers have published visual guides and scoring systems to do so (Schaefer et al. 2009; Brooks and Suchey 1990; Meindl and Lovejoy 1985, 1989; Buikstra and Ubelaker 1994; Samworth and Gowland 2006). A combination of methods will be utilized to place individuals into broad age categories: 30 years of age or younger, 31-50 years of age, and 51 years of age or older. The methods utilized in this study have all been repeatedly tested and evaluated for reliability and accuracy (Djuric et al. 2006; Nawrocki 2010; Falys and Lewis 2010; Osborne et al. 2004; Buckberry 2015). Application of these methods will involve examination of epiphyseal fusion, cranial suture closure, and post-cranial degenerative changes, separating younger from older individuals. Subadult individuals under the age of 18 will be excluded from this analysis. This approach is taken with consideration of method reliability, and in an attempt to limit potential error in ageing each individual skeleton.

Individuals that appear to have pathological conditions that are known to affect the entheses will be eliminated in this analysis. Those conditions are: diffuse idiopathic skeletal hyperostosis (DISH); seronegative spondyloarthropathies such as ankylosing spondylitis; fluorosis; and acromegaly. Ankylosing spondylitis is an inflammatory joint and connective tissue diseases known to cause pathological changes to the entheses (Benjamin and McGonagle 2001; Hutton 1989). DISH is a non-inflammatory joint disease that is observed in the thoracic region of the spinal column and is similarly seen to have extraspinal manifestations at the entheses (Hutton 1989; Cammisa et al. 1998; Mader et al. 2013). Fluorosis and acromegaly are two metabolic disorders that are also known to affect the entheses, presence of which would obstruct the other features scored in this analysis (Henderson 2008).

Body size is considered in this study to assess sexual dimorphism. Body size values will be determined through osteometric measurements of the upper limb as body size proxies (Nolte and Wilczak 2013; Wilczak 1998). The following osteometric measurements are going to be utilized: maximum length of the humerus; vertical head diameter of the humerus; distal articular breadth of the humerus. These body size measurements will be plugged into equations that calculate the percentage of sexual dimorphism, and are further analyzed through an independent samples t-test.

There are several notable limitations associated with this study that merit discussion. The skeletal sample used for this study was highly fragmented, and only 30 of the available 80 individuals were utilized for analysis, which is a relatively small sample for statistical analysis. Because of the small sample size, along with a lack of variability and asymmetry, full analyses of the effects of age and sex on entheseal changes could not be properly calculated. Another notable issue with this population was a lack of clear sociocultural information on the majority of individuals utilized in this analysis. The archaeological background literature briefly discusses probable high societal rank of the individuals based on the cemeteries from which they derive. However, clear information about daily activities that would have been undertaken by these individuals was mostly unavailable. This is problematic because entheseal change research in bioarchaeology is largely interested in understanding the biomechanical effects on entheseal changes, and the Coimbra method specifically is interested in being able to isolate which features of entheseal change are more closely related to biological factors such as age, or biomechanics that would pertain to particular physical activities. Because of the lack of information available on this population and the particular individuals in this skeletal sample, it was not possible to discuss the potential effects of daily life activities or habitual muscle usage.

Despite these limitations and issues with analysis, descriptive statistics and frequencies will be done using SPSS statistical software. This ultimately allows for a general discussion on entheseal changes within this particular skeletal sample, which has not been previously examined. This will provide new insight as to how entheseal changes could be further investigated in ancient Egyptian populations using the Coimbra method, and which factors should be considered an emphasized in future analyses.

CHAPTER 2

LITERATURE REVIEW

La Cava (1959) is identified having been the first to describe inflammation at tendon attachment sites using the terms “enthesis,” and “enthesitis” (Villotte and Knüsel 2012). Those terms have continued to be utilized throughout the biomedical literature and in recent decades has been adopted by bioarchaeologists describing morphological changes to the bone surfaces at the entheses. Entheseal changes are examined in bioarchaeology in order to reconstruct past lifeways and understand how past activity patterns and occupations are directly reflected on human skeletal remains. This further requires an understanding of the multifactorial etiology of entheseal changes, and distinguishing between the many different features of entheseal change. This chapter emphasizes the importance of considering entheses through both a biomedical and bioarchaeological lens to achieve a comprehensive understanding of entheseal changes in the bioarchaeological record.

Examining entheseal changes on human skeletal remains requires some knowledge of the ways in which soft tissues develop and attach to bone. This has been extensively covered in the biomedical literature (Apostolakos et al. 2014; Benjamin and Ralphs 1998; Benjamin et al. 2002; Benjamin et al. 2006; Villotte and Knüsel 2012; Schlecht 2012). Of particular importance is the research conducted by Benjamin and various colleagues who have contributed greatly to an understanding of enthesis formation and development, and the various biomechanical properties that affect entheseal changes (Benjamin et al. 1986; Benjamin et al. 1992; Benjamin and Ralphs 1998; Benjamin and McGonagle 2001; Benjamin et al. 2002; Benjamin et al. 2004; Benjamin et al. 2006; Benjamin and McGonagle 2009; Benjamin et al. 2009). This research has evolved since the 1980s with discussions of various effects on entheses such as age, disease and different levels of physical activity, as well as looking at the different ways in which both fibrous and fibrocartilaginous entheses attach to bone.

Entheses Types

There are two types of entheses, fibrous and fibrocartilaginous, which need to be considered separately in both bioarchaeological and medical analyses (Apostolakos et al. 2014; Benjamin et al. 2006; Villotte and Knüsel 2012). The two types of entheses contrast with one another in their responses to mechanical loading, development and ontogeny, pathological conditions, and injuries. There are distinct morphological differences between the two with regard to collagen types, the ways in which they attach to bone, and the location and surface area where they exist on bone.

Fibrous entheses consist of dense fibrous connective tissue and exist along the diaphysis and attach to bone either indirectly via the periosteum or directly to bone (Apostolakos et al. 2014; Benjamin et al. 2006). These are the larger attachments such as that of the deltoideus muscle and the linea aspera. Benjamin and McGonagle (2009) have discussed one of the characterizing differences, which is the migration of fibrous entheses that occurs during development. Fibrous entheses that attach along the diaphysis naturally must migrate as the bone itself grows. This migration, as they discuss it, likely occurs due to an indirect attachment to the periosteum as opposed to directly to the bone. The rate of migration differs amongst the tendon attachments, and is dependent upon the position of the enthesis relative to the growth plate (Benjamin and McGonagle 2009; Grant et al. 1981; Hurov 1986).

The fibrocartilaginous entheses are structurally different from the fibrous entheses. These entheses occur at the metaphyses and epiphyses, and as opposed to fibrous entheses, they maintain their relative position throughout ontogenic processes. The other major difference is the ways in which fibrocartilaginous entheses attach the bone. There are four distinct zones that have been identified, which create a structural gradient of soft tissue to bone attachment (Benjamin et al. 2008; Benjamin and McGonagle 2009). The first zone is the dense connective tissue, which then transitions to uncalcified fibrocartilage, to calcified fibrocartilage, and then to bone. An important structural component, which is emphasized in both biomedical and in bioarchaeological research, is the tidemark (Benjamin et al. 1986, 2002; Villotte 2012). The tidemark is a distinct line separating the uncalcified and calcified zones of fibrocartilage. Apostolakos and colleagues (2014) describe the tidemark as being the “mechanical boundary between hard and soft tissues” (Apostolakos et al. 2014:337). In dry bone at the fibrocartilaginous tendon attachment sites, the calcified zone remains intact after maceration of soft tissue, which definitively occurs at the tidemark. Because this zone is observable on dry bone, it is possible to identify which tendons have fibrocartilaginous zones (Benjamin et al. 2006).

Benjamin and colleagues (2004) also described the “enthesis organ complex,” or “enthesis organ concept” (Benjamin et al. 2004: 3306). This idea suggests that particular attachment sites function as part of a larger organ complex or system, in which stress dissipates away from the soft tissue-bone interface. This is to say that when studying how stress affects entheses, it is beneficial to consider the individual parts of the enthesis organ, which include the surrounding fibrocartilages found in the bursa adjacent to the insertion site. This concept has been applied in understanding pathological conditions like spondyloarthropathies that are known to effect pathological changes to not only the enthesis insertion site itself but surrounding areas. Benjamin and colleagues (2004) make clear that the ‘enthesis organ concept’ does not apply to all of the tendon and ligament attachment sites. In 2007, Benjamin and colleagues further looked into trabecular bone involvement in spondyloarthropathies, expanding on the ‘enthesis organ concept.’ In looking at rates of micro-damage and changes in vascularity at the trabecular level that occur alongside spondyloarthropathies, the authors conclude that an understanding of the relationship between the soft tissues and bone at fibrocartilaginous entheses provide insight as to how such diseases manifest at particular insertion sites.

Enthesis Development and Biomechanics

Benjamin and Ralphs (1998) described the dynamic nature of tendons and ligaments, as they are capable of responding to changes in mechanical loading. Tendons serve as the mechanism that anchors muscles to bone, transferring the pull of muscle forces to bone, whereas ligaments connect bones to one another (Benjamin and Ralphs 1998; Benjamin et al. 2002). Tendons and ligaments are made up of complex collagen networks. Tendons are also characterized by an extracellular matrix of dense fibrous connective tissues. At the cellular level, it is the extracellular matrix composition, and the collagen levels that are altered as a result of mechanical loading, and a change in mechanical loading is said to provoke cellular reactions to varying exercise levels (Benjamin and Ralphs 1998; Benjamin et al. 2008). These dynamic compositions of ligaments and tendons are a critical component in determining how the form and function of the soft tissues dictate responses to mechanical loading, and in discussion of enthesis etiology.

Various authors have examined the structure-function relationship and biomechanical properties of entheses (Benjamin et al. 2008; Benjamin and McGonagle 2009; Niinimaki 2012; Shaw et al. 2007). The literature has shown that it is the function of the entheses that dictates the structure, and mechanical loading will determine the amounts of collagen and fibrocartilage at the entheses (Benjamin and McGonagle 2009).

Initial development of tendons and ligaments in the fetus begin with attachment to hyaline cartilage, the hyaline cartilage is later resorbed and replaced by fibrocartilage. The resorption and replacement occur hand in hand and the fibrocartilage develops by metaplasia (changes of one cell type to another). Because it has been suggested that mechanical loading, and various types of exercise actually act as a signal for the metaplasia process, it is further important to consider what types of physical activity are responsible for such changes. It is generally accepted that mechanical loading, such as weight lifting activities, do promote such change, but it is unknown what effects activities like endurance training have on the overall enthesis structure (Benjamin and McGonagle 2009; Zumwalt 2006). The difference between fibrous entheses and fibrocartilaginous entheses is important to note here, as the two differ structurally and much of this literature focuses on the different quantities in fibrocartilage that occur as a reaction to mechanical loading (Benjamin and Ralphs 1998; Benjamin et al. 2002; Benjamin et al. 2008; Benjamin and McGonagle 2009).

Bone Functional Adaptation

The concept of bone functional adaptation or bone remodeling, as first described by Julius Wolff in the early 1870s, is the general idea that bone will remodel and adapt to mechanical stress (Hoyte and Enlow 1966; Ruff et al. 2006; Foster et al. 2014). This concept basically suggests that forces applied to bone will induce strain and increased strain levels will lead to bone deposition whereas decreased strain levels will lead to bone resorption (Foster et al. 2014). This idea was widely adapted in both the biomedical and bioarchaeological literature with initial examinations of entheseal changes as musculoskeletal stress markers or markers of occupational stress (Angel et al. 1987; Kennedy 1983, 1989, 1998; Hawkey and Merbs 1995; Hawkey 1998; Eshed et al. 2007; Lieverse et al. 2008, 2013).

Wolff's law was constructed with the intention of being a precise mathematical formula to predict bone changes to mechanical load, specifically geared towards looking at trabecular reorganization in long bones (Ruff et al. 2006). While this theory has been applied in analyses of specific types of bone remodeling, a couple of different authors have noted problems in taking this idea and applying it widely to the concept of bone remodeling (Hoyte and Enlow 1966; Ruff et al. 2006). Ruff and colleagues (2006) propose that 'bone functional adaptation' replace Wolff's Law when describing the changes that bone undergoes as a result of mechanical stress. This proposal is made in reference to the many changes, including apposition of bone that can be viewed via cross-sectional geometric analysis.

While robusticity has been a commonly observed feature in studies of MSM, MOS, and entheseal changes, it is a broad term that includes a myriad of morphological changes, and has therefore needed some refinement in the literature. Hawkey and Merbs (1995) for example, utilized robusticity as one of their primary features of entheseal change, or musculoskeletal stress markers in this particular study. Here, they do discuss robusticity as being related to the internal cross-sectional geometry of bone, but do not necessarily distinguish this from their robusticity feature which appears to refer more to general bone formation at tendinous attachment sites. This is just one example of how robusticity has been used too broadly in bioarchaeology and specifically in reference to entheseal changes.

Foster and colleagues (2104) discuss the general assumption that variation in robusticity specifically reflects adaptations to mechanical stress. However, in consideration of more recent studies on biomechanical influences and the structure-function relationship of tendons and ligaments, it is suggested that more specificity be taken into account with these types of analyses. The authors suggest that a closer look be taken at the relationship between enthesopathies, which include osteolytic and osteophytic changes at the entheseal surface, and entheseal robusticity because evidence of both does not necessarily mean they are related, as they may be two distinct processes.

Animal Studies

Mammalian species other than humans have also been studied understand the etiology of entheseal changes and development over the course of an individual's lifetime, though some researchers have suggested it best to stick to within species rather than between species comparisons (Ruff et al 2006). In their 2006 study, Wang et al. utilized three age groups of bovine ACL attachment sites to discuss age effects on the ACL and examine rates of injury at the attachment site, including the poor healing nature of those injuries. The correlation between development of the soft tissue and age was of particular importance in this study, in which three regions of the attachment site were observed: ligament, interface, and bone. The authors hypothesized that age-related changes occur within the extracellular matrix composition, cellularity, and mineral distribution. Results showed that there were clear differences between the age groups where neonatal and immature ACL interfaces showed similarities to hyaline cartilage and mature interfaces showed more fibrocartilage. They suggest that the observed age-related changes are indicative of "an active remodeling of the interface over time, with the primary modulator being the nature and magnitude of physiological loading experienced at the insertion during maturation." (Wang et al. 2006: 2753)

In a more recent study, Wallace and colleagues (2017) utilized ten turkeys to test the effects of treadmill running on overall limb bone structure and entheseal changes. This study considered a model that is applied by paleoanthropologists looking at effects of activity on our hominid ancestors. The turkeys were divided into two control groups, runners and non-runners, where the runners were exercised on a declined treadmill at an increased "high-magnitude limb loading events relative to the normal sedentary patterns of laboratory turkeys," (Wallace et al. 2017: 15). To assess entheseal changes the authors examined the lateral epicondyle attachment site of the distal femur. This attachment site was selected because the muscle that attaches at that point is activated during decline running. Topographic analysis of the entheseal surface was used to quantify any changes that occurred at the attachment site. The results of this study showed a general change in structure of the limb bones alongside a change in physical activity, yet there was no detection of any significant entheseal changes. This study presents findings that are relevant for bioarchaeologists looking at the effects of physical activities other than weight bearing exercises on entheseal changes. It further highlights the practicality in using other mammalian species as a reference for making inferences about anatomically modern humans and other hominid species.

Zumwalt (2006) used mature female sheep to test the notion that normal levels of physical activity are reflected in bone formation at entheses. Two samples of sheep – one group that was sedentary and one group that was exercised on a weighted treadmill – were utilized for this study, and a combination of both fibrous and fibrocartilaginous entheses were examined. A critical component of this study was controlling for body mass as the exercised group of sheep showed significantly larger muscle and tendon sizes compared to the sedentary group. However, the sizes of the actual muscle attachment site showed no significant difference, suggesting that varying levels of physical activity does not necessarily directly impact the size or morphology of entheses. The author suggests that the lack of effect of physical activity on enthesis morphology may be due to the age of the sheep. Other studies using mammalian species have shown more response to physical activity in immature or growing animals, whereas this study used mature individuals. It is suggested that further research be conducted on effects of activity on growing mammals to better understand the relationship between age and entheseal changes, which is similarly a pressing question in studies of entheseal changes in human populations.

While these studies of entheseal changes using mammalian species other than humans examine similar effects such as age and physical activity, the applicability of such information in studies examining human populations is limited. It is a large leap to assume that varying species of mammals with differing bone composition would have similar responses to physical activity. It is further necessary to consider that basic movements and types of activity performed by other mammals is different than that of humans.

Microtrauma and Macrotrauma effects on Entheses

In both the bioarchaeological and biomedical literature effects of trauma seen at entheses pertains more to activity-related changes, e.g., overuse injuries that may promote extra bony growth such as enthesophytes, at the entheses (Villotte and Knüsel 2014; La Cava 1959; Dutour 1986; Selvanetti et al. 1997; Adirim and Chen 2003). Such changes may result from microtraumas, which are repeated small tears of the tendons and ligaments from habitual activity, or macrotraumas, which pertains to complete avulsion of the tendon or ligament resulting in a more severe injury (Schlecht 2012; Hawkey and Merbs 1995).

Microtrauma is more of a continuous process in which changes at the entheses result from habitual muscle strain (Schlecht 2012; Hawkey and Merbs 1995). Prior to more recent developments in bioarchaeological research that has emphasized looking at potential biological effects that result in entheseal changes, effects from microtrauma have broadly been interpreted as MSM and MOS (Angel et al. 1987; Kennedy 1989; Hawkey and Merbs 1995; Hawkey 1998). In general, microtraumas are of more interest to bioarchaeologists seeking to understand effects of various occupations or physical activities on entheses that occur as a result of regularly repeated movements.

Hawkey and Merbs (1995) refer to macrotrauma as ossifications of the soft tissue, which occur due to abrupt injuries at the entheses. In the biomedical literature macrotrauma generally refers to overuse injuries or enthesitis (La Cava 1959; Selvanetti et al. 1997; Adirim and Chen 2003; Benjamin et al. 2009). Literature on overuse injuries often incorporates a discussion of the structure-function relationship of entheses, as these types of injuries are generally a failure of the extracellular matrix within the tendon to adapt to mechanical loading (Selvanetti et al. 1997). This is an important connection to make because the structure-function relationship of tendons and ligaments is a key component in understanding the multifactorial etiology of entheseal development and changes. Considering the idea that overuse injuries occur as a failure of the tendon or ligament to respond properly to mechanical load, observations of such injuries in living populations (as seen in the biomedical and sports medicine literature) can provide critical insight as to what types occupations or physical activities result in bone formation or enthesopathies occur at the entheses in archaeological populations.

Though these overuse injuries appear to be largely results of mechanical loading, the biological structure of entheses is also necessary to consider with these traumas. Age is important to consider in these types of injuries largely because of the ways in which the attachment of soft tissue to bone changes during and individual's lifetime (Foster et al. 2014; Wang et al. 2006; Adirim and Cheng 2003; Benjamin et al. 2008). While it is understood that changes to the soft tissue happen alongside ageing, there is little understood about the sole effects of biological age versus the sole effects of mechanical loading. It has therefore remained important to consider the structure-function relationship of tendons and ligaments in further investigations of entheseal changes and etiology.

Acosta and colleagues (2017) explored the possibility that entheseal change etiology is related to overuse injuries that occur as a result of an individual exerting mechanical loading above their normal capacity. This relies on the notion that individuals engage in a certain level of mechanical loading during bone development, which is later reflected in entheseal changes in adulthood. The authors here looked at previous studies examining lower limb entheses. The goal was to search for differences of entheseal change based on different types of terrain; i.e. flatter terrain versus more rugged terrain. It was hypothesized that individuals from flatter terrain would exhibit more severe entheseal changes, as their ‘normal capacity’ would be lower than that of individuals living in a more rugged terrain who would have a higher ‘normal capacity,’ (Acosta et al. 2017). Their results showed this was generally true, suggesting the need to consider not only microtraumas and habitual activity over an individual’s lifetime, but also how ‘overloading’ might contribute to entheseal change. This supports the notion that entheseal changes have a multifactorial etiology of not only biological and mechanical factors, but also of different types of mechanical strain.

Age Effects in the Biomedical Literature

Considering the effects of age and osteogenic processes on entheseal changes has proved to be imperative in both biomedical and bioarchaeological aspects of research on both fibrous and fibrocartilaginous entheses. These changes take place during bone growth and through degenerative processes associated with age. These age-related changes have been identified to occur independently of other factors such as sex or mechanical loading, however, it is important to understand how these changes may further affect or interact with other biological and physiological factors (Benjamin et al. 2008; Benjamin and McGonagle 2009; Schlecht 2012).

Examining the effects of age during adulthood largely relies on consideration of natural degradation processes of both the periosteum and decreases in collagen that makes up a significant component of the extracellular matrix of tendons. These effects of ageing may be due directly to the degenerative processes that occur to the body over time; however, in addition to the direct effects of ageing, decreases in collagen fibers might also be due to reduction in mechanical strength/mechanical loading. This pertains to the notion that tendons do not necessarily respond directly to mechanical loading, but that an increase in collagen may be promoted from exercise, and vice versa, a decrease in exercise levels may promote decreasing collagen alongside the effects of age (Benjamin et al. 2008; Foster et al. 2014; Benjamin and Ralphs 1998). This is to say that for an individual engaging in exercise and varying levels of mechanical loading during ages that are ideal for bone remodeling or periosteal apposition, entheseal changes may occur as a result of both biological age processes combined with levels of physical activity (Schlecht 2012; Benjamin and Ralphs 1998; Benjamin et al. 2006). Thus, it is imperative to look at age effects on entheses both in the biomedical field, often in sports medicine, and in the bioarchaeological record to see how such changes manifest skeletally. This will become further important in discussing how pathological conditions associated with age, and trauma or microtraumas may exacerbate entheseal changes not necessarily as independent agents, but also as occurring within certain age brackets in which bone and soft tissues are already responding to age-related changes.

The biomedical literature has been specifically useful in understanding developmental and degenerative age-related entheseal changes that are currently a primary focus in bioarchaeological research. Various papers have looked at how fibrous entheses, and notably the Achilles tendon fibrocartilaginous attachment, migrate during growth (Hurov 1986; Grant et al. 1981; Benjamin et al. 2008). Biomedical research on fibrocartilaginous entheses is often separate from that of fibrous entheses, and has looked at the changes that occur in the overall structure of the soft tissue, and factors that may stimulate such changes. In the fetus, the tendons and ligaments attach to hyaline cartilage, the hyaline cartilage is later resorbed and replaced by fibrocartilage; the resorption and replacement occur hand in hand and the fibrocartilage develops by metaplasia (Benjamin and McGonagle 2009). Benjamin and McGonagle (2009) have suggested that mechanical loading is possibly a signal for the metaplasia process, though it remains unclear as to whether or not something like endurance training actually affects the enthesis structure.

In considering the importance of how entheses develop under normal ontogenic processes, we can look at the work of Wang and colleagues (2006), in which they utilized three age groups of bovine anterior cruciate ligament (ACL) attachment sites to discuss age effects on development of the ligament. This study observed three regions of the attachment site: ligament, interface, and bone. The interface was further divided into nonmineralized and mineralized categories. There were clear differences between the age groups: neonatal and immature showed articular cartilage whereas mature showed fibrocartilage. Wang and colleagues (2006) concluded that the "composite organization of the mature insertion [site]… is the result of adaptation to the stress distribution or physiological loading present at the [soft tissue-bone] interface, (Wang et al. 2006: 1753). Utilizing other mammalian models, and looking at changes to the entheses during growth in general, is particularly relevant in understanding changes seen at various age groups in human skeletal remains (Schlecht 2012). It is important to highlight the ways in which age-related changes to the entheses can be considered as a biological effect on entheseal changes, and as working as part of an interconnected process alongside other mechanical stressors, or further biological effects such as pathological conditions and sex.

Disease Processes and Enthesopathies

The term ‘enthesopathies’ is typically utilized to indicate pathological changes that occur at the entheses (La Cava 1959; Villotte and Knüsel 2013), but pathological changes that are part of specific disease processes should be viewed differently from entheseal changes that can be associated with other biological factors such as age, or mechanical factors such as physical activities. While general biological and mechanical effects on entheseal changes are a major focus in bioarchaeological research, biomedical research focuses primarily on the correlations of disease or trauma with enthesopathies in much of the literature. There are several pathological conditions that are associated with the formation of enthesopathies. Typically, these include joint conditions such as ankylosing spondylitis (AS) and diffuse idiopathic skeletal hyperostosis (DISH) (Rogers et al. 1997; Cammisa et al. 1998; Benjamin and McGonagle 2001; Hannallah et al. 2007; Henderson 2008). Some metabolic disorders like fluorosis and acromegaly have also been identified as affecting the entheses (Henderson 2008).

Because much of the biomedical literature focuses more on fibrocartilaginous entheses versus fibrous entheses, there is generally more information available about pathological changes at fibrocartilaginous entheses that result from the above mentioned pathological conditions – DISH, AS, fluorosis, and acromegaly (Henderson 2008, 2013). Understanding pathological effects on entheses is of particular interest to bioarchaeologists who aim at understanding entheseal change etiology, and the multiple factors that contribute to a myriad of changes. It is therefore important to know which diseases are more likely to cause changes to the two different types of entheses, and what those changes typically look like.

Spondyloarthropathies encompass a few conditions including AS, psoriatic arthritis, and SAPHO syndrome (synovitis, acne, pustulosis, hyperostosis, osteitis) (Benjamin and McGonagle 2001; Fournié 2007). Benjamin and McGonagle (2001) discuss that prior to a study conducted by McGonagle in 1998, it was assumed that inflammatory responses seen at the entheses were separate conditions from spondyloarthropathies like AS. However, McGonagle (1998) and Benjamin and McGonagle (2001) identify that enthesitis (inflammation of the entheses) is particularly common among individuals afflicted with conditions like AS, and that in many cases enthesitis is an extraspinal manifestation of the condition. The ‘enthesis organ concept’ is applied here to further explain why AS affects different localized regions of tendon attachment sites as a result of surrounding soft tissues being functionally related. This provides a foundation for the authors’ discussion about how spondyloarthropathies like AS may be associated with instances of enthesitis. They conclude that there are genetic, anatomical, and mechanical factors that contribute to AS manifesting in sites with abundant fibrocartilage. An important correlation made here is with the HLA-B27 gene.

Benjamin and McGonagle (2001) make the connection between HLA-B27 being strongly associated with AS and the fibrocartilage that binds to the gene, suggesting that this actually triggers the disease. This discussion of interconnected properties of entheses to the rest of the musculoskeletal system is a common thread in biomedical literature, which has shown to be useful in understanding various aspects of entheseal development and associated changes, pathological and otherwise.

DISH was first identified and differentiated from AS in the biomedical literature by Forrestier and Rotés-Querol (1950). DISH is a non-inflammatory condition of soft tissue ossification that primarily affects the thoracic vertebrae, but also has extraspinal manifestation such as those at the entheses (Cammisa et al. 1998; Hannallah et al. 2007; Henderson 2008). Though similar to AS in that it is known to primarily affect the vertebral joints and have extraspinal manifestations at fibrocartilaginous entheses, there are notable differences in the general appearance of the disorder, and in genetic associations as there is no connection between DISH and a specific gene like there is with AS and HLA-B27.

Despite the lack of a specific gene association, Rogers and colleagues (1997) propose the idea that some individuals have a propensity for bone formation, which in combination with other biomechanical factors may result in the development of DISH with extraspinal manifestations at the entheses. Though the precise etiology of DISH is unknown, there are strong associations with diet, lifestyle, and age, all of which are associations seen in both contemporary and archaeological cases (Forrestier and Rotés-Querol 1950; Rogers and Waldron 2001; Rotés-Querol 1996; Cammisa et al. 1998; Hannallah et al. 2007). DISH tends to affect individuals over the age of 40, which is an important consideration in bioarchaeological studies that aim to examine the relationship between entheseal changes and biological age.

Henderson (2008) discusses the potential effects of fluorosis and acromegaly on bone development at the entheses. Fluorosis is a dietary condition in which excess of fluoride in water or cooking coals can lead to skeletal fluorosis. Henderson (2008) notes that instances of fluorosis are high among African and Asian populations. While fluoride that is ingested from water or food is typically absorbed in in bodily fluids, excess fluoride is deposited into the skeleton. Clinical and radiograph diagnosis shows that this most frequently manifests in the spine, pelvis, and ribs, but with widespread fluorosis enthesopathies can be found throughout the skeleton. Acromegaly is a condition that typically results from adenomas (benign tumors) of the pituitary gland. The most typical skeletal changes of acromegaly occur within the face, hands, and feet. This condition is less common than that of fluorosis but similarly is known to result in enthesopathy formation.

Effect of Sex and Hormones in Biomedical Literature

The effect of sex or hormonal differences on entheseal changes has been less explored than age in both the bioarchaeological and biomedical literature. However, within the biomedical literature there is a significant amount of discussion about differences in periosteal apposition or bone loss between the sexes, effects of estrogen on muscle development and muscle attachment to bone, and supposed differences in tendon and ligament response to mechanical loading between the sexes (Foster et al. 2014; Benjamin et al. 2008; Ruff and Hayes 1988; Frost 1999; Schiessl et al. 1998). These various differences between bone and soft tissue development or responses to mechanical loading are useful in considering potential sex differences between entheseal changes observed in skeletal remains, and it is therefore important to consider any differences that may result from sexual dimorphism and hormonal differences.

The effects of estrogen and testosterone have been described in the biomedical literature as contributing to overall bone and soft tissue development (Foster et al. 2014; Schiessl et al. 1998). During puberty, females show greater endosteal apposition than periosteal apposition compared to males (Foster et al. 2014; Schoenau et al. 2000). Schiessl and colleagues (1998) suggest that estrogen has an effect on overall bone strength. This is demonstrated by the assumption that during puberty females experience a faster increase in bone mass than males. This increase in bone mass eventually plateaus, but the strength of the bone will affect future remodeling processes so that during remodeling the existing bone is conserved. This becomes important later in life during menopause when remodeling thresholds are higher.

Ruff and Hayes (1988) have further discussed that males experience greater periosteal apposition during puberty and continue to show greater periosteal apposition than females throughout life. While such differences may have correlations with sex differences in entheseal changes in human skeletal remains, these changes pertain more to changes of the diaphysis and there is currently no conclusive evidence to suggest these hormonal effects similarly effect entheses or specifically the fibrocartilaginous entheses (Foster et al. 2014; Wilczak 1998). It should also be noted that these changes are relative to sex and age, in which it could be difficult to isolate sex from age as a factor.

Methods for Recording Entheseal Changes in Bioarchaeology

Past bioarchaeological methods for recording entheses, such as that of Hawkey and Merbs (1995, 1998) looked at changes at fibrous as well as fibrocartilaginous entheses. However, the more recently developed methods like that of Villotte (2006), Mariotti and colleagues (2007), and Henderson and colleagues (2013, 2015) have worked towards devising scoring methods that reflects more recent biomedical literature showing differences between fibrous and fibrocartilaginous entheses (Benjamin and Ralphs 1998; Milz et al. 1998; Henderson 2013; Villotte and Knüsel 2012). Villotte (2006) and Henderson and colleagues (2013, 205) have also focused on various types of changes that occur at the cortical surface of different entheses instead of robusticity. This consideration of the different types of entheses and their different morphological components is necessary for better understanding which processes, both biological and mechanical, will have effects on entheseal changes.

Some of the earliest methodologies for scoring entheseal changes were developed by Angel and colleagues (1987) and Robb (1998). Both studies examined various indicators of health and skeletal evidence of activity. In their 1987 study, Angel and colleagues aimed to examine the lifestyle of a group of individuals buried at the First African Baptist Church in Philadelphia. Included in their assessment of overall health and lifestyle was occupation, in which they interpreted “muscle crests,” (Angel et al. 1974: 215) as being indicative of muscle use associated with particular occupational stresses. They utilized a scoring system in which muscle crests were scored with a plus (+) degree system from absent to large or extraordinary.

Hawkey and Merbs (1995) utilized a method that was initially developed by Hawkey (1988) to look at MSM in a Hudson Bay Eskimo population. Three features are examined here for both fibrous and fibrocartilaginous entheses: robusticity, stress lesions, and ossification exostoses. Each feature is scored on a scale of 0-3. An interesting distinction with this method is the use of broad categories of features that are seen as indicative of either more normal changes related to repeated microtraumas like with robusticity and stress lesions or more extreme changes that could indicate macrotrauma like with ossification exostoses. Though it should be noted that variation in robusticity could be indicative of normal anatomical variation and is not necessarily activity-induced or indicative of repeated microtraumas or macrotraumas.

Robb's (1998) article is an early example of bioarchaeological studies that take a biomechanical approach in looking at entheseal change. This study utilized 56 adult skeletons from an Italian Iron Age cemetery. Following Hawkey and Merbs (1995), Robb (1998) examined general changes at muscle attachment sites, in which a comparative skeletal collection was used and morphological changes such as rugosity and ossifications were seriated in order from least to most morphological change. Sex and age were both incorporated into Robb's (1998) analysis. Observed differences in entheseal change, or "muscle marking," (Robb 1998: 370) between sexes were attributed to gender divisions of labor. Age was found to have a positive correlation with more severe morphological changes at the entheses. This study ultimately concluded that morphological changes and variation observed at the entheses is due to a combination of biological factors such as age and physical activity.

Since the Hawkey and Merbs (1995) study and the Robb (1998) study, several other methods have been developed to score and record entheseal changes. Mariotti and colleagues (2007) developed a scoring system for 23 different entheses that looked at variations in robusticity, osteophytic enthesopathies, and osteolytic enthesopathies. Because of difficulties in presuming that features like robusticity are directly related to variation in activity levels, more recent studies and methods have sought to refine the ways in which entheseal changes are scored and to look closely at more specific features with varying expressions of change.

Villotte (2006) developed a method that distinguishes between the two different types of entheses, fibrous and fibrocartilaginous. This distinction between types of entheses has been explored in the biomedical literature and is important because the two types attach to bone differently, thereby responding to mechanical or biological factors differently as well (Benjamin and Ralphs 1998; Benjamin et al. 2002; Benjamin et al. 2008). Villotte (2006) observed this difference in his method, and further acknowledged two different zones of fibrocartilaginous entheses that is also observed in the Coimbra method.

The Coimbra Workshop in Musculoskeletal Stress Markers

In 2009 researchers who had been involved in MSM research met at the University of Coimbra in Portugal to review past research and work towards developing a more effective methodology and terminology for future research. Researchers at this meeting divided up into three working groups: methodology, terminology, and occupation.

The methodology working group developed the first phase of the Coimbra method, which was revised during a second meeting in 2013 by altering some definitions and terminology to improve overall usability and rates of inter and intra-observer agreement (Henderson et al. 2013, 2015, 2016; Wilczak et al. 2017). This method is specifically for scoring and recording changes to fibrocartilaginous entheses and has elements from some previously established methods like Villotte (2006) and Mariotti et al. (2007). The researchers in this working group conducted some initial tests using this method, looking at entheseal changes in historical European populations (Henderson et al. 2013, 2015, 2016, 2017 Henderson and Cardoso 2013; Wilczak et al. 2017). Initial results showed that certain recorded features, like bone formation, positively correlated with age. These results suggest that some entheseal changes show strong correlations with biological factors, further indicating that it is probable entheseal changes in general are likely a result of biological effects as opposed to solely reflecting varying levels of activity. Another motivating factor in developing a new method is the idea that there could, and should, be one universal method for recording all fibrocartilaginous entheses as the use of multiple methods proves to be difficult for population or study comparisons (Henderson et al. 2015, Henderson 2013). Upon refining the method and inter and intra-observer agreement, the “new” Coimbra method is the most suitable method for examining changes occurring at fibrocartilaginous entheses because it incorporates the most recent related biomedical literature about enthesis structure and function and differentiates between specific features and variations of those features on the enthesis.

In a 2017 study, the methodology working group reported their more recent improvements in inter-observer and intra-observer agreement using the new Coimbra method (Wilczak et al. 2017). After the initial meeting in 2009, attempts were made to improve their inter-observer agreement by doing analyses using photographs, which the researchers suggested was ultimately unsuccessful, concluding that the Coimbra method is best applied in person with skeletal remains. This 2017 study highlights the difficulty in developing a new methodology in which the developers speak different languages and in finding agreement amongst definitions created for the separate features of the entheses that are scored within the Coimbra method. While the initial inter-observer agreement percentage was 68.6%, which the authors note is relatively low, upon a secondary meeting (Coimbra B) the group was able to obtain up to 80% agreement. It should be noted that the percentage agreement was determined for each feature scored in the Coimbra method, in which there was some variation between features.

The terminology working group concluded that the term entheseal changes was more appropriate than MSM for discussing the multifactorial etiology of entheseal morphology (Jurmain and Villotte 2010; Villotte et al. 2016). MSM has an implied mechanical, or activity-specific etiology attached to the term. As Jurmain and Villotte (2010) note, a variety of other terms had previously been used in the bioarchaeological literature like enthesopathies, muscle markings, and muscle crests (Dutour 1986; Robb 1998; Angel et al. 1987). All of these applied terms share a similar issue with that of MSM, in that their precise definitions do not encompass all the morphological changes and variation that can be described by using ‘entheseal changes’.

Because much of the bioarchaeological literature has focused on the correlation between various activities or occupations and entheseal change, the occupation working group worked towards developing a standard protocol for grouping occupations based on socio-cultural and physical activity criteria (Lopreno et al. 2008; Milella et al. 2015). It is also common for entheseal change research to utilize identified skeletal collections with documented occupations, which can prove to be difficult in that documented occupations do not necessarily encompass the various physical activities and individual engaged in throughout his or her life. As such, researchers from this working group worked towards standardizing the concept of occupation using eight case studies based on seven identified European skeletal collections (Lopreno et al. 2008). The biological and physical criteria they used to classify occupations were based on categories of manual labor versus non-manual labor, heaviness of loads carried, overall intensity of physical activities, repetitiveness of motions, and specialized professions other than farmers. Separate socio-cultural criteria were also established based on the social and economic contexts in which the individuals lived. The authors ultimately concluded that knowing an individual's occupation recorded at death does not hold the same weight as being able to understand the various physical activities that an individual would have engaged in on a regular basis. They did, however, make an argument for utilizing a chart of compiled occupational categories that could be useful in making future comparisons between occupations.

Since the first workshop in creating the Coimbra method, a few revisions and tests of the method have been conducted (Henderson et al. 2015, 2016, 2017; Michopoulou et al. 2016). Michopoulou and colleagues (2016) sought to test whether or not entheseal changes recorded using the Coimbra method would be appropriate for identifying activity patterns. The Coimbra method examines distinct morphological features separately in order to better understand which features of entheseal change are more related to biological factors such as age, or biomechanical factors, and which features might be more indicative of particular occupations and activity patterns. The authors utilized 78 adult males from a 20th century Greek population. Two fibrocartilaginous entheses of the upper limb were examined for the purposes of this study. Aside from activity patterns, which were considered using cross-sectional geometric data as a proxy, age and body mass were also incorporated. The authors found no significant correlations between activity pattern data and entheseal change data, though the authors note limitations in using cross-sectional geometric data as a proxy for activity markers. The issues noted here are the inability to distinguish between different types of activity and the effect on entheseal changes as well as the issue of not being able to assess the impact of occupational mobility. Occupational mobility remains an important issue because individuals likely are changing activities over the course of their lifetime, making it difficult to understand the etiology of various expressions of entheseal change. The results also showed that age and body mass both have less of a significant correlation than previous studies (Michopoulou et al. 2016: 414; Henderson et al. 2013), though age was still the factor most affecting entheseal change. This article is an important pilot study in testing the various ways in which the Coimbra method can be applied and posing the questions of how researchers might continue to approach examining activity patterns alongside biological effects such as age and body mass.

Entheseal Changes in Bioarchaeology: Effects of Activity, Age, Sex, and Body Size

The effects and relationship of occupation and physical activity with entheseal changes has been the primary and most extensively discussed in the bioarchaeological literature. Initially discussed as MSM and MOS, researchers sought to understand how certain types of movements or activities would manifest in human skeletal remains. It was long thought that variation on robusticity of long bones or robusticity of muscle crests (Angel et al. 1987; Hawkey and Merbs 1995, Kennedy 1989) reflected various occupations or cultural activities. More recent research with the Coimbra workshop and in other prior research began to refine the ways in which our understanding of how changes present at different entheses may be reflecting biological and biomechanical effects (Henderson et al. 2009, 2013, 2015, 2017; Wilczak 1998; Nolte and Wilczak 2013; Villotte et al. 2010; Villotte and Knüsel 2014; Milella et al. 2012).

Kennedy (1983) was among the first to describe MOS and the applicability of forensic methodology in identifying individuals and characteristics such as handedness in bioarchaeological analyses of individuals' physical activities during life. Kennedy's explorations into MOS and how that can be interpreted from MSM and varying degrees of robusticity was further explored by other researchers in the 1980s and 1990s when anthropologists were looking into various interpretations of changes seen on human skeletal remains that could all be viewed as reflecting activity patterns in past populations.

In 1987 Kelley and Angel looked at skeletal evidence of life stresses for Black individuals from sites across Maryland, Virginia, and the Carolinas. Here, they examined various nutritional stress indicators as well as occupational stress indicators. They utilized "muscle crests," (Kelley and Angel 1987: 207) of the deltoid, pectoral, teres, and supinator, as those particular muscles can be associated with lifting and twisting movements. The plus (+) scoring methodology was applied in this study to score and record entheseal changes, or in this case, development of muscle crests. Kelley and Angel (1987) make the argument that the observed degree of development in these individuals alongside other abnormal changes observed at the fifth lumbar vertebra provide evidence for labor intensive work that would have begun at young ages. Through a discussion of the ways in which certain muscles move with certain activities, the authors conclude that there was evidence of activities like precision grip that would be used for cutting trees with an axe or other crafts affiliated with these sites. This study aligns with early notions that robusticity of muscle attachment sites is directly correlated with mechanical stress.

Another notable study that was published around the same time is that of Hawkey and Merbs (1995). They were the first to apply a method that was initially developed by

Hawkey (1988) to look at MSM in a Hudson Bay Eskimo population. The variation seen within this population were interpreted as being indicative of gendered division of labor, which continues to be a recurring area of interest for bioarchaeologists looking at MSM, or entheseal changes. These earlier studies evolved from considering general variations or changes observed at muscle attachment sites to recognizing more specific changes that could be examined as separate features. Such research set a foundation for identification of more specific changes and further investigation into the multifactorial etiology of entheseal changes.

A number of studies that succeeded these initial Kennedy (1983), Kelley and Angel (1987), and Hawkey and Merbs (1995) papers similarly looked at entheseal changes as being indicative of occupations and activities. A bulk of this research has looked at specific activities and occupations like that of spear throwing, foraging, and farming (e.g., Eshed et al. 2003; Lieverse et al. 2009, 2013; Lopreno et al. 2013; Milella et al. 2015; Villotte et al. 2010; Villotte and Knüsel 2014; Stirland 1988). Some studies have looked at these changes as MSM, but since the Coimbra workshop in 2009, studies looking at occupation and activity reconstruction have adopted the new terminology or at least discussed the issues with using terminology that has an implied etiology.

In 2003 Eshed and colleagues looked at a population of Neolithic farmers and MSM of the upper limb. The authors wanted to examine how a transition away from hunter-gatherer lifestyles to agricultural lifestyles, as well as sexual division of labor would be reflected in MSM. It was suggested that because a transition to agriculture resulted in heavier mechanical loading of the upper limb, that there should be differences in MSM between hunter-gatherer populations and agriculturalist populations. Using the Hawkey and Merbs (1995) scoring method, they concluded that the Neolithic lifestyle was more physically demanding. They also concluded, because females in the agricultural population yielded higher MSM scores than of the hunter-gatherer population, that there was a shift in sexual divisions of labor upon adoption of an agricultural lifestyle. This study is one example where the authors were looking at activity or occupational type differences and sexual divisions of labor, both of which have been of great interest in bioarchaeological studies of entheseal changes.

Studies conducted by Lieverse and colleagues (2009, 2013) also examined MSM in hunter-gatherer populations using Hawkey and Merbs (1995) to score MSM, and similar to Eshed and colleagues (2003), looked at how MSM in these populations reflected a cultural change in different time periods. In 2009, Lieverse and colleagues looked at the upper limb entheses of populations from the Early Neolithic and Late Neolithic; the authors revisited the sample in 2013 when they examined the lower limb entheses. In their initial study in 2009, they attributed differences in MSM to different activities, but more specifically to differences in the degree of physical activities rather than general differences between activities performed. Sex differences were documented here as well, where females were exhibiting evidence of having less muscle use in some areas like their forearm flexors than their male counterparts. This study also discusses some differences between their age categories as well. They saw a positive correlation between MSM score and age in their male sample.

Lieverse and colleagues' 2013 study examining the lower limb entheses yielded some interesting changes that reflect the general change in entheseal change research in bioarchaeology. First, this study altered their terminology in which they use entheseal changes as opposed to MSM. Second, while they still utilize Hawkey and Merbs (1995) to score entheseal changes, they do incorporate information from Alves Cardoso and Henderson (2009) to distinguish between fibrous and fibrocartilaginous entheses. Another new incorporation to this study versus their 2009 study is the discussion of bilateral asymmetry and effects of body size, though no body size differences nor asymmetry differences were found. This study concluded that their results of sexual dimorphism and intensity of physical activity supported their previous findings in 2009. This article is important in that it represents a critical shift in entheseal change research in which new terminology was being adopted, the distinction was being made between the two types of entheses, and the analysis was looking more closely at other biological effects like body size.

Villotte has collaborated with other researchers in studies that also examined upper limb entheseal changes as indications of the sexual division of labor (Villotte et al. 2010; Villotte and Knüsel 2014). Villotte and colleagues (2010) looked at the prevalence of enthesopathies at the distal humerus, which are characteristic of medial and lateral epicondylosis. These are conditions known to affect individuals that engage in habitual throwing activities. The aim of this study was to assess whether or not females were engaging in throwing activities using the types of weapon technology available during the Upper Paleolithic. The Villotte (2006) methodology is applied here in scoring enthesopathies at fibrocartilaginous entheses in three time-successive skeletal samples: prehistoric; pre-industrial historic; and a modern, documented sample. Age-at-death was not a control factor in this study, and limited the authors' ability to compare medial and lateral epicondylosis results across the skeletal samples. However, there was a tendency towards unilateral epicondylosis that was seen throughout the prehistoric male sample, which is a phenomenon commonly seen with young male baseball players and indicates that these enthesopathies are activity-related, rather than due to age degeneration. The prevalence of medial epicondylar enthesopathies was consistently higher for males across hunter-gatherer and farming groups, which indicated there was a sexual division of labor with tasks linked to throwing.

Following this 2010 study, Villotte and Knüsel (2014) published a study that looks at evidence of medial and lateral epicondylosis to also examine differences between sexes in specific activities that involve an overhead throwing motion. Unilateral enthesopathy at the medial epicondyle of the humerus is suggested to be a good indication of throwing activities, and can therefore be used to look at sexual divisions of labor. This study used a lateral/medial epicondylosis ratio in three samples: prehistoric, preindustrial historic, and modern populations, all of which had known age and sex.

Results showed an increase of enthesopathies with age. Enthesopathies were also more common on the lateral epicondyle versus the medial epicondyle. However, medial epidcondylosis was more prevalent on the right side in males, and even when the lateral side was affected with enthesopathies, this occurrence was most often accompanied by presence of enthesopathies on the medial side as well. Within the three populations, evidence of enthesopathies on both medial and lateral epicondyles, or medial epicondylosis only was seen to affect males more often than females, indicating a sexual division of labor or other cultural activities involving overhead throwing, such as spear throwing.

Milella and colleagues (2015) conducted a study in which patterns of entheseal changes were examined within a contemporary skeletal collection with documented occupations. This study used previously recorded entheseal change data (Milella et al. 2012; Alves Cardoso 2008) in which the robusticity data was the only factor examined, ensuring consistency and allowing for comparison between multiple datasets (Milella et al. 2015: 216). The previously recorded entheseal change data used both fibrous and fibrocartilaginous entheses and recorded entheseal changes following two methods: Hawkey and Merbs (1995), and Mariotti et al. (2007). A main focus of this study was to classify occupations and explore the notion that specific types of occupations (more physically demanding vs. physically undemanding) would affect degrees of entheseal change. The authors divided known occupations into three classes: physically demanding occupations that are related to farming; physically demanding occupations that are not related to farming; and physically undemanding occupations (Milella et al. 2015: 219). Their results comparing occupation classes showed significant differences between the physically demanding occupations related to farming and physically undemanding occupations, in which the farmers in the first class appear most distinct compared to the latter two occupational classes. Bilateral asymmetry was another aspect examined in Milella et al.'s (2015) study, and it is a component of entheseal change research seen in multiple studies (Wilczak 1998; Villotte and Knüsel 2014; Henderson et al 2017). The authors found no difference in the degree of bilateral asymmetry between the occupational groups examined.

Bilateral asymmetry has been examined using different methods for recording entheseal change, and is an aspect of entheseal changes that merits further research (Henderson et al. 2017). Understanding effects of various types of occupations is critically important in that is an underlying theme of entheseal change research. This study points to the importance of being able to classify occupations in a systematic way that considers sociocultural information as well as the physiological biomechanics of certain occupations and daily cultural activities.

The studies discussed above are merely a few of many examples of bioarchaeological studies looking at the effects of occupations and physical activities on entheseal changes. The studies show the chronological changes in entheseal change research from using MSM and the Hawkey and Merbs (1995) method, to incorporating different terminology, different methodology, and exploring other factors impacting entheseal change in addition to activity. After 2009, studies began to utilize ‘entheseal changes’ and branched out into different scoring methods for quantifying such change.

The effect of age on entheseal changes has been of increasing interest in the bioarchaeological literature (Wilczak 1998; Henderson et al. 2012, 2015, 2017; Alves Cardoso and Henderson 2009). There are general changes to bone that occur with age, whether it be with degenerative changes that can be observed on pelvic features and used to estimate biological age-at-death of an individual, or specific types of bone formation at fibrocartilaginous entheses that have more recently been discussed as positively correlated with age (Henderson et al. 2013, 2015, 2017).

Alves Cardoso and Henderson (2009) utilized an historic, Portuguese male skeletal sample to look at the relationship between enthesopathy formation of the upper limb and age. They documented entheseal change on this skeletal sample in which age-at-death and occupations were documented. A connection can be drawn here to the 2012 study conducted by Villotte and colleagues examined the connection between enthesopathies and specific activities of three Paleolithic skeletal samples. A critical difference, however, is this study aimed at not only demonstrating the potential effects of occupations on enthesopathy formation, but also looked at the effects of age. The authors concluded that occupation could not be considered a contributing factor in enthesopathy formation, but results indicated that age was a primary factor in the development of enthesopathies.

Upon development of the Coimbra method, researchers from the methodology group have continuously worked towards exploring the effect of age on each feature scored using the Coimbra method. Most of the literature has made note of the potential or recorded effects of age on most entheseal changes. Henderson and colleagues (2012) discuss the fact the effect of age needed to be considered against all features of entheseal change within in the method. This particular study did find a significant correlation with age in the historic Geneva skeletal collection using the Coimbra method to score the entheses (Henderson et al. 2012). While bone formation yielded the most significant results with age, the authors did find most of the features showed some increase in score with older ages.

The most recent 2017 study, conducted by the same researchers who developed to Coimbra method, tested for age effects using the new Coimbra method (which had been revised since their 2012 study). Similarly, this study tested the effects of age on all of the features recorded using the method. The results here are particularly interesting in that some of the features were positively correlated with older ages, like bone formation and erosion, and other features like textural change and fine porosity showed stronger correlations with younger ages. With these differences in age correlation and different features, the authors do suggest that there could be multiple factors to consider. It was suggested that the fine porosity and textural change correlations with younger ages might have to do more with a biomechanical, developmental etiology as opposed to just age alone. It also remains unclear as to whether the correlations between bone formations and erosions are specific to degenerative age changes, or also having to do with biomechanical effects of habitual mechanical stress.

Other studies like that of Milella and colleagues (2012), and Nolte and Wilczak (2013) have also looked at correlations between entheseal change and age, the latter looking at differences in entheseal surface area. It has been consistently reported that across various methods, but perhaps most importantly with use of the Coimbra method, that certain features whether it be enthesopathy formation or other bone formations and erosions do appear to show positive correlation with age. These studies do make note that further research needs to be conducted in understanding the biomechanical influences of entheseal changes and which features may be more intensely affected by age.

Nolte and Wilczak (2013) explore the effects of age, sex, and body size using 37 females and 48 males from the Terry skeletal collection at the Smithsonian. In order to determine body size, body size proxies of the upper limb were used here. Contrary to the results from the 2013 study by Livierse and colleagues, body size was found to be a significant effect on entheseal area observed on the biceps brachii attachment site. This study was critical in expanding upon the various effects on entheseal changes, and made a strong argument for further exploration into the effects of body size as well as age and sex.

Niinimäki and Sotos (2013) also look at the effects of body size on entheseal changes. This study focused lower limb entheses and aimed to test whether or not entheseal changes were more reflective of activity patterns or more strongly correlated with biological factors of body size and age. As with Nolte and Wilczak (2013), a few osteometric measurements were taken as body size proxies. For recording entheseal changes the authors chose to utilize the Hawkey and Merbs (1995) method to score both fibrous and fibrocartilaginous entheses, however there was consideration of more recent methods and suggestions to reduce variance and better incorporate both types of entheses in the analysis. The results of this study showed an insignificant effect of body size, which the authors note as surprising considering that body size has shown to be a significant effect of entheseal changes for the upper limbs (Niinimäki and Sotos 2013; Nolte and Wilczak 2013). These results suggest that entheseal changes may occur as a result of different factors for lower and upper limbs due to different types of mechanical loading.

Recent developments in examining activity patterns via entheseal changes are illustrated through two studies done by Karakostis and various colleagues (2016, 2017). Both studies utilize a method in which the 3D surface area of hand entheses are calculated and examined for certain morphometric patterns. Karakostis and Lorenzo

(2016) introduced this method of calculating surface area of hand entheses, in which 17 entheses from 50 adult males and females from the 13th to 15th century were utilized. Individuals were separated into three age groups, in which age was tested against size of entheses. Raw 3D entheseal surface size and relative 3D entheseal surface (raw entheseal size relative to the total bone size) were both incorporated in this method in order to assess how the size of entheseal surfaces may alter due to repeated mechanical stress in consideration of the notion that articular surfaces and bone length should not be affected by mechanical stress (Karakostis and Lorenzo 2016: 704). Results of this study showed no correlation between the raw surface size of the entheses and bone length or between surface size of entheses and articular surface size. An important finding in this study was two morphometric patterns, which the authors suggest are indicative of synergistic muscle movements referring to forceful grips and thumb-index finger interactions. These notable patterns led to further investigation as to how entheseal morphology of the hands could provide insight on effects of habitual manual activity (Karakostis et al. 2017).

Karakostis and colleagues (2017) later applied this method in examining how occupational activity is reflected in hand entheses. Using a documented 19th century population consisting of 45 adult males, the authors analyzed the entheseal surfaces of six hand elements. The authors tested for correlations between age and body mass and entheseal surface size, as well as evaluating effects of physical labor using documented occupations and morphometric patterns of the hand entheses. The authors make clear that the availability of historical documentation provided necessary information to understand the physical demands of the occupations held by this population, which is critically important criteria in testing for effects of occupation on entheseal changes. The results showed that individuals holding higher physically demanding occupations had larger mean entheseal surface sizes in areas associated with high force gripping, and individuals in less physically demanding occupations had larger mean entheseal surface sizes in areas more related to the thumb-index finger interactions. These two studies (Karakostis and Lorenzo 2016; Karakostis et al. 2017) present important new findings in how specific physical activities may affect specific types entheseal change.

Archaeological Site Context

In 1902 George A. Reisner was granted direction of the Giza ‘Hearst Expedition’ of University of California, Berkeley. This expedition and the excavations took place from 1902 until 1905, and after 1905 the expedition was transferred over to Harvard University and the Boston Museum of Fine Arts. This long-term project continued through the early 1900s until Reisner passed away at Giza in 1942. The excavated Giza Necropolis housed four “nucleus” cemeteries, one of which held the individuals utilized for this study (Reisner 1942: 13). Reisner (1942) suggested that the Necropolis began under the reign of Menes with one private mastaba (an ancient Egyptian tomb or burial chamber) during the first Dynasty and continued through to the fourth. During the fifth and sixth dynasties, the Necropolis is said to have expanded into multiple mastabas. There were five identified fields of tombs that belong to family members and court members of three Egyptian pharaohs of the fourth Dynasty: Cheops (Khufu), Chephren (Khafra), and Mycerinus (Menkaure). According the Phoebe A. Hearst Museum database, the individuals utilized in this study derive from two cemeteries in the Western Mastaba Field, which was located west of the Great Pyramid (Reisner 1942). The Western Mastaba Field was started under the reign of Cheops and was continuously in use until the end of the Old Kingdom. This field of mastabas was further divided into two parts: the North-Eastern Cemetery and the Western Cemetery (Reisner and Fisher 1913). Reisner and Fisher (1913) discuss the North-Eastern Cemetery as not being a cohesive unit, and is further subdivided into four parts: Northern Cemetery, Southern Cemetery, Western Cemetery, and Eastern Cemetery. The individuals in this study derive from two areas, G. 2100 in the Northern Cemetery, and G. 2300 in the Eastern Cemetery.

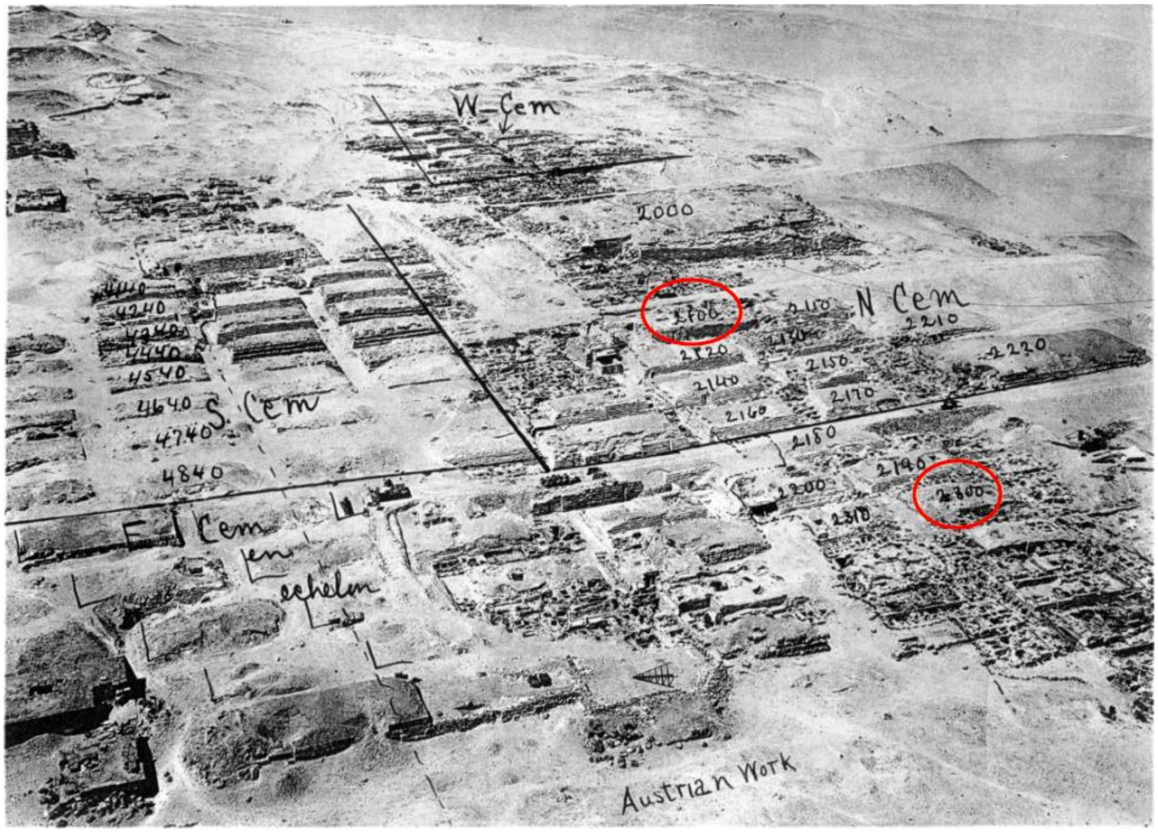

Fig. 2.1. Plan view image of royal cemetery from Great Pyramid looking WNW, G. 2100 and G. 2300 circled in red (Reisner and Fisher 1913).

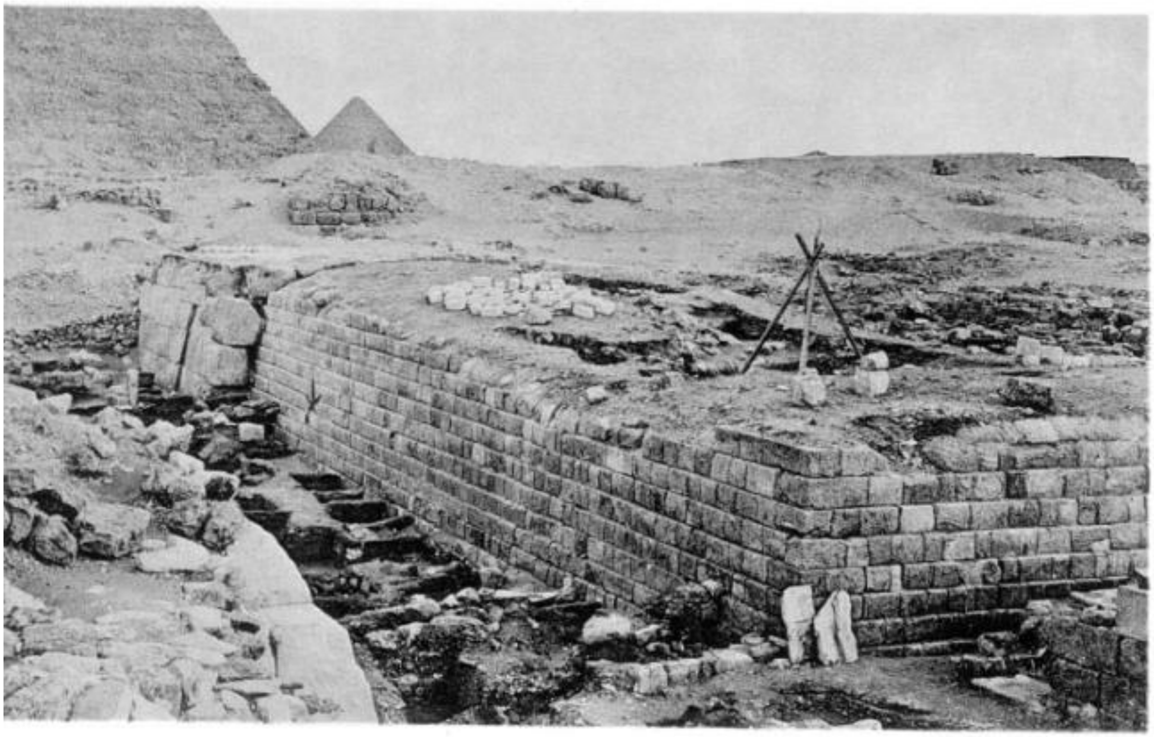

Fig. 2.2. G. 2100, view SSW (Reisner and Fisher 1913).

Western Mastaba Field of the Great Pyramid of Cheops

Cemetery G. 2100 is part of the four nucleus cemeteries in the Western Field of mastabas, which was located to the east of Cheops pyramid, also referred to as the Great Pyramid of Giza. This cemetery was comprised of eleven small mastabas and divided into four main rows. G. 2100 was in use from the 4th through the 6th Dynasty, and appears to have been occupied primarily by family members of the pharaoh, royal priests, royal scribes, and royal advisors (Der Maneulian 2010). Cemetery G. 2300 is also a part of the four main nucleus cemeteries and located east of cemetery G. 2100. Similar to G. 2100, this mastaba complex was in use through to the 6th Dynasty, and also was utilized for individuals who held higher rank within the society (Brovarski 2003).

Reisner extensively covered excavations of these cemeteries in his 1942 publication, in which he created a typology of the cemeteries and mastabas within them as well as discusses the ways in which they were constructed and organized around the pyramids. There is no information provided as to what types of physical activities the individuals buried here would have performed on a regular basis. Nonetheless, it is clear that these cemeteries and mastabas were constructed based on some sort of a socio-cultural hierarchical organization in which family members of pharaohs, royal priests, royal advisors and their families were buried in close proximities to one another, and that the construction of these cemeteries occurred under the reign of particular pharaohs.

This study will contribute to the previous research primarily through use of a population that is vastly different from the other populations utilized in previous studies using the new Coimbra method (Henderson et al. 2015, 2017; Michopoulou et al. 2016). Such studies have used historic European populations, and here the use of an ancient Egyptian population hopes to provide some new insight as to whether or not the consistent patterns seen within those historic European populations similarly shows up within this population. The results of this study will also provide a basis as to how future studies on entheseal changes using other ancient Egyptian skeletal collections might be put forth.

CHAPTER 3

METHODS AND MATERIALS

Choosing the most appropriate methods is a critical first step in defining the parameters of a project. The methods employed in a bioarchaeological study should reflect the skeletal sample, as well as the specific variables being examined. The goals of this project were to look at the effects of age, sex, and body size on entheseal changes within an ancient Egyptian skeletal collection, and also to test for presence or absence of asymmetry. Five fibrocartilaginous entheses of the upper limb were examined for this project: infra- and supra-spinatus insertions, subscapularis insertion, common extensor origin, common flexor origin and biceps brachii insertion. The new Coimbra method was used here to record and score entheseal changes in this skeletal collection. This method was developed to address a few core concerns within this area of research: to better understand the effects of biological variables on entheseal changes and to consider the differences between features of entheseal changes at fibrocartilaginous entheses (Henderson et al. 2015, 2013).

Earlier methods such as the Hawkey and Merbs (1995) method and Mariotti and colleagues' (2007) method were developed without differentiating between fibrous and fibrocartilaginous entheses and scored features within broad categories as opposed to separating out specific features as is done with the Coimbra method. Because the other published methods were not developed to specifically address biological variables such as age and sex, nor were they developed specifically for fibrocartilaginous entheses, the new Coimbra method is most appropriate for this analysis (Wilczak 1998; Nolte and Wilczak 2013; Milella et al. 2012; Henderson 2013).

Coimbra Method

The Coimbra method was initially developed in 2009 by researchers at a workshop held at the University of Coimbra in Portugal (Henderson et al. 2015; 2013; 2012; Wilczak et al. 2017). This method is intended to examine fibrocartilaginous entheses and to look at variation resulting from biological factors on different types of entheseal changes or features (Henderson et al. 2015). In developing a new method, the researchers conducted preliminary tests checking rates of inter-observer error and reliability in order to test the usability of the method. Initial reliability was relatively low with inter-observer agreement rates of 68.6% (Wilczak et al. 2017). A second meeting was held in 2013 to revise the existing method and improve rates of inter-observer error (Henderson et al. 2015). This was ultimately successful in improving inter-observer agreement rates up to 80%. This revised version of the Coimbra method, or the “new Coimbra method”, with minor clarifications (Henderson et al. 2015; Henderson et al. 2016), will be applied in this study.

This method is a single feature scoring system. In this scoring system, the fibrocartilaginous entheses are divided up into two zones, the margin of the enthesis and the remainder of the entheseal surface. Zone 1, or the margin of the enthesis, is defined as the most distant from the acute angle formed by the intersection of tendon and bone, and zone 2 is the remainder of the tendon attachment surface (Villotte 2013). Each zone expresses different characteristics of changes (Henderson et al. 2015; 2016). Unlike a phase scoring system that would score the total morphology of the enthesis as a whole, the Coimbra method examines specific features and each zone of the enthesis individually. A series of features on each zone of the enthesis are assessed and assigned a score of 0, 1, or 2 depending on the degree of expression except for textural change, which is scored as 0 or 1. Table 3.1 displays the definitions of features and the ways in which a feature should be scored.

Table 3.1. Coimbra Method Scoring Guidelines

Zone	Feature	Definition	Degrees of Expression
Zone 1	Bone Formation (BF)	Sharp, demarcated new bone along the margin. Normal, morphological smooth rounded or mound-like margins are scored as 0.	1 = distinct sharp new bone along margin or enthesophyte that does not meet criteria for score of 2. 2 = distinct sharp new bone along margin or enthesophyte >/= 1mm in elevation and >/= 50% of margin.
Zone 1	Erosion (ER)	Depressions or excavations of any shape, involving discontinuity of the floor of the lesion, greater in width than in depth with irregular margins. Only erosions >1mm where floor is clearly visible are recorded; this does not include pores. Erosions occurring on bone formation also recorded.	1= <25% of margin 2 = >/= 25% of margin

Zone 2	Textural Change (TC)	A non-smooth, diffuse granular texture with appearance of fine-grained sand paper, or a vertically aligned striated surface. Should only be recorded if it covers more than 50% of surface	1 = covering >50% of surface
Zone 2	Bone Formation (BF)	Any bone production from roughness of surface to true exostoses; distinct bone projections of any form like bony spurs, bony nodules and amorphous bone formation.	1 = distinct bone formation >1mm in size and any direction, affecting <50% of surface. 2= distinct bone formation >1mm in size and any direction, affecting >/= 50% of surface.
Zone 2	Erosion (ER)	Depressions or excavations of any shape (not covered by definition of macro-porosity), involving discontinuity of the floor of the lesion greater in width than depth with irregular margins. Only erosions >2mm are recorded. Fine porosity and Macro-porosity should not be recorded separately. Bone formation only recorded if it exceeds height of depression. Score erosions if occur on bone formation.	1 = <25% of surface 2 = >/= 25% of surface
Zone 2	Fine Porosity (FPO)	Small, round to oval perforations <1mm with smooth, rounded margins. Should be visible to the naked eye and in a localized area. Do not score if they are at the base of an erosion or occur as part of woven bone.	1 = <50% of surface 2 = >/= 50% of surface
Zone 2	Macro-porosity (MPO)	Small, round to oval perforations about 1mm or larger in size with appearance of a channel, and with rounded margins. Internal aspect is rarely visible. Do not score if they are at base of an erosion.	1 = one or two pores 2 = >2 pores
Zone 2	Cavitation CA	Subcortical cavity with a clear floor, which is not a channel. The opening should be >2mm and the whole floor must be visible.	1 = 1 cavitation 2 = >1 cavitation

The five fibrocartilaginous entheses recorded in this study are: the infra-and -supra-spinatus insertions; subscapularis insertion; common extensor origin; and biceps brachii insertion. Publications detail the exact locations of zones 1 and 2 for each enthesis scored in this study, which were referenced to ensure accuracy of recording entheseal changes (Henderson et al. 2015, 2016). Prior to data collection, Dr. Cynthia Wilczak – one of the researchers who collaborated in developing this method – conducted training sessions with this researcher. These training sessions took place at San Francisco State University using their osteological collection.

Sex Estimation

Humans are moderately sexually dimorphic, with cranial and post-cranial differences that occur as a result of testosterone and estrogen secretion (White et al. 2012:408; Jenkins et al. 2009:621). Differences in testosterone and estrogen levels contribute to the development of certain morphological features observable on the skeleton, which are used to distinguish between males and females. Despite population and idiosyncratic differences in skeletal morphology, several reliable qualitative methods for sex estimation have been published that are applicable across the range of variation.

The ossa coxae are the most reliable elements for sex estimation in human skeletal remains, relating to the fact that females have a birth canal and males do not. Certain features that are examined in sex estimation methods are typically unique to each sex. The Phenice (1969) method is considered the most reliable method for sex estimation and will be the primary method employed in this study. Researchers have repeatedly tested the method and achieved high accuracy rates, between 83% and 94%, across various skeletal samples and populations (Ubelaker and Volk 2002; Lovell 1989; Sutherland and Suchey 1990). This method examines three features in the sub-pubic region, presence of which are indicative of a female individual. Other methods examining the os coxae will also be utilized to ensure accuracy of sex estimation. Walker (2005) developed a series of drawings showing a scale of different shapes and widths of the greater sciatic notch feature on the os coxae. Variations of greater sciatic notch width and shape are shown on a scale of 1 to 5 with 1 indicating female and 5 indicating male. Walker similarly prepared a visual aid to accompany a scoring system for the preauricular sulcus feature also on the os coxae, which is featured in Buikstra and Ubelaker's (1994) guide to data collection of human remains. Both Walker scoring systems will be applied in this study alongside the Phenice (1969) method.

In the event that any of these features on the os coxae are unavailable for sex estimation, sex will be determined from cranial features using a method developed by Ascadi and Nemeskeri (1970). This scoring system examined five features on the skull, all of which have associated drawings of feature variations on a scale of 1 to 5, with 1 indicating female and 5 indicating male. Walker (2008) ran discriminant function analyses to test the accuracy of this method in which 87.1% to 92.7% of cases were correctly classified as male or female. It should be noted, however, that sexually dimorphic features of the skull can vary across different populations, meaning that accuracy rates could be lower for this particular Giza population.

Age-at-Death Estimation

Age-at-death estimation relies on the ontological growth processes an individual undergoes overtime. Growth plates at the epiphyses as well as cranial sutures progressively fuse during stages of skeletal maturation, which is typically reached around the age of 26 (Schaefer et al. 2009; Scheuer and Black 2009; Albert and Maples 1995; Albert et al. 2010). Upon skeletal maturation, there are several degenerative processes that occur at specific landmarks on the skeleton, e.g. the pubic sympheseal surface, the auricular surface, and cranial sutures (Albert and Maples 1995; Buckberry and Chamberlain 2002; Cheng et al. 2011; Lovejoy et al. 1985; Todd 1921; Shirley and Lantz 2011).

For the purposes of this study, a combination of methods will be utilized to place individuals into broad categories of skeletal maturation. It is important to note that the methods utilized in this study have all been repeatedly tested and evaluated for reliability and accuracy (Djuric et al. 2006; Nawrocki 2010; Falys and Lewis 2010; Osborne et al. 2004; Buckberry 2015). Application of these methods will involve examination of epiphyseal fusion, cranial suture closure, and post-cranial degenerative changes to separate younger from older individuals. Because chronological age is not being determined for this study, individuals will correspond to one of the following three biological age categories: 30 years of age or younger; 31 to 50 years of age; 51 years of age or older. Subadult individuals under the age of 18 will be excluded from this analysis. This approach is taken with consideration of method reliability, and in an attempt to limit potential error in ageing each individual skeleton.

The first step in age estimation will be to reject individuals under 18 years of age by examining the points of fusion in the cranium and post-cranial skeleton that are typically the last to fully fuse. Unfused spheno-occipital and basilar sutures, or unfused long bone epiphyses is indicative of individuals who have not completed puberty and most have not yet reached their early 20s (Schaefer et al. 2009; Scheuer and Black 2008; Scott 1958; Albert and Maples 1995). Second, examination of other points of fusion that typically occur in the early 20s up to the early 30s will be applied to help place individuals into the youngest age category (Schaefer et al. 2009; Scheuer and Black 2008; Brooks and Suchey 1990; Todd 1921; Lovejoy et al. 1985; Albert et al. 2010; Chen et al. 2011). These points of fusion include: medial clavicle, iliac crest, ischial tuberosity, and stage 2 vertebral ring epiphyses of the thoracic and lumbar region (Albert et al. 2010; Scheuer and Black 2008). If all skeletal elements are completely fused, the morphological features of the pubic symphyseal surface will first be considered. For retention in the youngest age category, individuals should show at least residual surface billows with a ventral rampart and dorsal margin that have not completely formed on the pubic symphysis (Dudzik and Langley 2015; Brooks and Suchey 1990; Buckberry and Chamberlain 2002). If the pubic symphysis is not available, the criterion of retention of billowing, and an absence of porosity, retroauricular and apical activity for the auricular surface will be used (Lovejoy et al. 1985).

For individuals between the ages of 30 and 50 years the pubic symphysis is the primary point of investigation, and in the absence of the pubic symphysis the criteria of auricular surface will be considered. The pubic symphysis should exhibit a disappearance of clear ridges and furrows, where only some residual ridges might remain comprising of less than 10% of the surface typically on the lower extremity (Chen et al. 2008; Todd 1921a, 1921b; Brooks and Suchey 1990). Following Lovejoy and colleagues (1985), individuals within this age bracket will exhibit diminishing striae and transverse organization of the auricular surface, as well as slight retroauricular activity and uniform coarse granularity over most of the surface. Individuals in the oldest age bracket over 50 years will exhibit extensive irregularities of the pubic symphysis, with erosions of the margins and loss of clear oval shape, as well as macroporosity and irregular small ossifications of the symphyseal face (Brooks and Suchey 1990; Todd 1921a, 1921 b). The auricular surfaces of individuals over 50 years will exhibit subchondral bone destruction, a complete lack of transverse organization, also showing microporosity and macroporosity (Lovejoy et al. 1985; Buckberry and Chamberlain 2002).

Pathological Conditions

Individuals that exhibit signs of having either diffuse idiopathic skeletal hyperostosis (DISH) or seronegative spondyloarthropathies will be excluded from this study. Seronegative spondyloarthropathies, such as ankylosing spondylitis, are inflammatory joint and connective tissue diseases known to cause pathological changes to the entheses (Benjamin and McGonagle 2001; Hutton 1989). DISH is a non-inflammatory joint disease that is observed in the thoracic region of the spinal column and is similarly seen to have extravertebral manifestations at the entheses (Hutton 1989; Cammisa et al. 1998; Mader et al. 2013). Flourosis and acromegaly are two metabolic pathological conditions that are known to result in enthesopathy formations throughout the skeleton (Henderson 2008). Because all of these conditions are known to have extravertebral impacts at the entheses, any pathological changes to the entheseal attachment sites would affect the scoring process.

Body Size Proxies

Body size is a factor considered in this study in order to better assess sexual dimorphism and asymmetry in this skeletal sample. Three osteometric measurements of the upper limb were used as body proxies (Nolte and Wilczak 2013; Wilczak 1998). The following osteometric measurements were taken: maximum length of the humerus; vertical head diameter of the humerus; distal articular breadth of the humerus. Descriptive statistics and an independent samples t-test were used to compare mean measurements between males and females. To test for the degree of sexual dimorphism the following equation was utilized (Wilczak 1998): %SXD = ([male mean – female mean]/[male mean + female mean/2]) x 100.

Statistical Analysis

SPSS statistical analysis software was utilized for assessing overall demographics of the skeletal sample, as well as looking at frequencies of entheseal change scores and testing for bilateral asymmetry. Descriptive statistics were run for assessing variability of scores and for calculated asymmetry in which left side entheseal change scores were subtracted from right side entheseal change scores.

Materials

The individuals utilized for this study derive from the human osteological collection at the Phoebe A. Hearst Museum of University of California, Berkeley. These individuals are a part of the ancient Giza, Egypt collection, which was originally excavated in the early 1900s during an expedition led by archaeologist, George A. Reisner. A total of 80 individuals are housed within this collection, 33 of which were selected based on the age, sex, preservation state of the entheses, and pathological criteria considered for this study. There were a total of 21 males and 12 females chosen. The distribution of males and females within each age bracket can be seen below in Fig. 2.

According to the museum database, eight individuals derive from G. 2100. It is unclear, however, which six of the eleven mastabas these individuals owned. The remaining twenty-five individuals are identified as having been affiliated with the mastaba complex G. 2300. Some of this complex was a family complex belonging to the family of Senedjemib Inti, who served as a royal advisor in the 5th and 6th Dynasties (Brovarski 2003). The other individuals whom these mastabas belonged to were similarly individuals of high rank, likely serving similar advisory roles to the pharaoh.

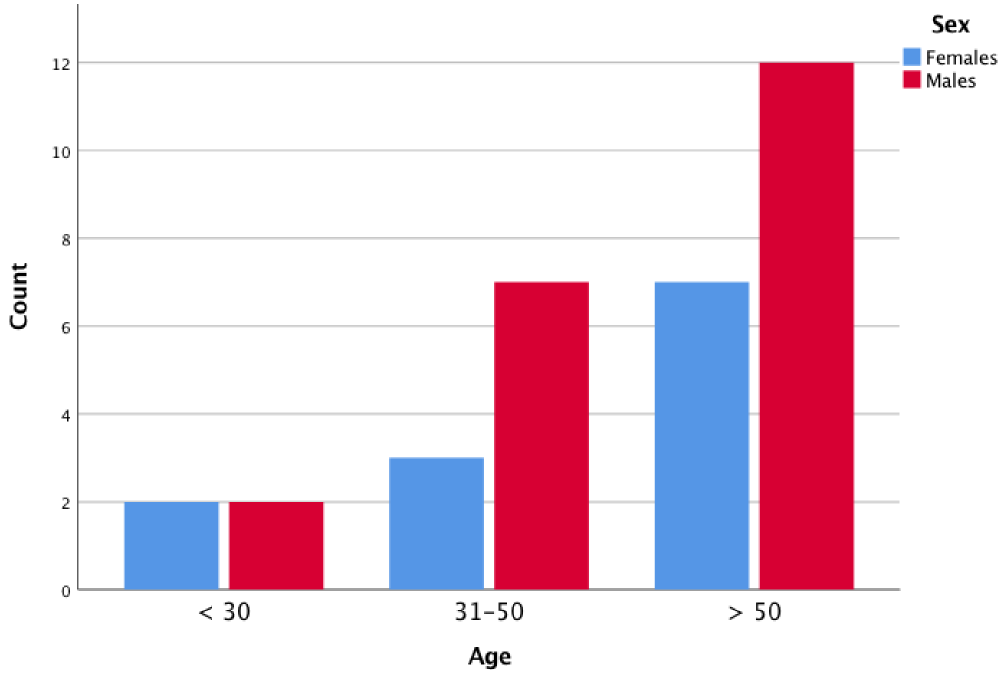

Fig. 3.1. The distribution of males and females within each of the three age categories.

Equipment

Few physical tools were used during data collection. The primary devices that were required include LED lamps and a camera to document notable features of entheseal change. The LED lamps are worth noting particularly because quality lighting is an important component in the Coimbra method. Guidelines for the method recommend outdoor lighting when possible, though this was not an option in using this particular skeletal sample for analysis. The best possible option for lighting during data collection was to combine the overhead lighting at the Phoebe A. Hearst Museum with additional LED lamps when necessary. A Nikon D40 camera was used for documentation of particular pathological conditions, trauma, and to document a range of variation seen at the entheses.

CHAPTER 4

RESULTS

Initial plans for this analysis included statistical testing of the effects of age and sex on entheseal changes, as well as testing for asymmetry. Previous studies (Henderson et al. 2017; Milella et al. 2012) have used ordinal regression to analyze correlations between age and entheseal change. It was hoped that similar or the same testing would be used for this analysis, but due to the small sample size and low variability of change, the most effective method in showing age correlations with different entheseal change features was to construct scatter-plot charts showing age by feature scores. For the remaining factors, the descriptive statistics were compared and an independent samples t-test was used to determine significance of sexual dimorphism.

Examples of Entheseal Change Variation

This section shows examples of scores for some of the major types of entheseal change. The attachment sites chosen for these examples are the subscapularis and infra- and supra-spinatus. Each individual featured below is male, which is congruent with the results for score variability showing males having more variation than females. It is important to note, however, that there are more males than females in this skeletal sample, and there is generally not a wide variety of entheseal change with the majority of attachment sites for both males and females across all ages assigned scores of 0.

Fig. 4.1 Infra- and supra-spinatus of individual 12-5222, Male 31-50 years of age with scores of across all features of attachment site.

Fig. 4.2. Right subscapularis of individual 12-5219, Male 31-50 years of age showing example of bone formation scores of 2 on zone 1 indicated by the white arrow and zone 2 indicated by the black arrow

Fig. 4.3. Left subscapularis of individual 12-5195, Male over 50 years of age, showing a score of 1 for cavitation indicated by the black arrow and a score of 1 for erosion indicated by the white arrow.

Fig. 4.4. Right subscapularis of individual 12-5237, Male younger than 30 years of age with a score of 1 for macroporosity indicated by the black arrow.

Fig 4.5. Left subscapularis of individual 12-5142, Male over 50 years of age with a score of 1 for fine porosity indicated by the black arrow.

Variability of Enthesis Scores

In order to assess how much variability was recorded for this sample and to see if there were any clear differences in variation between males and females, date is presented in two descriptive statistical tables separated by sex. Tables 4.1 and 4.2 display the distribution of changes with the total count of each score (NA, 0, 1, 2) recorded for each feature of each enthesis. The tables below show generally low variability between entheses, with relatively consistent scores for each of the features. Initially, these tables were put together showing variability for males and females with both left and right sides included. Upon examination of those initial results, it was clear that there was low variability overall. Because of this, the small sample size, and a lack of asymmetry,

Table 4.1. Descriptive statistics showing variability of scores per enthesis amongst females[1,2]

additional statistics were run pooling left and right sides for each feature. For this purpose, the right side was used as default unless the left side yielded more scorable features than the right side.

Table 4.1 shows the distribution of scores amongst the females of this skeletal sample. The majority of the scores for each feature of each enthesis were 0, and the second highest numbers were NA, or not able to be scored. This was due to the skeletal remains being highly fragmented, and in some instances, individuals had missing elements. There were some instances in which the percentage of scores other than zero were notably high over 10%, which are made bold in the table. Some of which are: the infra- and supra-spinatus attachment site, 16.7% of cases for cavitation in zone 2 were assigned scores of 2; and at the common flexor origin attachment site 33.3% of cases for fine porosity in zone 2 were assigned scores of 1.

Enthesis	Score	BF (Z1) %	ER (Z1) %	TC (Z2) %	BF (Z2) %	ER (Z2) %	FPO (Z2) %	MPO (Z2) %	CA (Z2) %
Infra/Supra-spinatus	**NA**	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
	0	83.3	83.3	83.3	66.7	75.0	75.0	83.3	58.3
	1	0.0	0.0	0.0	8.3	0.0	8.3	0.0	8.3
	2	0.0	0.0	0.0	8.3	8.3	0.0	0.0	**16.7**
Subscapularis	**NA**	25.0	25.0	16.7	16.7	16.7	16.7	16.7	16.7
	0	75.0	75.0	75.0	66.7	75.0	58.3	75.0	75.0
	1	0.0	0.0	8.3	**16.7**	0.0	**25.0**	8.3	0.0
	2	0.0	0.0	0.0	0.0	8.3	0.0	0.0	8.3
Com. ext. origin	**NA**	33.3	33.3	25.0	25.0	25.0	25.0	25.0	25.0
	0	66.7	58.3	75.0	66.7	58.3	75.0	75.0	66.7
	1	0.0	8.3	0.0	8.3	**16.7**	0.0	0.0	8.3
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Com. flex. origin	**NA**	25.0	25.0	8.3	8.3	8.3	8.3	8.3	8.3
	0	66.7	66.7	91.7	83.3	75.0	58.3	91.7	91.7
	1	0.0	0.0	0.0	0.0	**16.7**	**33.3**	0.0	0.0
	2	8.3	8.3	0.0	8.3	0.0	0.0	0.0	0.0
Biceps *brachii*	**NA**	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
	0	75.0	75.0	58.3	91.7	66.7	75.0	91.7	91.7
	1	**16.7**	8.3	**33.3**	0.0	**16.7**	**16.7**	0.0	0.0
	2	0.0	8.3	0.0	0.0	8.3	0.0	0.0	0.0

[1]Z1 refers to zone 1; Z2 refers to zone 2. BF = bone formation; ER = erosion; FPO = fine porosity; MPO = macroporosity; CA= cavitation; TC = textural change
[2]Total N= 12 for each enthesis attachment site

Table 4.1. Descriptive statistics showing variability of scores per enthesis amongst males[1,2]									
Enthesis	**Score**	**BF (Z1) %**	**ER (Z1) %%**	**TC (Z2) %**	**BF (Z2) %**	**ER (Z2) %**	**FPO (Z2) %**	**MPO (Z2) %**	**CA (Z2) %**

Infra/Supra-spinatus	**NA**	52.4	52.4	23.8	23.8	23.8	23.8	23.8	23.8
	0	47.6	47.6	76.2	57.1	61.9	61.9	76.2	57.1
	1	0.0	0.0	0.0	9.5	0.0	**14.3**	0.0	4.8
	2	0.0	0.0	0.0	9.5	**14.3**	0.0	0.0	**14.3**
Subscapularis	**NA**	38.1	38.1	28.6	28.6	28.6	28.6	28.6	28.6
	0	52.4	61.9	71.4	47.6	71.4	61.9	52.4	52.4
	1	4.8	0.0	0.0	**14.3**	0.0	9.5	9.5	9.5
	2	4.8	0.0	0.0	9.5	0.0	0.0	9.5	9.5
Com. ext. origin	**NA**	14.3	14.3	4.8	4.8	4.8	4.8	4.8	4.8
	0	57.1	85.7	95.2	52.4	90.5	81.0	85.7	85.7
	1	**19.0**	0.0	0.0	**33.3**	4.8	9.5	9.5	9.5
	2	9.5	0.0	0.0	9.5	0.0	4.8	0.0	0.0
Com. flex. origin	**NA**	33.3	28.6	9.5	9.5	9.5	9.5	9.5	9.5
	0	52.4	71.4	90.5	71.4	76.2	76.2	90.5	90.5
	1	**14.3**	0.0	0.0	**19.0**	**14.3**	**14.3**	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biceps *brachii*	**NA**	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
	0	71.4	66.7	66.7	66.7	66.7	66.7	76.2	90.5
	1	**19.0**	**19.0**	**23.8**	**19.0**	**19.0**	**19.0**	9.5	0.0
	2	0.0	4.8	0.0	4.8	4.8	4.8	4.8	0.0

[1] Z1 refers to zone 1; Z2 refers to zone 2. BF = bone formation; ER = erosion; FPO = fine porosity; MPO = macroporosity; CA= cavitation; TC = textural change
[2] Total N= 12 for each enthesis attachment site

Table 4.2 shows the distribution of scores amongst the males in this skeletal sample. There was slightly more variability seen here compared to the female sample.

This can be seen in that males exhibit a higher quantity of scores of one and two over the arbitrary cutoff of 10%. Similar to Table 4.1, the majority of scores for each feature of each enthesis were 0 or NA. The features that had noticeably higher scores over 10 % males were made bold in the table. Some of which are: the infra-/supra-spinatus attachment site 14.3% of cases for both erosion and cavitation in zone 2 were assigned scores of 2; at the common extensor origin attachment site 33.3% of cases for bone formation in zone 2 were assigned scores of 2; at the biceps brachii attachment site 23.8% of cases for textural change in zone 2 were assigned scores of 1.

Asymmetry

Asymmetry was examined to discern whether or not the individuals in this skeletal sample had any sort of pattern where scores would be consistently higher for one side of the body over the other, and in turn suggest an inclination for right or left handedness. Asymmetry was calculated by subtracting the left side scores from the right side scores (R – L) for each feature of each enthesis. If the result was a positive number, that indicated the right side scores were higher and suggests a favor towards the right side of the body; conversely, if the result was a negative number that indicated the left side score was higher suggesting a favor towards the left side of the body. If the result was zero, that indicated equal scores for both sides of the body.

Table 4.3. Asymmetry scores divided by enthesis and by feature.

Enthesis	**Asymm.**	**BF (Z1)**	**ER (Z1)**	**BF (Z2)**	**FPO (Z2)**	**MPO (Z2)**	**ER (Z2)**	**CA (Z2)**	**TC (Z2)**

Infra- and supra-spinatus	N	9	9	9	9	9	9	9	9
	R. Higher	0%	0%	**22.2%**	11.1%	0%	11.1%	**44.4%**	0%
	Equal	88.9%	100%	77.8%	77.8%	100%	66.7%	55.6%	100%
	L. Higher	**11.1%**	0%	0%	**11.1%**	0%	**22.2%**	0%	0%
Subscapularis	N	11	11	11	11	11	11	11	11
	R. Higher	0%	0%	0%	9.1%	9.1%	0%	**18.2%**	0%
	Equal	90.1%	90.9%	90.9%	81.8%	81.8%	90.9%	72.7%	100%
	L. Higher	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%	0%
Com. ext. origin	N	13	13	13	13	13	13	13	13
	R. Higher	0%	0%	**23.1%**	0%	7.7%	0%	7.7%	0%
	Equal	92.3%	92.3%	61.5%	76.9%	100%	92.3%	92.3%	92.3%
	L. Higher	7.7%	7.7%	**15.4%**	**15.4%**	0%	7.7%	0%	7.7%
Com. flex. origin	N	10	10	10	10	10	10	10	10
	R. Higher	0%	0%	**20.0%**	10.1%	0%	**20.0%**	0%	0%
	Equal	90.0%	90.0%	60.0%	90.0%	100%	70.0%	100%	100%
	L. Higher	10.0%	10.0%	20.0%	0%	0%	10.0%	0%	0%
Biceps *brachii*	N	20	20	20	20	20	20	20	20
	R. Higher	5.0%	5.0%	10.0%	5.0%	5.0%	**20.0%**	0%	10.0%
	Equal	90.0%	90.0%	90.0%	75.0%	90.0%	50.0%	100%	85.0%
	L. Higher	5.0%	5.0%	0%	**20.0%**	5.0%	**30.0%**	0%	5.0%

[1]Z1 refers to zone 1; Z2 refers to zone 2. BF = bone formation; ER = erosion; FPO = fine porosity; MPO = macroporosity; CA= cavitation; TC = textural change

Table 4.3 shows frequencies for asymmetry scores. These results show no clear pattern of asymmetry. There is a lack of asymmetry for each feature and the majority come in as equal, meaning the R – L = 0. Some of the features exhibited greater than

10.0% asymmetry with one side significantly higher than the other (made bold in Table 2), and only two of the features exhibit strong directional asymmetry (>10% difference between sides): bone formation zone 2 and cavitation zone 2 of the infra-/supra-spinatus. For these features, 22.2% of cases for bone formation were higher on the right side where 0.0% was higher on the left, and 44.4% of cases for cavitation were higher on the right side where 0.0% was higher on the left. One additional test was run excluding scores of zero, however the results were similarly erratic and lacking in any inclination towards either side for any entheses or features.

Sexual Dimorphism

Body size and sexual dimorphism was analyzed through a variety of different statistical tests. A series of osteometric measurements were taken for the humerus, and descriptive statistics were run separating males and females, which can be seen in Table 4.4. Further calculations were done to better quantify the differences in mean measurements for males and females. Finally, an independent samples t-test was done in order to test the significance of sexual dimorphism between males and females for each humeral osteometric measurement taken.

Table 4.4. Descriptive statistics of body size proxies for males and females

Sex	Measurement	N	Minimum	Maximum	Mean		Std. Deviation
					Mean	Std. Error	
Female	Max Length	9	286	340	303.6	5.75	17.25
	Vertical Head Diameter	9	37	47	40.4	1.07	3.21

	Distal Articular Breadth	9	51	64	55.0	1.35	4.06
Male	Max Length	18	293	332	308.2	2.84	12.07
	Vertical Head Diameter	18	41	48	43.7	0.41	1.74
	Distal Articular Breadth	18	57	69	60.8	0.61	2.58

Significance of Sexual Dimorphism

Wilczak (1998) used an equation that determined the percentage of sexual dimorphism from various osteometric measurements. Here, the same equation was utilized as another means for quantifying the differences between males and females in this skeletal sample. Below are the equations and results for the three acquired humeral measurements. The greatest percentage is seen with the distal articular breadth of the humerus at 9.97%,

followed by the vertical head diameter of the humerus a 7.72%, and finally the least percentage was seen in the maximum length of the humerus at 1.52%.

<u>Humerus Maximum Length</u>

([308.22 – 303.55]/[308.22+303.55/2]) x 100 = ([4.67]/[611.77/2]) x 100 = ([4.67]/[305.89]) x 100 = (0.0152) x 100 = **1.52**

<u>Humerus Vertical Head Diameter</u>

([43.69 - 40.44]/[43.69+40.44/2]) x 100 = ([3.25]/[84.13/2]) x 100 = ([3.25]/[42.06]) x 100 = 0.0772 x 100 = **7.72**

<u>Humerus Distal Articular Breadth</u>

([60.77 – 55]/[60.77+55/2]) x 100 = ([5.77]/[115.77/2]) x 100 = ([5.77]/[57.88]) x 100 = 0.0996 x 100 = **9.97**

Table 4.5 shows the results from an independent samples t-test with an α-level of 0.05. The three categories: maximum length, vertical head diameter, and distal articular breadth are the osteometric measurements taken from the humerus. This test compared the mean measurements between males and females, and is used to assess significance of sexual dimorphism within this skeletal sample.

Table 4.5. Independent sample t-test for humeral measurements testing significance of difference between males and females

Humeral Measurement	**Levene's Test for Equality of Variances**			**t-test for Equality of Means**	
	Assumption	**Sig.**	**d.f.**	**Sig. (2-tailed)**	**Mean Difference**
Maximum Length	Equal Variances Assumed	0.393	25	**0.420**	-4.67
	Equal Variances Not Assumed		12.1	0.481	-4.67
Vertical Head Diameter	Equal Variances Assumed	0.044	25	0.002	-3.25
	Equal Variances Not Assumed		10.4	**0.017**	-3.25
Distal Articular Breadth	Equal Variances Assumed	0.206	25	**0.000**	-5.78
	Equal Variances Not Assumed		11.3	0.002	-5.78

For vertical head diameter, equal variance is not assumed with a Levene's test sig. value of 0.044, which then gives a p-value for the t-test of 0.017. This indicates a significant difference between males and females as the p-value is less than 0.05. For the distal articular breadth, equal variance is assumed for the t-test where p = 0.000, also indicating a significant difference between males and females. There is no significant difference between males and females in the maximum length, with a p-value of 0.420.

Effects of Age

It was originally hoped that effects of age on entheseal change would be calculated through ordinal regression analysis. However, due the low variability of enthesis score and small sample size that was not feasible for this study. Alternatively, age was compared against mean score of each feature for each enthesis and is separated by sex, which can be seen in fig. 4.6.- 4.21. The correlations that can be seen with age are variable. Scores for bone formation in both zone 1 and 2 have a tendency to increase with males, but the same is not seen with females. Scores for erosion in zone 1 and 2 increase with age, particularly with females over the age of fifty. There are no clear trends with cavitations, though scores higher than zero are not seen in individuals under the age thirty. There are less clear trends for textural change and macroporosity. There was some tendency for textural change to be associated with the two older age groups for both males and females, though there was not much consistency between which entheses showed this trend. Macroporosity did not yield any clear trends but was more often observed in individuals over the age of thirty. Finally, fine porosity had some tendency to be associated with younger age groups at three entheses for females and two entheses for males, but the results are generally mixed with no clear trend.

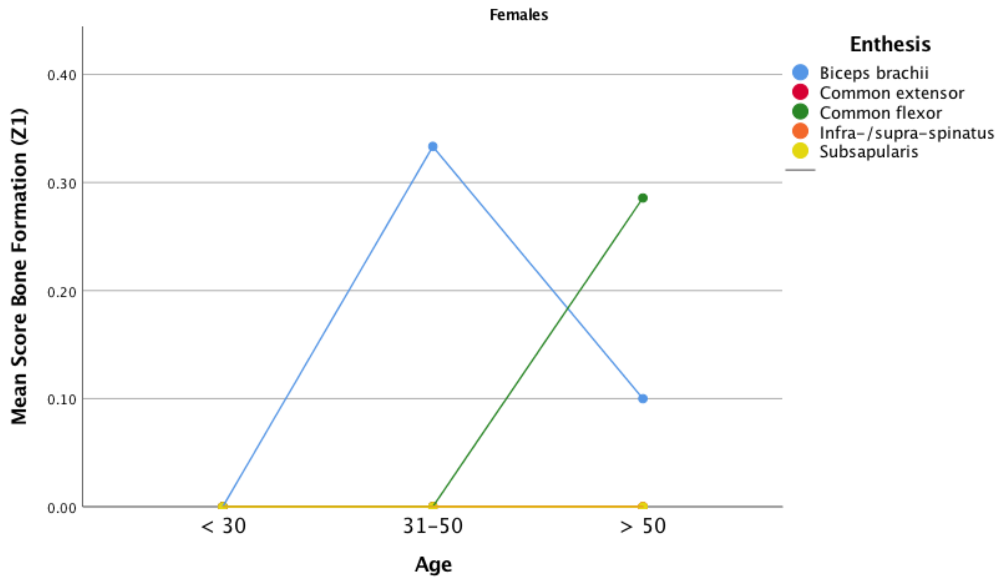

Fig. 4.6. Age of females compared against mean score for bone formation in zone 1.

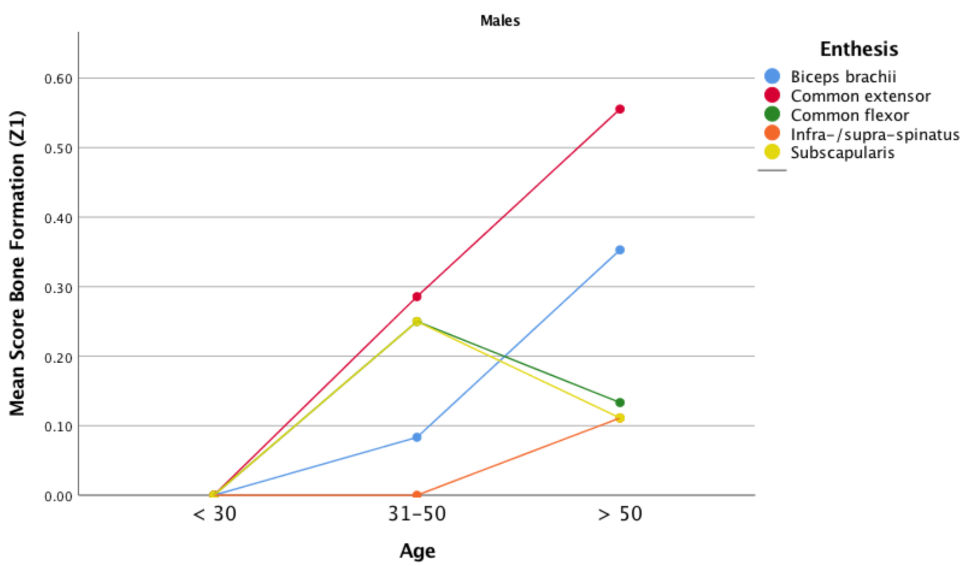

Fig. 4.7. Age of males compared against mean score for bone formation in zone 1.

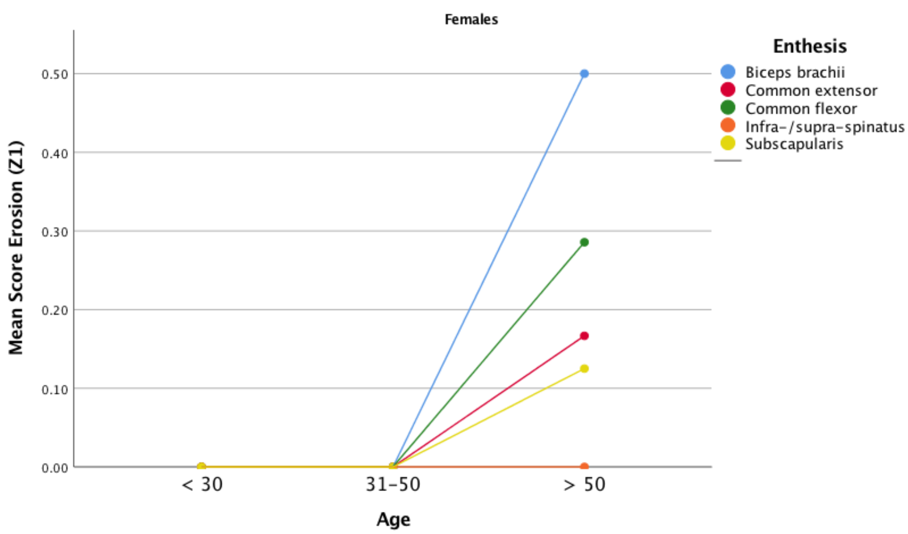

Fig. 4.8. Age of females compared against mean score for erosion in zone 1.

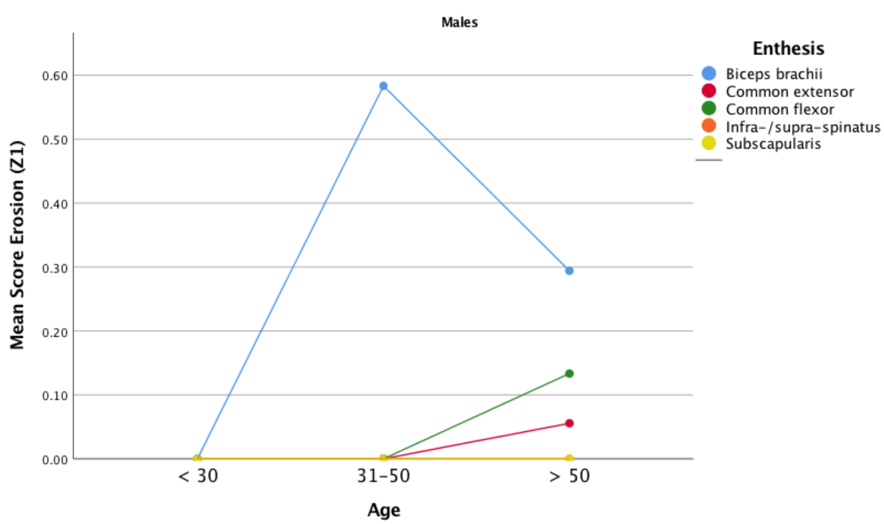

Fig. 4.9. Age of males compared against mean score for erosion in zone 1.

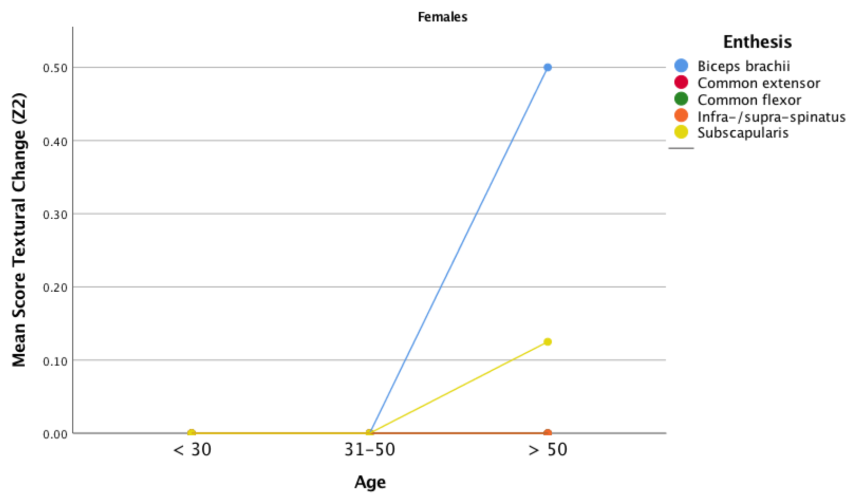

Fig. 4.10. Age of females compared against mean score for textural change in zone 2.

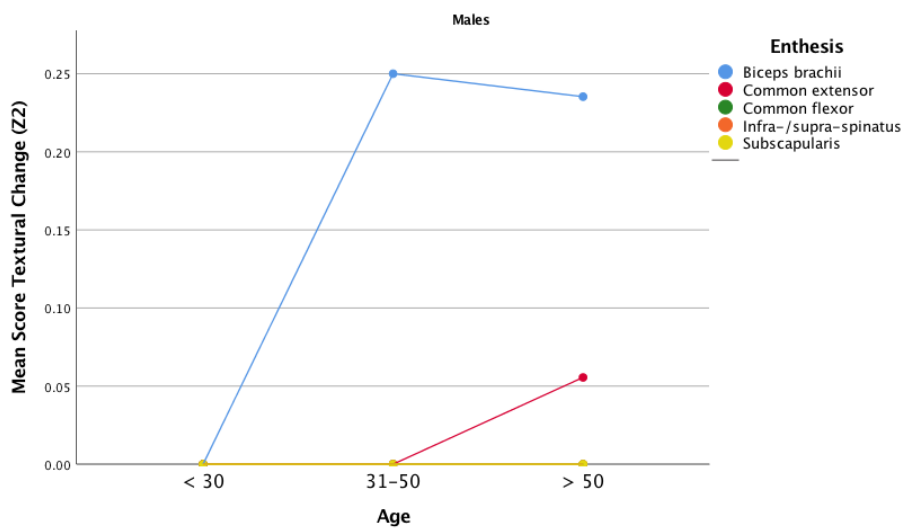

Fig. 4.11. Age of males compared against mean score for textural change in zone 2.

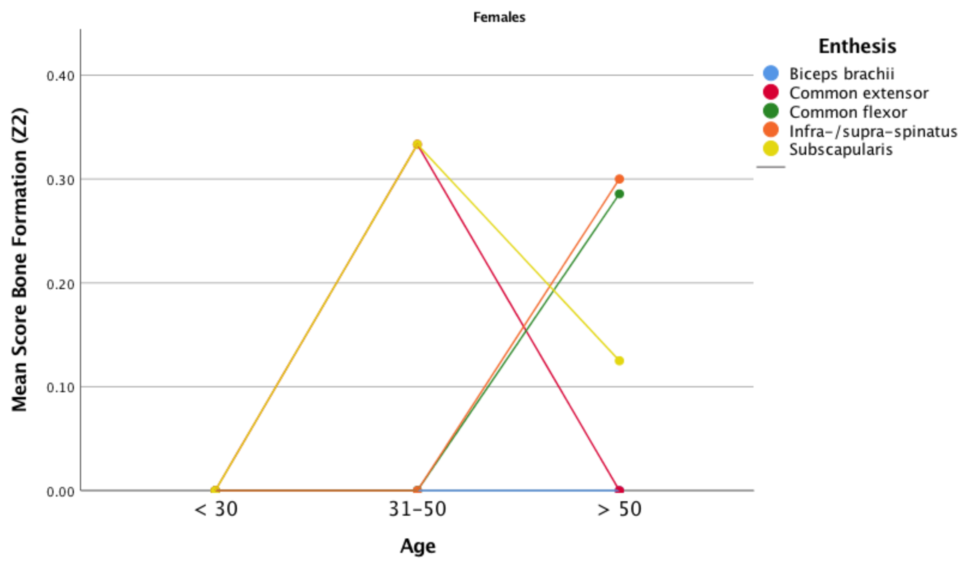

Fig. 4.12. Age of females compared against mean score for bone formation in zone 2.

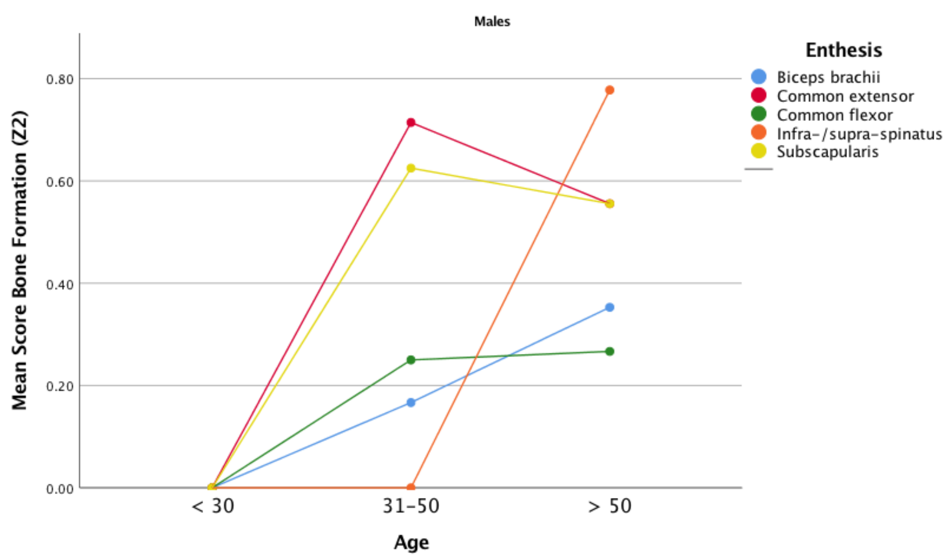

Fig. 4.13. Age of males compared against mean score for bone formation in zone 2.

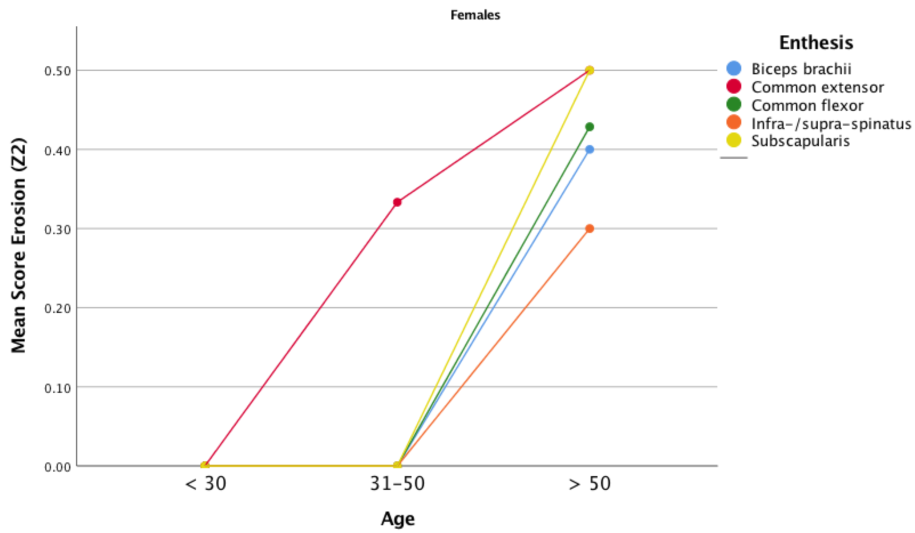

Fig. 4.14. Age of females compared against mean score for erosion in zone 2.

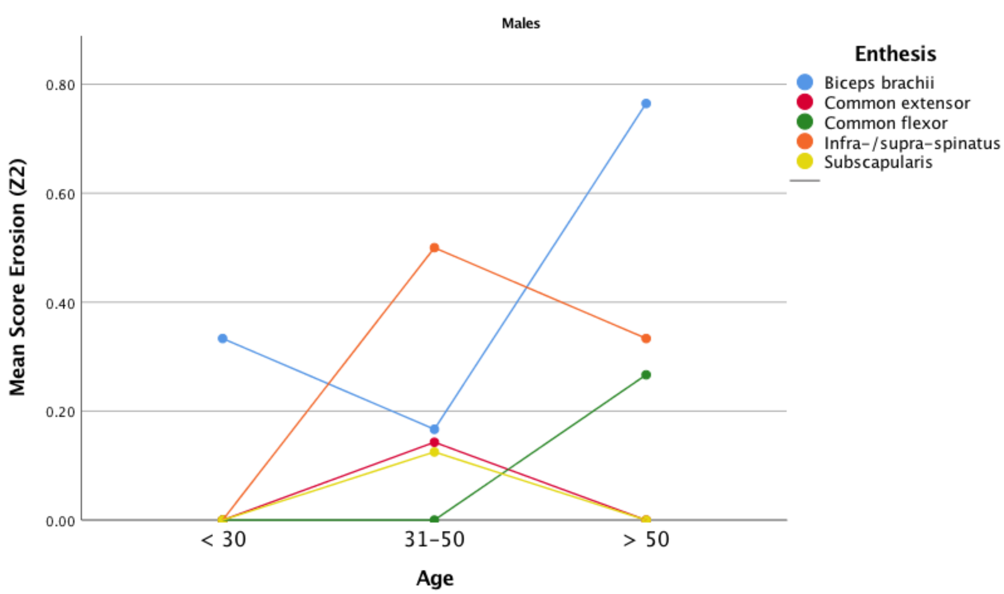

Fig. 4.15. Age of males compared against mean score for erosion in zone 2.

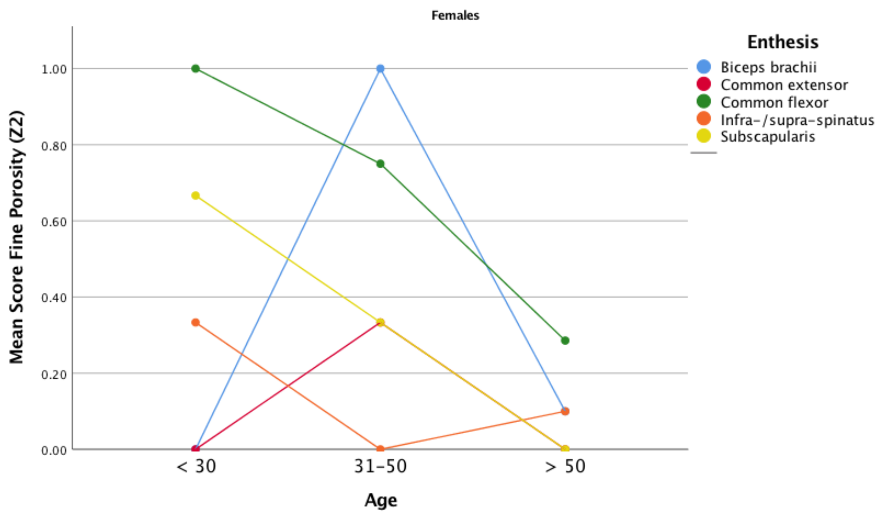

Fig. 4.16. Age of females compared against mean score for fine porosity in zone 2.

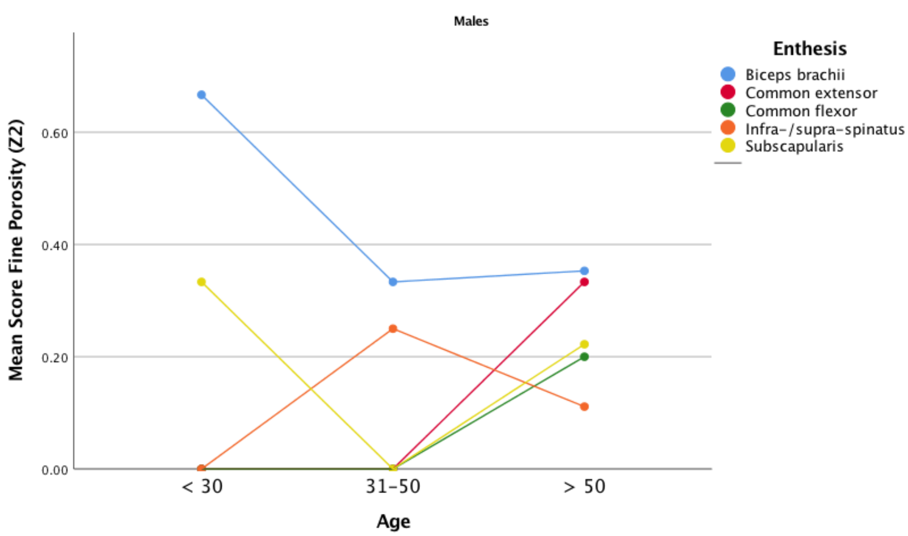

Fig. 4.17. Age of males compared against mean score for fine porosity in zone 2.

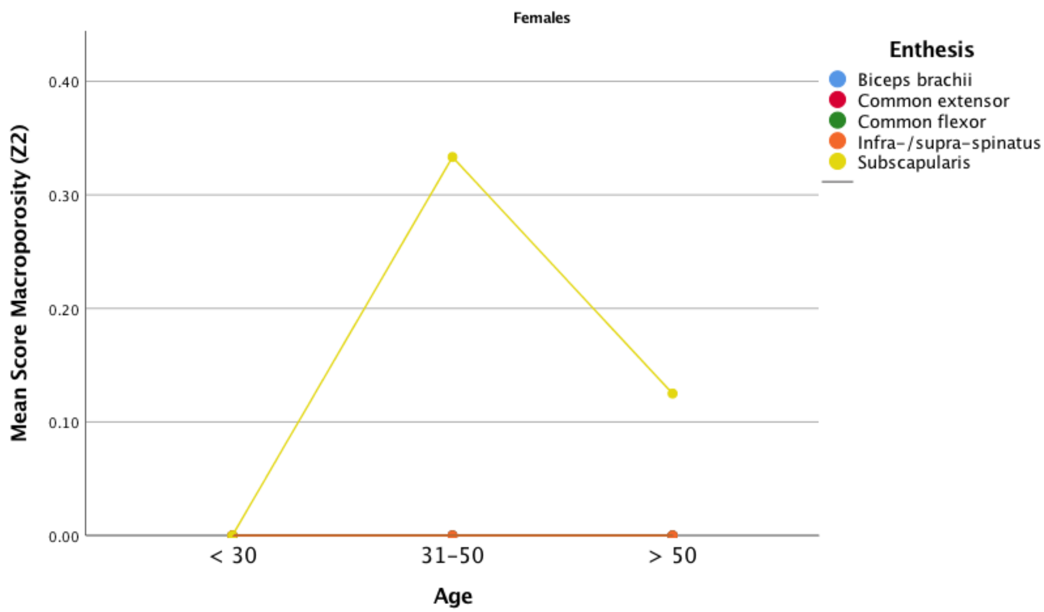

Fig. 4.18. Age of females compared against mean score for macroporosity in zone 2.

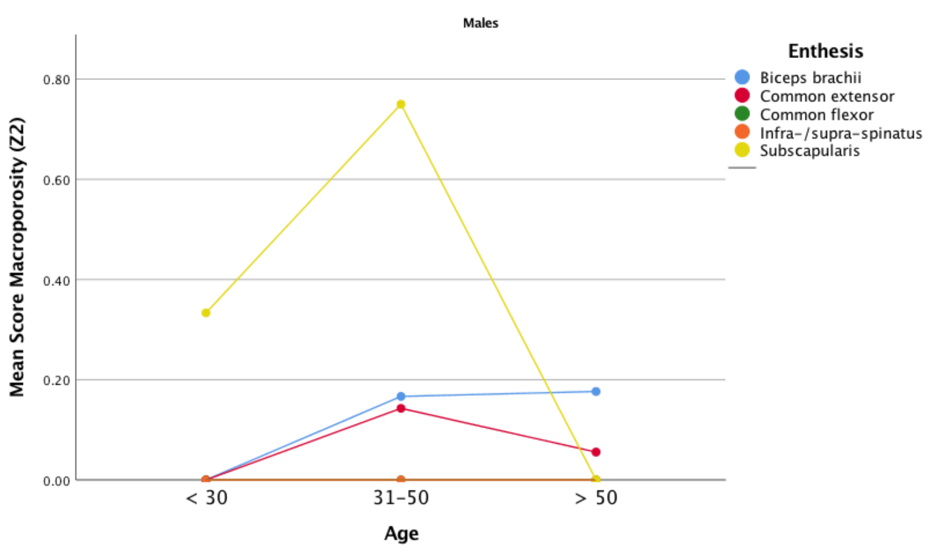

Fig. 4.19. Age of males compared against mean score for macroporosity in zone 2.

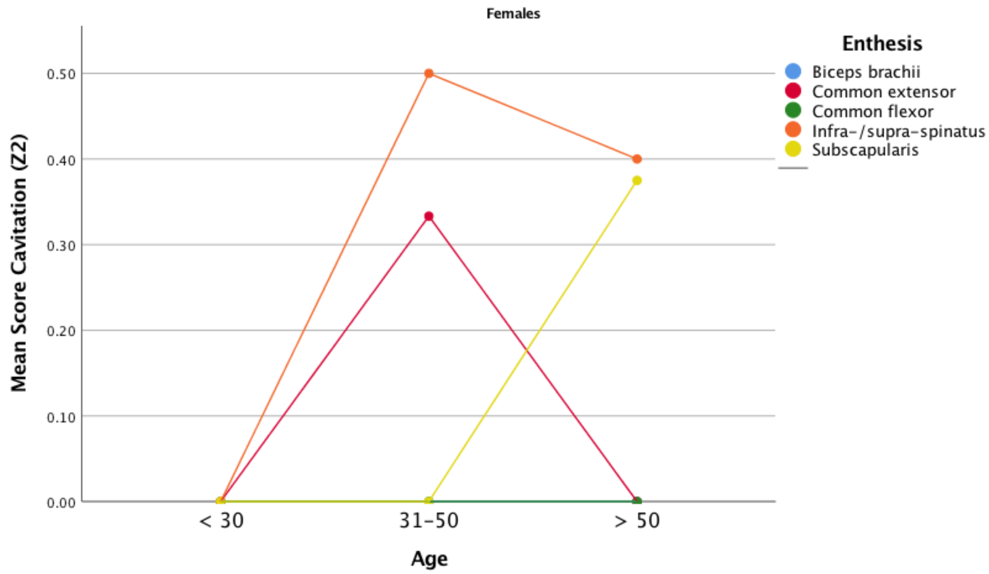

Fig. 4.20. Age of females compared against mean score for cavitation in zone 2.

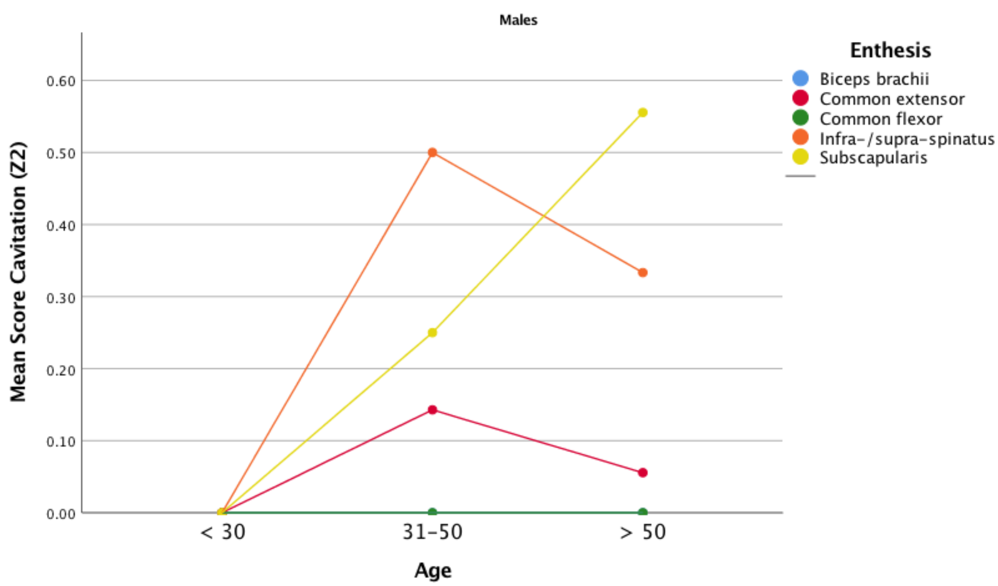

Fig. 4.21. Age of males compared against mean score for cavitation in zone 2.

CHAPTER 5

DISCUSSION

The previous chapter presented the statistical analyses and various descriptive results performed for this study. This chapter interprets and discusses those findings. The first section discusses the results from the various statistical analyses run for each of the primary factors in this study: asymmetry, body size, sex, and age. The second section presents two case studies on two notable individuals, one of whom exhibited ankylosis of the left hand, and the other who had a mid-shaft oblique fracture of the left radius. It is atypical to include individuals afflicted with such conditions in this type of analysis, as such this section will discuss the potential ways in which including such individuals might have impacted the results.

Interpretation of Statistical Analyses

The descriptive statistics and additional statistical testing were specifically done based on previous studies using the Coimbra method to examine similar effects on entheseal changes (Henderson et al. 2013, 2015, 2017; Wilczak 1998). The use of Henderson and colleagues' (2013, 2015, 2017) studies were essential in guiding the analytical specifics for age and asymmetry and in providing comparable results. Wilczak (1998) examined sexual dimorphism and body size alongside entheseal change, which similarly guided the analysis for those two factors. The results here are discussed in comparison to the results from those previous studies. Additionally, biomedical research and *in vivo* studies provide important insights as to what a number of the features of entheseal change represent clinically or what they might be caused by (Benjamin et al. 2008, 2009; Fritz et al. 2007; Jiang et al. 2001; Williams et al. 2006). Specifically, there is a good amount of information on ageing effects and why certain features may be significantly correlated with older ages or younger ages (Benjamin et al. 2008, 2009; Foster et al. 2014), as well as relatively new information on the presence of cavitations (Fritz et al. 2007; Jiang et al. 2001; Williams et al. 2006).

Asymmetry

Asymmetry is an important factor in this study with regard to consideration of mechanical factors in the etiology of entheseal change. If one side of the body consistently yielded significantly higher scores than the other, it could be indicative of the ways in which individuals were performing various physical activities. In this study, however, the asymmetry results did not show any clear patterns indicating the scores for one side were consistently higher than the other. At the infra- and supra-spinatus attachment site bone formation and cavitation in zone 2 had the only evidence of some directional asymmetry. Here, there were relatively large percentages of cases where there was a bias towards the right side. It is important to recognize that these are only two instances out of the rest of the features and attachment sites in which the majority of features had equal scores. Henderson and colleagues (2017) had similar results. They discuss that it is possible that the general lack of asymmetry could be due to the high percentage of zero scores, which was another similarity in this study (Henderson et al. 2017: 145). Another aspect to consider is that these particular individuals were affiliated with a relatively high social class and would not likely have engaged in particularly demanding physical activities on a regular basis.

Variation in Feature Scores

It was originally postulated that there would be a difference between males and females in feature scores. The results showed that males generally have more variation with an overall higher quantity of scores of one and two than was seen with females. This could be due to a number of reasons pertaining to the sample distribution, sexual dimorphism and body size, or a potential difference in activity levels between males and females. Males comprised a higher percentage of this skeletal sample, so it is possible that this discrepancy contributed to the appearance that males actually had more variation in entheseal change scores. There was also some significant sexual dimorphism seen in the humeral measurements at the humeral head and distal epiphyses where the subscapularis, infra- and supra-spinatus, common flexor origin, and common extensor origin are all located. This suggests the difference in variation may be related to an effect of sex and body size on entheseal change development. It is possible that this speaks to a difference in activity levels between males and females and potentially gendered division of labor. However, given that this was a higher social class population who were likely not engaging in strenuous, habitual activity and the lack of asymmetry in entheseal changes, this seems less likely of a cause.

Despite the apparent difference between males and females in how much variation there was in feature scores, there was not a clear pattern in which features were showing more variation than others. It was generally mixed, and there were some instances where females exhibited higher percentages over males in scores of one and two for certain features. This is consistent with Milella and colleagues' (2012) study, which looked at difference between the sexes in an Italian skeletal collection. They similarly hypothesized there would be a difference between males and females, and specifically anticipated that males would yield higher entheseal change scores. However, they found that while there was some significant difference between males and females with some features it was also mixed and scores did not consistently favor males.

Sex and Body Size

Body size proxies were calculated using a few osteometric measurements of the humerus. The initial plan was to use the measurements to assess the correlation of entheseal change scores with body size and sex but the sample size was too small for the statistical analysis. In hindsight, humeral circumference also should have been measured and compared to the variability and asymmetry of entheseal scores. Humeral circumference is particularly useful when exploring activity factors such as handedness and would have added to the overall discussion of impacts from biological factors versus mechanical stressors (Danforth and Thompson 2008; Jaskulska 2009).

It was still possible to use the acquired measurements to compare males and females and test for significance of sexual dimorphism. Wilczak (1998) used an equation for descriptive purposes to quantify the difference in body size between males and females. That equation was also used in this analysis and yielded relatively low percentages of sexual dimorphism for all of the humeral measurements taken. The independent sample's t-test was also run to assess the significance of sexual dimorphism in comparing mean measurements between males and females. With an α-level of 0.05, there was significant difference between sexes at the vertical head diameter and distal articular breadth. It is worth noting these are measurements of breadth and are taken around the same loci of four of the entheses recorded for this study. This may relate back to the difference in score variation between males and females wherein males tended to show more overall variation than females.

Wilczak (1998) similarly observed significant sexual dimorphism in distal articular breadth and this consistency with other populations indicates that measurements of breadth should be considered when examining sexual dimorphism. With regard to future research, it would be beneficial to take additional osteometric measurements pertaining to robusticity to better understand whether or not this is a consistent pattern. It was anticipated that significant difference would also be seen in the maximum length, but the average for males and females were not significantly different.

The combination of relatively low body size dimorphism and small difference between males and females in entheseal changes is consistent with results from Wilczak's (1998) study. Wilczak (1998) compared five populations, one of which was Egyptian. The percentage of sexual dimorphism seen between humeral lengths for this population was comparatively very low whereas the percentage of sexual dimorphism at the distal articular breadth measurement is high within this population. While the percentage of sexual dimorphism for the Egyptian population is still low compared against the other populations examined, it is still significant within the population. This is similar to what is seen in the present study, where there is little to no significant sexual dimorphism seen within the arm length, but there is within the arm breadth where males appear to be broader. Another, possibly related, issue to mention with regard to body size is that the majority of these individuals are notably gracile and exhibited signs of nutritional deficiencies with significant amounts of cranial porosity and antemortem tooth loss. This could in turn impact overall growth during an individual's lifetime as well as maybe having an effect on entheseal changes (Ortner 2003).

Age

A primary aim in developing the new Coimbra method was to have a biologically appropriate method for scoring entheseal changes and to differentiate which types of features have stronger correlations with biological factors (Henderson et al. 2015). Age has been one of the central focuses with regard to biological effects of entheseal change. Henderson and colleagues (2013, 2017) have consistently seen some features associated with age, which is a similar occurrence seen in *in vivo* biomedical studies (Benjamin et al. 2008, 2009). In their 2017 study, Henderson and colleagues do make clear that it is more difficult to parse exactly what part of the ageing process – general tissue degeneration or habitual muscle usage, microtraumas, and macrotraumas – is most affecting entheseal changes associated with age. They continue to discuss that "normal age-related tissue degeneration" (Henderson et al. 2017: 145) would occur on both sides rather than asymmetrically as would more likely be seen with habitual muscle use and repeated stress. A lack of asymmetry was observed in both their 2017 study and here in this study, which suggests that some of these changes, like that of bone formation, are occurring due to normal age degeneration processes.

For bone formation in zone 1, males did show a correlation with higher mean score and older age for three of the attachment sites, though this was not consistent with females. Benjamin and colleagues (2009) conducted some compelling research regarding bone formation as an age-related phenomenon that yielded similar results to those seen here. They found that bone formation was typically age-related, and they also saw bone formation occurring more often in the fibrous part of the enthesis. The latter piece of information is interesting with relation to the results here, where bone formation in zone 1 was positively correlated for more entheses than was seen with bone formation in zone 2. The primary reason for the zone distinction with fibrocartilaginous entheses in the Coimbra method is because the properties of zone 1 are more similar to that of fibrous entheses.

As for fine porosity, females showed higher mean scores associated with younger age for three attachment sites. Males showed the same association for two attachment sites, but the opposite correlation at three attachment sites. Henderson and colleagues had similar results in their 2013 and 2017 studies, though it was a clearer pattern of association than was observed here. Despite this not being seen at a majority of entheses for both males and females, the consistency of this occurrence merits discussion. There is generally less information as to why this feature scores higher in younger age groups, but there are discussions in biomedical literature with regard to general differences in the cellular matrix of soft tissues between various age groups, and with regard to differences in how bone at younger versus older ages responds to repeated stress (Benjamin et al. 2008; Foster et al. 2014; Wang et al. 2006).

Erosion in zone 1 and zone 2 showed a correlation with higher mean scores and older ages, for both males and females. In zone 1, both males and females showed this pattern at three attachment sites for males and four attachment sites for females. In zone 2 females showed this pattern at all of the attachment sites and more specifically individuals fifty years of age and older. Erosions, like bone formation, tend to be correlated with individuals of older ages (Henderson et al. 2017). It is possible that this feature could be due to accumulated stress and wear at these attachment sites as well as age-related degeneration.

Textural change for both males and females had a tendency to correlate with older age groups, opposite to what has been seen in a previously in Henderson and colleague's (2017) study. They found a correlation between textural change and younger age, which was the same trend seen with fine porosity. The authors do note that this was a different result from their initial study testing the Coimbra method (Henderson et al. 2013), where they had not distinguished between textural change and bone formation and therefore did not see the critical difference between the two features and age effects. Here, there were only two entheses for females and one for males that showed the trend for textural change to be positively correlated with the fifty and older age group. This is not a strong trend, so while it is noteworthy, it does not necessarily indicate a significant trend for this population and different results may have been seen had a larger skeletal sample been recorded.

Cavitations

There was an unusually high presence of cavitations seen with both males and females at the infra- and supra-spinatus. For females, 16.7% of cases were scored as 2, and for males 14.3% of cases were scored as 2. There are a few biomedical studies that describe changes similar what are referred to here as cavitations at the infra- and supra-spinatus, and are discussed as possibly being related to rotator cuff tears and age degeneration (Fritz et al. 2007; Jiang et al. 2001; Williams et al. 2006).

Williams and colleagues (2006) describe 'cysts' as "well-demarcated rounded or ovoid foci," (Williams et al. 2006: 911). These were observed radiographically and are similar to what is observed here in skeletal remains as cavitations, based on radiographic imaging and their description. Cysts have been commonly observed at the infra- and supra-spinatus attachment sites, but there is still debate as to why this is the case. Williams and colleagues' (2006) study, and Fritz and colleagues' (2007) study both found no statistically significant correlations between the occurrence of cysts at the infra- and supra-spinatus enthesis and patients diagnosed with rotator cuff injuries, despite some previous research that had suggested a correlation between the two (Jiang et al. 2001). It should be noted that this is different from other Coimbra method studies that have generally had a low frequency of cavitations (Henderson et al. 2013; 2017). It remains possible that cavitations are correlated with rotator cuff injuries, and possibly as a result of normal age degeneration, but there is further research required to determine an etiology of this particular feature of entheseal change.

Scoring Individuals afflicted with Trauma and Pathological Conditions

Individuals with pathological conditions or notable trauma are typically excluded from studies on entheseal changes. This is because certain pathological conditions, like AS, DISH, acromegaly, and fluorosis are known to also affect entheses (Henderson 2009). However, for this study two individuals that would typically be excluded were included and their entheseal changes were recorded. With only 80 total individuals in this particular Giza, Egypt collection it was necessary to carefully examine all individuals that did have well-preserved attachment sites and could therefore be included in the recordation of entheseal changes. These two particular individuals did meet that criteria. One individual displayed a significant case of ankylosis of carpals and metacarpals of their right hand. The other individual had a healed fracture of their left radius.

Case Study #1: Carpal Ankylosis

Individual 12-5142 was a male older than 50 years of age and exhibited signs of ankylosis of their left hand, in which all of the carpals were fused together and fused to the proximal ends of the metacarpals. It is important to note that the right hand of this individual did not exhibit fusion of the carpals and metacarpals as is seen on the left side, nor was there any additional bone formation or osteophytes on any of the hand bones.

There are a number of pathological conditions, or trauma that could result in this type of fusion, and that could further affect other entheses. Rheumatoid arthritis is a condition in which fusion of the metacarpals and phalanges typically occurs, as well as instances of fusion of the carpals as is seen with this individual (Burns and Clain 1983; Moldonado-Cocco et al. 1980; Ortner 2003). However, if this were the case it would be expected that this would be bilateral and it was only present on the left hand.

Spondyloarthropathy is another possibility, as this refers to diseases that typically involve new bone formation, which can in turn result in ankylosis. Bone formation and ankylosis are features that characterize both spondyloarthropathies and rheumatoid arthritis makes it difficult to definitively diagnose in skeletal samples. In 1999 Rothschild and colleagues examined individuals from various African regions who exhibited features of spondyloarthropathies, but had been misclassified as having rheumatoid arthritis (Rothschild et al. 1999). One individual from Mali is described as having the exact same features as individual 12-5142, "asymmetrical wrist fusion," (Rothschild et al. 1999: 262). Another individual from Sudan is similarly described as having wrist fusion, both of which were characterized here as spondyloarthropathy. On vertebrae associated with this individual there was some evidence of marginal lipping and few marginal osteophytes, though it was not consistent throughout the vertebral column. Finally, it is also possible that this is due to soft-tissue trauma that could trigger abnormal bone formation and fusion (Ortner 2003).

While these conditions may be expected to result in other enthesis bone formation, this individual did not yield any particularly abnormal scores and was fairly consistent with other scores for the rest of the population with the majority of scores being zero. As only five upper limb entheses were considered in this study, it is worth noting the possibility that other entheses of the body would yield inconsistent scores and possibly show more bone formation.

Fig. 5.1. Individual 12-5142; Male Age older than 50 years of age showing fusion of hand bones

Table 5.1. Scores for Individual 12-5142

SIDE	ENTHESIS	BF (Z1)	ER (Z1)	TC (Z2)	BF (Z2)	ER (Z2)	FPO (Z2)	MPO (Z2)	CA (Z2)
R	Subscapularis	0	0	0	0	0	0	0	0
R	Infra- and supra-	0	0	0	1	0	0	0	0

	spinatus								
R	Com. flex. origin	0	0	0	1	0	1	0	0
R	Com. ext. origin	0	0	0	1	0	0	0	0
L	Subscapularis	0	0	0	0	0	1	0	0
L	Infra- and supra-spinatus	0	0	0	1	1	0	0	0
L	Com. flex. origin	0	0	0	0	0	1	0	0
L	Com. ext. origin	0	0	0	0	0	1	0	0
R	Biceps *brachii*	0	1	0	2	0	0	0	0
L	Biceps *brachii*	1	0	0	0	1	1	0	0

Case Study #2: Mid-shaft Radial Fracture

Individual 12-5169 exhibited signs of a healed mid-shaft oblique fracture of the left radius, in which the fracture has been obliterated through stages healing and callus formation (Wilczak and Jones 2011). The photo below also shows post-mortem damage with a break in the middle of the callus. There was no other evidence of trauma on the remaining elements with this individual. It can be assumed that a significant fracture on the radius would prevent an individual from performing any strenuous physical activities, and depending on when the fracture was acquired could affect entheseal changes especially on the upper limb entheses and on the side of the body with the fracture. The left side scores here are different from that of the right side at the biceps brachii attachment site, however with so many other attachment sites unavailable for this individual it remains unclear as to whether or not such a difference could be attributed to the fracture.


Fig. 5.2; 5.3. Individual 12-5169 showing mid-shaft oblique fracture of left radius. The complete break of the radius is post-mortem damage.

Table 5.2. Scores for Individual 12-5169

SIDE	ENTHESIS	BF (Z1)	ER (Z1)	TC (Z2)	BF (Z2)	ER (Z2)	FPO (Z2)	MPO (Z2)	CA (Z2)
R	Subscapularis	99	99	99	99	99	99	99	99
R	Infra- and supra-spinatus	99	99	99	99	99	99	99	99
R	Com. flex. origin	0	0	0	0	0	0	0	0
R	Com. ext. origin	0	0	0	0	0	0	0	0
L	Subscapularis	99	99	0	0	1	0	0	0
L	Infra- and supra-spinatus	99	99	99	99	99	99	99	99
L	Com. flex. origin	0	0	0	0	0	0	0	0
L	Com. ext. origin	0	0	0	0	0	0	0	0
R	Biceps *brachii*	0	1	0	0	0	0	0	0
L	Biceps *brachii*	0	1	0	0	2	1	0	0

The results of this study were consistent with previous findings in some areas and inconsistent in others. Ultimately it would have been beneficial to have a more equal number of males and females, and a generally larger sample size to allow a more conclusive analysis. Future studies aimed at addressing questions about entheseal change etiology and biological factors in particular should use larger sample sizes and a more balanced number of males and females or perhaps include only one sex.

CHAPTER 6

CONCLUSIONS

The study presented here ultimately serves as a pilot study in which the new Coimbra method was utilized on an Ancient Egyptian skeletal sample, different from other studies that have used historical European populations. It was an important task to explore the potential similarities and differences in the results from this study and results from previous works. Additionally, it was worthwhile to examine entheseal changes in a population that has yet to be used for this type of analysis, and within a sample of a particular social class. Despite some inevitable limitations in this study, the results opened up some interesting questions and avenues for future research.

Age remains an important factor to consider in this area of research. The results here did show some correlation between certain features at certain attachment sites and age. It would have been beneficial to have a larger sample size to gain a better sense on variability of entheseal change in this population and to have used ordinal regression analysis as originally planned, as this has been noted to be an ideal method in gauging age effects (Henderson et al. 2013, 2017). However, there are notable similarities between results from this study and results from Henderson and colleagues' studies that have tested for age effects, as well as some similarities with Benjamin and colleagues' research (Henderson et al. 2013, 2017; Benjamin et al. 2008, 2009). Mention where differs. Textural change in particular is interesting. Future research will need to continue working towards differentiating between age effects due to normal age degeneration and age-related changes associated with repeated mechanical stress. Asymmetry is an important factor to consider alongside age effects and important in further investigations of the biomechanical impacts on entheseal changes.

There was no asymmetry observed in this sample. This was not particularly surprising as it is consistent with other studies (Henderson 2017). These results were compounded by the fact that the sample size was limited and that some osteometric measurements that could have contributed to this analysis were not taken. It is important to highlight that a lack of asymmetry does argue against the notion that mechanical factors are the primary cause of entheseal change, which in turn suggests that some of the primary changes seen here are more closely associated with biological factors like age.

Sexual dimorphism and body size is another intriguing area for future research. While the results here showed significant differences between males and females for two of the three measurements used, vertical head diameter and distal articular breadth. Both of these are measurements of breadth, which could be interpreted as robusticity and (with additional research) could add to the discussion of entheseal change differences between sexes. Additional research should incorporate more measurements to use as body size proxies to see if differences between males and females are observed in other areas to better infer overall significance of sexual dimorphism within this population. This would further help to discuss the impact of sex on entheseal changes. Similarly, it would be worthwhile to conduct more research on how body size may affect entheseal changes. This was a particularly gracile population with generally low variability of entheseal change, which were similar results seen in Wilczak's (1998) study that compared three different populations of different sizes (gracile versus more robust). Is there an effect of body size on how entheseal changes are expressed on skeletal remains?

Effects of nutritional deficiencies and potential differences between sociocultural classes are two factors relevant to this population that merit future research. The majority of individuals in this skeletal sample, including those that were not utilized for this study, exhibited signs of nutritional deficiencies. Those signs included extensive cranial porosity and antemortem tooth loss. Because that was not a component of this study those conditions were not carefully analyzed or considered, though it would be compelling to discuss the effects of such conditions on growth and therefore effects on entheseal change. Finally, these individuals were of a higher societal rank and it can be inferred that they likely did not engage in many physical activities on regular basis that are associated with other professions and lifestyles.

This study aimed at answering some of the primary questions being asked in this realm of bioarchaeological research, specifically, how are entheseal changes affected by biological factors? The etiology of entheseal changes is a broad, multifactorial area of research in bioarchaeology. It is hoped that the research presented here serves its purpose a pilot study and provides some foundational information about entheseal changes within ancient Egyptian populations that will inform further investigation within the population and in entheseal change research in general.

LITERATURE CITED

Acosta, A, CY Henderson, and E Cunha. 2017. The effect of terrain on entheseal changes in the lower limbs. *International Journal of Osteoarchaeology* Early View

Adirim, T., T. Cheng. 2003. Overview of injuries in the young athlete. Sports Medicine 33:75-81

Albert, AM and WR Maples. 1995. Stages of epiphyseal union for thoracic and lumbar vertebral centra as a method of age determination for teenage and young adult skeletons. *Journal of Forensic Science* 40(4): 623–33.

Albert, AM, D Mulhern, MA Torpey, and E Boone. 2010. Age Estimation Using Thoracic and First Two Lumbar Vertebral Ring Epiphyseal Union. *Journal of Forensic Sciences* 55(2): 287–94.

Alves Cardoso, F., C. Henderson. 2009. Enthesopathy formation in the humerus: Data from known age-at-death and known occupation skeletal collections. *American Journal of Physical Anthropology* 141(4):550-560.

Alves Cardoso, F., Henderson, C. 2013. The Categorisation of Occupation in Identified

Skeletal Collections: A Source of Bias? *International Journal of Osteoarchaeology* 23(2):186-196.

Angel, JL. 1976. Colonial to modern skeletal change in the U.S.A. *American Journal of Physical Anthropology 45*:723-736.

Angel JL, Kelley JO, Parrington M, and Pinter S. 1987. Life stresses of the free Black community as represented by the First African Baptist Church, Philadelphia, 1823- 1841. *American Journal of Physical Anthropology* 74:213-229.

Apostolakos, J, TJS Durant, CR Dwyer, RP Russell, JH Weinreb, F Alaee, K Beitzel, MB McCarthy, MP Cote, and AD Mazzocca. 2014. The enthesis: a review of the tendon-to-bone insertion. *Muscle, Ligaments and Tendons Journal* 4(3): 333-342.

Benjamin M, EJ Evans, and L Copp. 1986. The histology of tendon attachments to bone in man. Journal of Anatomy 149: 89–100.

Benjamin M, Newell RL, Evans EJ, Ralphs JR, Pemberton DJ. 1992. The structure of the insertions of the tendons of biceps brachii, triceps and brachialis in elderly dissecting room cadavers. *Journal of Anatomy* 180: 327–332.

Benjamin M, J.R. Ralphs. 1998. Fibrocartilage in tendons and ligaments--an adaptation to compressive load. *Journal of Anatomy* 193(4):481–494.

Benjamin, M, and D McGonagle. 2001. The anatomical basis for disease localization in seronegative spondyloarthropathy at entheses and related sites. *Journal of Anatomy* 199(5): 503-526.

Benjamin, M., T. Kumai, B. Boszcyk, A. Boszcyk, and J. Ralphs. 2002. The skeletal attachment of tendons – tendon 'entheses.' *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 133(4):931-945.

Benjamin M, Moriggl B, Brenner E, Emery P, McGonagle D, Redman S. 2004. The "enthesis organ" concept: why enthesopathies may not present as focal insertional disorders. Arthritis and Rheumatism 50:3306–3313.

Benjamin, M., H. Toumi, J.R. Ralphs, G. Bydder, T.M. Best, S. Milz. 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.

Benjamin, M., E. Kaiser, S. Milz. 2008. Structure-function relationships in tendons: a review. *Journal of Anatomy* (212)3:211-228.

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

Benjamin, M., H. Toumi, D. Suzuki, K. Hayashi, and D. McGonagle. 2009. Evidence for a distinctive pattern of bone formation in enthesophytes. *Annals of the Rheumatic Diseases* 68:1003-1010.

Brooks, ST and JM Suchey. 1990. Skeletal Age Determination Based on the Os Pubis: A Comparison of the Ascadi-Nemeskeri and Suchey-Brooks Methods. *Human Evolution* 5:227-238.

Brovarski, E. 2003. The Senedjemib Complex Part I. In *Giza Mastabas 7*. William Kelly Simpson and Peter Der Manuelian, eds. Museum of Fine Arts: Boston, MA.

Buckberry, JL, and AT Chamberlain. 2002. An estimation from the auricular surface of the ilium: A revised method. *American Journal of Physical Anthropology* 119(3):231-239.

Buckberry, J. 2015. The (Mis)Use of Adult Age Estimates in Osteology. *Annals of Human Biology* 42(4): 323–31

Buikstra, Jane E., and Douglas H. Ubelaker, eds. 1994. *Standards for Data Collection from Human Skeletal Remains.* Arkansas: Arkansas Archaeological Society.

Burns, TM, and A Calin. 1983. The hand radiograph as a diagnostic discriminant between seropositive seronegative 'rheumatoid arthritis': a controlled study. *Annals of the Rheumaic Disease*. 42(6): 605-612.

Cooper RR, and Misol S. 1970. Tendon and ligament insertion. A light and electron microscopic study. The Journal of Bone and Joint Surgery [Am] 52: 1–20.

Chen, XP, ZY Zhang, GY Zhu, and LY Tao. 2011. Determining the Age at Death of Females in the Chinese Han Population: Using Quantitative Variables and Statistical Analysis From Pubic Bones. *Forensic Science International* 210 (1-3): 278.

Chew, ML and BM Giuffre. 2005. Disorders of the Distal Biceps Brachii Tendon. *RSNA RadioGraphics* 25(5):1227-1237.

Danforth, ME, and A Thompson. 2008. An Evaluation of Determination of Handedness Using Standard Osteological Measurements. *Journal of Forensic Sciences* 53(4): 777-781.

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

Der Manuelian, P. 2009. Mastabas of Nucleus Cemetery G 2100. In *Giza Mastabas: 8.* Museum of Fine Arts: Boston, MA.

Djuric, M, D Djonic, S Nikolic, D Popovic, and J Marinkovic. 2006. Evaluation of the Suchey-Brooks method for aging skeletons in the Balkans. *Journal of Forensic Sciences* 52(1): 21-23.

Dörfl J. 1969. Vessels in the region of tendinous insertions. II. Diaphysoperiosteal insertion. Folia Morphologica 17:79-82.

Dörfl J. 1980a. Migration of tendinous insertions. I. Cause and mechanism. Journal of Anatomy 131: 179–195.

Dörfl J. 1980b. Migration of tendinous insertions. II. Experi- mental modifications. Journal of Anatomy 131: 229–237.

Eshed, V, A Gopher, E Galili, and I Hershkovitz. 2007. 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.

Falys, CG, and ME Lewis. 2010. Proposing a way forward: a review of standarisation in the use of age categories and ageing techniques in osteological analysis (2004-2009). *International Journal of Osteoarchaeology* 21(6): 704-716.

Forthman, CL, RM Zimmerman, MJ Sullivan, GT Gabel. 2008. Cross-sectional anatomy of the bicipital tuberosity and biceps brachii tendon insertion: Relevance to anatomic tendon repair.

Foster, A, H Buckley, and N Tayles. 2014. Using enthesis robusticity to infer activity in the past: a review. *Journal of Archaeological and Method Theory* 21(3): 511-533.

Forrestier, J. and Rotès-Querol, J. 1950. Senile ankylosing hyperostosis of the spine. Ann. Rheumat. Dis. 9: 321–30.

Fournié, B. 2004. Pathology and clinic-pathologic correlations in spondyloarthropathies. *Joint Bone Spine* 71: 525-529.

François RJ, Braun J, Khan MA. 2001. Entheses and enthesitis: a histopathologic review and relevance to spondyloarthritides.

Galtés, I., A. Rodriguez-Baeza, A. Malgosa. 2006. Mechanical morphogenesis: A concept applied to the surface of the radius. The Anatomical Record 288:794-805.

Grant PG, Bushang PH, Drolet DW, Pickerell C. 1981. The effect of changes in muscle function and bone growth on muscle migration. American Journal of Physical Anthropology 54: 547–553.

Hawkey, D.E., and C.F. Merbs. 1995. Activity-induced musculoskeletal stress markers (MSM) and subsistence strategy changes among ancient Hudson Bay Eskimos. *International Journal of Osteoarchaeology* 5:324-338.

Hawkey, D.E. 1998. Disability, compassion and the skeletal record: using musculoskeletal stress markers (MSM) to construct an osteobiography from early New Mexico. *International Journal of Osteoarchaeology* 8:326-340.

Havelková, P, S Villotte. 2007. Enthesopathies: Test of reproducibility of the new scoring system based on current medical data. *Slovenska Antropologia* 10:51-57.

Havelková. P, S Villotte, P Velemínský, L Poláček, M Dobisíková. 2010. Enthesopathies and activity patterns in the Early Medieval Great Moravian population: Evidence of division of labour. *International Journal of Osteoarchaeology* 21:487–504.

Havelková, P, M Hladík, P Velemínsky. 2013. Entheseal changes: Do they reflect socioeconomic status in the Early Medieval Central European population? *International Journal of Osteoarchaeology* 23:237-251.

Henderson CY. 2008. When hard work is disease: the interpretation of enthesopathies. Proceedings of the 8th annual conference of the British Association of Biological Anthropology and Osteoarchaeology, M Brickley, M Smith (eds). Archaeopress: Oxford; 17–25.

Henderson, C. 2009. Musculo-Skeletal Stress Markers in Bioarchaeology: Indicators of Activity Levels or Human Variation? A re-analysis and Interpretation., Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/1953/

Henderson CY, DD Craps, AC Caffell, AR Millard, and R Gowland. 2012. Occupational Mobility in 19th Century Rural England: The Interpretation of Entheseal Changes. *International Journal of Osteoarchaeology* 23:197– 210.

Henderson, CY, V Mariotti, D Pany-Kucera, S Villotte, and C Wilczak. 2013. Recording Specific Entheseal Changes of Fibrocartilaginous Entheses: Initial Tests Using the Coimbra Method. *International Journal of Osteoarchaeology* 23(2):152-162.

Henderson, CY, FA Cardoso. 2013. Special Issue Entheseal Changes and Occupation: Technical and Theoretical Advances and Their Applications. *International Journal of Osteoarchaeology* 23:127-134.

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

Henderson, CY. 2013. Subsistence strategy changes: The evidence of entheseal changes. *HOMO – Journal of Comparative Human Biology* 64(6): 491-408.

Henderson, CY, V Mariotti, D Pany-Kucera, S Villotte, C Wilczak. 2015. The new "Coimbra method": a biologically appropriate method for recording specific features of fibrocartilaginous entheseal changes. *International Journal of Osteoarchaeology* 26(5): 925-932.

Henderson, CY, C Wilczak, and V Mariotti. 2016. Commentary: An Update to the new Coimbra Method for Recording Entheseal Changes. *International Journal of Osteoarchaeology* [need issue number]

Henderson, CY, and E Nikita. 2016. Accounting for multiple effects and the problem of small sample sizes in osteology: a case study focusing on entheseal changes. *Archaeological and Anthropological Sciences* 8(4): 805-817.

Henderson, CY, V Mariotti, F Santos, S Villotte, and CA Wilczak. 2017. The new Coimbra method for recording entheseal changes and the effect of age-at-death. *Bulletins et mémoires de la Société d'Anthropologie de Paris* [need issue info]

Hoyte DAN, Enlow DH. 1966. Wolff's law and the problem of muscle attachment on resorptive surface of bone. American Journal of Physical Anthropology 24: 205–214.

Hurov JR. 1986. Soft-tissue bone interface: How do attachments of muscles, tendons, and ligaments change during growth? A light microscopic study. Journal of Morphology 189: 313–325.

Ibanez-Gimeno, P., S. De Esteban-Trivigno, J. Manyosa, A. Malgosa, I. Galtes. 2013. Functional plasticity of the human humerus: shape, rigidity, and muscular entheses. *American Journal of Physical Anthropology* 150:609-617.

Ibanez-Gimeno, P., I. Galtes, X. Jordana, E. Florin, J. Manyosa and A. Malgosa. 2013. Entheseal changes and functional implications of the humeral medial epicondyle. *International Journal of Osteoarchaeology* 23:211-220.

Jaskulska, E. 2009. Skeletal bilateral asymmetry in a medieval population from Deir an-Naqlun (Nekloni), Egypt. *Bioarchaeology of the Near East* 3: 17-26.

Jurmain R, F Alves Cardoso, CY Henderson, and S Villotte. 2012. Bioarchaeology's Holy Grail: The Reconstruction of Activity. A Companion to Paleopathology, AL Grauer (ed.). Wiley-Blackell: New-York; 531–552.

Kacki, S. 2013. Erosive polyarthropathy in a Late Roman skeleton
from northern France: A new case of rheumatoid arthritis from the pre-Columbian Old Word? *International Journal of Paleopathology* 3(1):59-63.

Karakostis, FA, and C Lorenzo. 2016. Morphometric Patterns Among the #D Surface Areas of Human Hand Entheses. *American Journal of Physical Anthropology* 160: 694-707.

Karakostis, FA, G Hotz, H Scherf, J Wahl, and K Harvati. 2017. Occupational manual activity is reflected on the patterns among hand entheses. *American Journal of Physical Anthropology* 164: 30-40.

Kelley, JO and JL Angel. 1987. Life stresses of slavery. *American Journal of Physical Anthropology* 74(2):199-211.

Kennedy, KAR. 1983. Morphological variations in ulnar supinator crests and fossae as identifying markers of occupational stress. *Journal of* Forensic *Sciences* 28:871-876.

Kennedy, KAR. 1989. Skeletal markers of occupational stress. In *Reconstruction of Life from the Skeleton.* Iscan, MY and KAR Kennedy, editors. New York, NY: Alan R. Liss.

Kennedy, KAR. 1998. Markers of occupational stress: conspectus and prognosis of research. *International Journal of Osteoarchaeology* 8:305-310.

Kumagai J, Sarkar K, Uhthoff HK. 1994. The collagen types in the attachment zone of rotator cuff tendons in the elderly: an immunohistochemical study. Journal of Rheumatology 21: 2096–2100.

La Cava G. 1959. Enthesitis-traumatic disease of insertions. J Am Med Assoc. 169:254-255.

Lane, W.A. 1887. A remarkable example of the manner in which pressure-changes in the skeleton may reveal the labour history of the individual. *Journal of Anatomical Physiology* 22: 592-628.

Lane, W.A. 1888. Anatomy and physiology of the shoemaker. *Journal of Anatomical Physiology* 22:592-628

Laros, G.S., C.M., R.R. Cooper. 1971. Influence of physical activity on ligament insertions in the knees of dogs. *The Journal of Bone and Joint Surgery* [Am] 53:275-286.

Lieverse, AR, VI Bazaliiskii, OL Goriunova, AW Weber. 2008. Upper limb musculoskeletal stress markers among middle Holocene foragers of Siberia’s Cis-Baikal region. *American Journal of Physical Anthropology* 138(4): 458-472.

Lieverse, AR, VI Bazaliiskii, OL Goriunova, AW Weber. 2013. Lower limb activity in the Cis-Baikal: Entheseal changes among middle Holocene Siberian foragers. *American Journal of Physical Anthropology* 150:421-432.

Lopreno, GP, FA Cardoso, S Assis, M Milella, and N Speith. 2013. Categorization of Occupation in Documented Skeletal Collections: Its Relevance for the Interpretation of Activity-Related Osseous Changes. *International Journal of Osteoarchaeology* 23(2): 175-185.

Lovejoy, CO, RS Meindl, TR Pryzbeck, and RP Mensforth. 1985. Chronological Metamorphosis of the Auricular Surface of the Ilium: A New Method for the Determination of Age at Death. *American Journal of Physical Anthropology* 68:1-28.

Lovell, NC. 1989. Test of Phenice’s technique for determining sex from the os pubis. *American of Journal of Physical Anthropology* 79(1): 117-120.

Mader, R, JJ Verlaan, and D Buskila. 2013. Diffuse idiopathic skeletal hyperostosis: clinical features and pathogenic mechanisms. *Nature Reviews Rheumatology* 9: 741-750.

Maldonado-Cocco, JA, O Garcia-Morteo, AJ Spindler, O Hubscher, and S Gagliardi. 1980. Carpal Ankylosis in Juvenile Rheumatoid Arthritis. *Arthritis and Rheumatism* 23(11): 1251-1255.

Mann, R, SA Symes, WM Bass. 1987. Maxillary Suture Obliteration: Aging the Human Skeleton Based on Intact or Fragmentary Maxilla. *Journal of Forensic Sciences* 32:148-157.

Mariotti V., F. Facchini, M.G. Belcastro. 2007. The study of entheses: proposal of a standardised scoring method for twenty-three entheses of the postcranial skeleton. *Coll Antropol* 31:291–313.

Mariotti V., F. Facchini, M.G. Belcastro. 2004. Enthesopathies--proposal of a standardized scoring method and applications. *Coll Antropol* 28:145–159.

Mazzocca, AD., M Cohen, E Berkson, G Nicholson, BC Carofino, R Arciero, AA Romeo. 2007. The anatomy of the bicipital tuberosity and distal biceps tendon. *Journal of Shoulder and Elbow Surgery* 16(1):122-127.

Meindl, RS and CO Lovejoy. 1985. Ectocranial Suture Closure: A Revised Method for the Determination of Skeletal Age at Death Based on the Lateral-Anterior Sutures. *American Journal of Physical Anthropology* 68:57-66.

Meyer, C, N Nicklisch, P Held, B Fritsch, and KW Alt. 2011. Tracing patterns of activity in the human skeleton: An overview of methods, problems, and limits of interpretation. *HOMO – Journal of Comparative Human Biology* 62(3): 202-217.

Michopoulou, E, E Nikita, and CY Henderson. 2016. A test of the effectiveness of the Coimbra method in capturing activity-induced entheseal changes. *International Journal of Osteoarchaeology* [Early View].

Michopoulou E, E Nikita, and ED Valakos. 2015. Evaluating the efficiency of different recording protocols for entheseal changes in regard to expressing activity patterns using archival data and cross-sectional geometric properties. *American Journal of Physical Anthropology* 158:557–568.

Milella M., F.A. Cardoso, S. Assis, G.P. Lopreno, N. Speith. 2015. Exploring the relationship between entheseal changes and physical activity: A multivariate study. *American Journal of Physical Anthropology* 156:215– 223.

Milella, M, M Belcastro, C Zollikofer, and V Mariotti. 2012. The effects 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, G. Transition Analysis Scoring Procedures Version 1.01. Fordisc documentation. Downloaded from: http://math.mercyhurst.edu/~sousley/Software/

Milz, S, R Putz, JR Ralphs, and M Benjamin. 1998. Fibrocartilage in the extensor tendons of the human metacarpophalangeal joints. *The Anatomical Record* 256(2):139-145.

Molnar P. 2005. Tracing prehistoric activities: Musculoskeletal stress marker analysis of a stone- age population on the Island of Gotland in the Baltic sea. *American Journal of Physical Anthropology* 129:12–23

Myszka, A, and J Piontek. 2011. Shape and size of the body vs. musculoskeletal stress markers. *Journal of Biological and Clinical Anthropology* 68(2): 139-152.

Niinimaki, S, and AK Salmi. 2014. Entheseal changes in free-ranging versus zoo reindeer – observing activity status of reindeer. *International Journal of Osteoarchaeology* 26(2): 314-323.

Niinimaki, S, S Soderling, JA Junno, M Finnila, and M Niskanen. 2013. Cortical bone thickness can adapt locally to muscular loading while changing with age. *HOMO – Journal of Comparative Human Biology* 64(6):474-490.

Niinimaki S. 2012. The relationship between musculoskeletal stress markers and biomechanical properties of the humeral diaphysis. *American Journal of Physical Anthropology* 147:618-628.

Niinimäki S. 2009. What do muscle marker ruggedness scores actually tell us? *International Journal of Osteoarchaeology* 21:292–299.

Nolte, M., and C. Wilczak. 2013. Three-dimensional Surface Area of the Distal Biceps Enthesis, Relationship to Body Size, Sex, Age and Secular Changes in a 20th Century American Sample. *International Journal of Osteoarchaeology* 23(2):163-174.

Ockert, B, V Braunstein, C Sprecher, Y Shinohara, C Kirchhoff, and S Milz. 2012. Attachment sites of the coracoclavicular ligaments are characterized by fibrocartilage differentiation: a study on human cadaveric tissue. *Scandanavian Journal of Science and Medicine in Sports* 22(1):12-17.

Ortner DJ. 2003. Identification of Pathological Conditions in Human Skeletal Remains. Academic Press: San Diego, CA.

Osborne, D, T Simmons, and S Nawrocki. 2004. Reconsidering the auricular surface as an indicator of age at death. *Journal of Forensic Sciences* 49(5): 1-7.

Palmer, JLA, MHL Hoogland, and AL Waters-Rist. 2016. Activity Reconstruction of Post-Medieval Dutch Rural Villagers from Upper Limb Osteoarthritis and Entheseal Changes. *International Journal of Osteoarchaeology* 26(1):78-92.

Phenice, TW. 1969. A newly developed visual method of sexing the os pubis. *American Journal of Physical Anthropology*. Springfield, Illinois: Charles C. Thomas.

Punnett, L, R Herbert. 2000. Work-related musculoskeletal disorders: is there a gender differential, and if so, what does it mean? Women and Health, M.B. Goldman, M. Hatch (eds.). Academic Press: San Diego, 474-492.

Reisner, GA, and CS Fisher. 1913. Preliminary Report on the Work of the Harvard – Boston Expedition.

Reisner, GA. 1942. *A History of the Giza Necropolis: Volume 1*. Harvard University Press: Cambridge, MA.

Robb JE. 1998. The interpretation of skeletal muscle sites: a statistical approach. International Journal of Osteoarchaeology 8:363-377

Rogers, J, L Shepstone, and P Dieppe. 1997. Bone formers: osteophyte and enthesophyte formation are positively associated. *Annals of Rheumatic Diseases* 56: 85-90.

Rogers, J. and Waldron, T. 2001. DISH and the monastic way of life. Int. J. Osteoarchaeology 11: 357–65.

Rothschild, BM, B Arriaza, RJ Woods, and O Dutour. 1999. Spondyloarthropathy Identified as the Etiology of Nubian Erosive Arthritis. *American Journal of Physical Anthropology* 109: 259-267.

Ruff, C. 1999. Skeletal structure and behavioral patterns of prehistoric Great Basin populations. In *Understanding Prehistoric Lifeways in the Great Basin Wetlands: Bioarchaeological Reconstruction and Interpretation.* B.E. Hemphill and C.S. Larsen, editors. Salt Lake City, UT: University of Utah Press.

Ruff, C. 2006. Environmental influences on skeletal morphology. In *Handbook of North American Indians: Environment, Origins, and Population.* Douglass Ubelaker, editor. Washington, D.C.: Smithsonian Institution Press.

Ruff, C., B. Holt, and E. Trinkaus. 2006. Who's afraid of the big bad Wolff?: "Wolff's law" and bone functional adaptation. *American Journal of Physical Anthropology* 129(4):484-498.

Samworth, R and R Gowland. 2006. Estimation of adult skeletal age-at-death: statistical assumptions and application. *International Journal of Osteoarchaeology* 17(2):174-188.

Santana-Cabrera, J., J. Velasco-Vazquez, A. Rodriguez-Rodriguez. 2015. Entheseal changes and sexual division of labor in a North-African population: The case of the pre-Hispanic period of the Gran Canaria Island (11th–15th c. CE). *HOMO – Journal of Comparative Human Biology* 66(2): 118-138.

Santos, AL, F Alves-Cardoso, S Assis, S Villotte. 2011. The Coimbra workshop in musculoskeletal stress markers (MSM): An annotated review. *Antropologia Portuguesa* 28:135-161.

Selvanetti, A., M. Cipolla, and G. Puddu. 1997. Overuse tendon injuries: basic science and classification. *Operative Techniques in Sports Medicine* 5:110-117.

Schaefer, M, S Black, L Scheuer. 2009. Juvenile Osteology: a laboratory and field manual. Academic Press: San Diego, CA.

Schiessl, H, HM Frost, and WSS Jee. 1998. Estrogen and Bone-Muscle Strength Mass Relationships. *Bone* 22(1): 1-6.

Schlecht, Stephen H. 2012. Understanding Entheses: Bridging the Gap Between Clinical and Anthropological Perspectives. *The Anatomical Record* 295:1239-1251.

Schrader, S.A. 2012. Activity patterns in New Kingdom Nubia: An examination of entheseal remodeling and osteoarthritis at Tombos. *American Journal of Physical Anthropology* 149:60–70.

Scott, JH. 1958. The cranial base. *American Journal of Physical Anthropology* 16(3): 319-348.

Shaw, HM, and M Benjamin. 2007. Structure-function relationships of entheses in relation to mechanical load and exercise. *Scandinavian Journal of Medicine and Science in Sports* 17(4): 303-315.

Shirley, Natalie R, and Richard L Jantz. 2011. Spheno-Occipital Synchondrosis Fusion in Modern Americans. *Journal of Forensic Sciences* 56 (3): 580–85.

Shuler K.A., P. Zeng, M.E. Danforth. 2012. Upper limb entheseal change with the transition to agriculture in the Southeastern United States: a view from Moundville and the central Tombigbee River valley. *HOMO – Journal of Comparative Human Biology* 63:413–434.

Snodgrass, JJ. 2004. Sex Differences and Aging of the Vertebral Column. *Journal of Forensic Sciences* 49(3): 458–63.

Stefanović S, M. Porčić. 2011. Between-group Differences in the Patterning of Musculo-skeletal Stress Markers: Avoiding Confounding Factors by Focusing on Qualitative Aspects of Physical Activity. *International Journal of Osteoarchaeology* 23:94–105.

Stirland, A.J. 1998. Musculoskeletal evidence for activity: problems of evaluation. *International Journal of Osteoarchaeology* 8:354-362.

Sutherland, LD and JM Suchey. 1991. Use of the Ventral Arc in Pubic Sex Determination. *Journal of Forensic Sciences* 36(2): 501-511.

Taikigawa, W. 2014. Age changes of musculoskeletal stress markers and their inter-period comparisons. *Anthropological Science* 122:7-22.

Todd, TW and DW Lyon Jr. 1925. Cranial Suture Closure, Its Progress and Age Relationship Part II. Ectocranial Suture Closure in Adult Males of White Stock. *American Journal of Physical Anthropology* 8:23-45

Thomas, A. 2014. Bioarcheology of the middle Neolithic: Evidence for archery among early European farmers. *American Journal of Physical Anthropology* 18:65-85.

Todd, TW. 1921a. Age Changes in the Pubic Bone. I The White Male Pubis. *American Journal of Physical Anthropology* 3 (3): 285–89.

Todd, TW. 1921b. Age Changes in the Pubic Bone II-IV. *American Journal of Physical Anthropology* 4 (1): 1-70.

Todd, TW and DW Lyon Jr. 1925. Cranial Suture Closure, Its Progress and Age Relationship Part II. Ectocranial Suture Closure in Adult Males of White Stock. *American Journal of Physical Anthropology* 8: 23-45

Ubelaker, D and C Volk. 2002. A Test of the Phenice Method for the Estimation of Sex. *Journal of Forensic Sciences* 47(1): 19-24.

Villotte, S. 2006. Connaissances médicales actuelles, cotation des enthésopathies: Nouvelle method. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 18-65-85.

Villotte, S, SE Churchill, OJ Dutour, and D Henry-Gambier. 2010. Subsistence activities and the sexual division of labor in the European Upper Paleolithic and Mesolithic: evidence from upper limb enthesopathies. *Journal of Human Evolution* 59(1): 35-43.

Villotte, S, D Castex, VCouallier, O Dutour, CJ Knüsel and D Henry-Gambier. 2010. Enthesopathies as occupational stress markers: Evidence from the upper limb. *American Journal of Physical Anthropology* 142(2):224-234.

Villotte, S. 2013. Practical protocol for scoring the appearance of some fibrocartilaginous entheses on the human skeleton.

Villotte, S., and C. Knūsel. 2013. Understanding Entheseal Changes: Definition and Life Course Changes. *International Journal of Osteoarchaeology* 23(2):135-146.

Villotte, S, and CJ Knüsel. 2014. "I sing of arms and of a man…": medial epicondylosis and the sexual division of labour in prehistoric Europe. *Journal of Archaeological Science* 43: 168-174.

Villotte, S. Assis, S. Alves Cardoso, F. Henderson, C. Mariotti, V. Milella, M. Pany Kucera, D. Speith, N. Wilczak, C. and Jurmain, R. 2016. In search of consensus: terminology for entheseal changes (EC). *International Journal of Paleopathology* 13: 49-55.

Walker, PL. 2005. Greater sciatic notch morphology: Sex, age, and population differences. *American Journal of Physical Anthropology* 127(4): 385-391.

Walker, PL. 2008. Sexing Skulls Using Discriminant Function Analysis of Visually Assessed Traits. *American Journal of Physical Anthropology* 136(1): 39-50.

Wallace, IJ, JM Winchester, A Su, DM Boyer, and N Konow. 2017. Physical activity alters limb bone structure but not entheseal morphology. *Journal of Human Evolution* 107: 14-18.

Wang, INE, S Mitroo, FH Chen, HH Lu, and SB Dotty. 2006. Age-dependent changes in matrix composition and organization at the ligament-to-bone insertion. *Journal of Orthopedic Research* 24:1745-1755.

Weiss, E, L Corona, and B Schultz. 2010. Sex differences in musculoskeletal stress markers: Problems with activity pattern reconstructions. *International Journal of Osteoarchaeology* 22(1): 70-80.

Weiss, E. 2015. Examining Activity Patterns and Biological Confounding Factors: Differences between Fibrocartilaginous and Fibrous Musculoskeletal Stress Markers. *International Journal of Osteoarchaeology* 25(3):281-288.

Wilczak, CA, KAR Kennedy. 1998. Mostly MOS: technical aspects of identification of skeletal markers. In: Reichs, KJ, WM, Bass, editors. *Forensic osteology: advances in the Identification of human remains.* 2nd ed. Springfield: Charles C. Thomas. p 461-490.

Wilczak, Cynthia A. 1998. Consideration of sexual dimorphism, age, and asymmetry in quantitative measurements of muscle insertion sites. *International Journal of Osteoarchaeology* 8(5):311-315.

Wilczak, CA, and EB Jones. 2011. *Osteoware Software Manual Volume II: Pathology Module.* Smithsonian Institution: Washington D.C.

Wilczak, C, V Mariotti, D Pany-Kucera, S Villotte, C Henderson. 2017. Training and Interobserver Reliability in Qualitative Scoring of Skeletal Samples. *Journal of Archaeological Science* 11: 69-79.

Yonemoto, S. 2015. Differences in the effects of age on the development of entheseal changes among historical Japanese populations. *American Journal of Physical Anthropology* 159(2): 267-283.

Zumwalt, A. 2005. A new method for quantifying the complexity of muscle attachment sites. *The Anatomical Record* 286B(1):21-28.

Zumwalt, A. 2006. The effect of endurance exercise on the morphology of muscle attachment sites. *The Journal of Experimental Biology* 209:444-454.

APPENDICES

Individual	Age	Sex	Side	Enthesis	BF Zone 1	ER Zone 1	TC Zone 2	BF Zone 2	ER Zone 2	FPO Zone 2	MPO Zone 2	CA Zone 2
*12-5180	> 50	2	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	1	0	0	1	0	0	0	0
			R	COM. EXT	1	0	0	1	0	0	0	0
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	0	1	0	0	1	0	0	0
			L	COM. EXT	2	0	1	0	0	0	0	0
			R	BB	1	1	0	1	1	0	0	0
			L	BB	0	1	0	1	1	0	0	0
*12-5183	> 50	2	R	SS	0	0	0	0	0	0	0	2
			R	INFRA/SUPRA	99	99	0	0	0	0	0	2
			R	COM. FLEX	0	0	0	0	1	0	0	0
			R	COM. EXT	0	0	0	0	0	0	0	1
			L	SS	0	0	0	0	0	0	0	1
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	0	0	0	0	0	0	0	0
			L	COM. EXT	1	0	0	2	0	0	0	0
			R	BB	1	0	0	0	1	0	0	0
			L	BB	1	0	0	0	2	0	0	0
*12-5187	31-50	2	R	SS	0	0	0	0	0	0	0	1
			R	INFRA/SUPRA	0	0	0	0	2	0	0	2
			R	COM. FLEX	0	0	0	0	0	0	0	0
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	0	0	0	0	1	0	0	0
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	0	0	0	0	0	0	0	0
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	2	1	0	0	0	0	0
			L	BB	0	2	0	0	0	0	0	0
*12-5185	> 50	1	R	SS	0	0	0	0	2	0	0	0
			R	INFRA/SUPRA	0	0	0	0	0	0	0	0
			R	COM. FLEX	0	2	0	0	0	0	0	0
			R	COM. EXT	0	1	0	0	0	0	0	0
			L	SS	0	1	0	0	2	0	0	0
			L	INFRA/SUPRA	0	0	0	0	0	1	0	0

			L	COM. EXT	99	99	99	99	99	99	99	99
			R	BB	0	0	0	1	0	0	0	0
			L	BB	0	0	0	1	1	1	0	0
*12-5200	31-50	2	R	SS	99	99	0	0	0	0	0	2
			R	INFRA/SUPRA	99	99	0	0	0	0	0	2
			R	COM. FLEX	99	99	0	0	0	1	0	0
			R	COM. EXT	99	99	0	2	0	0	0	0
			L	SS	0	0	0	0	0	0	0	1
			L	INFRA/SUPRA	99	99	0	1	0	0	0	0
			L	COM. FLEX	99	99	0	0	0	0	0	0
			L	COM. EXT	0	0	0	2	0	0	0	0
			R	BB	0	0	0	0	0	0	0	0
			L	BB	0	1	0	0	0	0	0	0
*12-5221	> 50	2	R	SS	0	0	0	2	0	0	0	2
			R	INFRA/SUPRA	0	0	0	2	2	0	0	2
			R	COM. FLEX	99	99	99	99	99	99	99	99
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	99	99	99	99	99	99	99	99
			L	COM. EXT	99	99	0	1	0	0	0	0
			R	BB	0	0	0	0	2	0	0	0
			L	BB	0	0	0	0	1	0	1	0
*12-5163	> 50	1	R	SS	0	0	0	0	0	0	0	0
			R	INFRA/SUPRA	0	0	0	0	0	0	0	2
			R	COM. FLEX	0	0	0	0	0	1	0	0
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	0	0	0	0	0	0	0	0
			L	INFRA/SUPRA	0	0	0	0	1	0	0	0
			L	COM. FLEX	0	0	0	0	0	1	0	0
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	0	0	0	0	0	0	0
			L	BB	0	0	0	0	0	0	0	0
*12-5162	31-50	1	R	SS	0	0	0	0	0	0	0	0
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	0	0	0	0	0	1	0	0
			R	COM. EXT	99	99	99	99	99	99	99	99

			L	COM. FLEX	99	99	99	99	99	99	99	99
			L	COM. EXT	99	99	0	0	0	0	0	0
			R	BB	0	1	1	0	2	0	0	0
			L	BB	99	99	99	99	99	99	99	99
*12-5195	> 50	1	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	0	0	0	0	1	0	0	0
			R	COM. EXT	0	0	0	0	1	0	0	0
			L	SS	0	0	0	1	0	0	0	2
			L	INFRA/SUPRA	0	0	0	2	2	0	0	0
			L	COM. FLEX	0	0	0	0	1	0	0	0
			L	COM. EXT	0	0	0	0	2	0	0	0
			R	BB	0	2	0	0	1	0	0	0
			L	BB	0	2	1	0	0	0	0	0
*12-5203	< 30	1	R	SS	99	99	0	0	0	0	0	0
			R	INFRA/SUPRA	0	0	0	0	0	0	0	0
			R	COM. FLEX	99	99	0	0	0	0	0	0
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	0	0	0	0	0	0	0	0
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	99	99	0	0	0	0	0	0
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	0	0	0	0	0	0	0
			L	BB	0	0	0	0	0	0	0	0
*12-5164	> 50	2	R	SS	1	0	0	1	0	1	0	0
			R	INFRA/SUPRA	0	0	0	2	0	1	0	0
			R	COM. FLEX	0	0	0	0	1	1	0	0
			R	COM. EXT	2	0	0	1	0	2	0	0
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	1	0	0	1	0	0	0	0
			L	COM. FLEX	0	0	0	1	0	0	0	0
			L	COM. EXT	1	0	0	2	0	1	0	0
			R	BB	0	0	1	0	0	0	0	0
			L	BB	1	0	1	0	0	0	0	0
*12-5195	> 50	1	R	SS	0	0	0	0	0	0	0	0
			R	INFRA/SUPRA	0	0	0	1	0	0	0	0
			R	COM. FLEX	99	99	0	0	0	0	0	0

*12-5237	< 30	2	R	SS	0	0	0	0	0	1	1	0
			R	INFRA/SUPRA	99	99	0	0	0	0	0	2
			R	COM. FLEX	0	0	0	0	0	0	0	0
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	0	0	0	0	0	0	0	0
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	99	99	0	0	0	0	0	0
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	0	0	0	0	0	0	0
			L	BB	99	99	99	99	99	99	99	99
*12-5219	31-50	2	R	SS	2	0	0	2	0	0	2	0
			R	INFRA/SUPRA	99	99	0	0	0	1	0	0
			R	COM. FLEX	99	99	99	99	99	99	99	99
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	99	99	0	0	1	0	0	0
			L	COM. EXT	1	0	0	2	1	0	0	0
			R	BB	0	0	0	1	1	1	1	0
			L	BB	0	0	0	0	0	1	0	0
*12-5169	> 50	2	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	0	0	0	0	0	0	0	0
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	99	99	0	0	1	0	0	0
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	0	0	0	0	0	0	0	0
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	1	0	0	0	0	0	0
			L	BB	0	1	0	0	2	1	0	0
*12-5210	> 50	2	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	99	99	0	0	0	0	0	0
			R	COM. EXT	2	0	0	0	0	1	0	0
			L	SS	99	99	0	0	0	0	0	0
			L	INFRA/SUPRA	99	99	0	1	2	0	0	0
			L	COM. FLEX	99	99	0	0	1	0	0	0

			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	0	0	0	0	1	0	0	1
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	99	99	0	0	0	0	0	0
			L	COM. EXT	99	99	99	99	99	99	99	99
			R	BB	1	0	1	0	1	0	0	0
			L	BB	99	99	99	99	99	99	99	99
*12-5142 (AS-H	> 50	2	R	SS	0	0	0	0	0	0	0	0
			R	INFRA/SUPRA	0	0	0	1	0	0	0	0
			R	COM. FLEX	0	0	0	1	0	1	0	0
			R	COM. EXT	0	0	0	1	0	0	0	0
			L	SS	0	0	0	0	0	1	0	0
			L	INFRA/SUPRA	0	0	0	1	1	0	0	0
			L	COM. FLEX	0	0	0	0	0	1	0	0
			L	COM. EXT	0	0	0	0	0	1	0	0
			R	BB	0	1	0	2	0	0	0	0
			L	BB	1	0	0	0	1	1	0	0
*12-5143	> 50	2	R	SS	0	0	0	1	0	0	0	0
			R	INFRA/SUPRA	0	0	0	0	0	0	0	1
			R	COM. FLEX	0	0	0	0	0	0	0	0
			R	COM. EXT	0	0	0	1	0	0	0	0
			L	SS	0	0	0	1	0	0	0	0
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	0	1	0	0	0	0	0	0
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	0	1	0	1	2	0	0
			L	BB	99	99	99	99	99	99	99	99
*12-5249	> 50	1	R	SS	0	0	1	0	0	0	1	0
			R	INFRA/SUPRA	0	0	0	0	0	0	0	2
			R	COM. FLEX	99	99	99	99	99	99	99	99
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	99	99	0	0	0	0	0	0
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	2	0	0	2	0	0	0	0
			L	COM. EXT	99	99	99	99	99	99	99	99
			R	BB	0	0	0	0	0	0	0	0
			L	BB	0	0	0	0	0	0	0	0

			L	SS	0	0	0	0	0	0	1	0
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	0	0	0	0	0	1	0	0
			L	COM. EXT	99	99	99	99	99	99	99	99
			R	BB	1	0	0	0	0	1	0	0
			L	BB	0	0	0	0	0	2	0	0
*12-5161	31-50	2	R	SS	0	0	0	1	0	0	2	0
			R	INFRA/SUPRA	99	99	0	0	0	0	0	0
			R	COM. FLEX	99	99	0	0	0	0	0	0
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	0	0	0	1	0	0	2	0
			L	INFRA/SUPRA	99	0	0	0	0	0	0	0
			L	COM. FLEX	99	0	0	0	0	0	0	0
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	1	1	0	0	0	0	0
			L	BB	0	1	1	0	1	0	0	0
*12-5157	< 30	1	R	SS	0	0	0	0	0	1	0	0
			R	INFRA/SUPRA	0	0	0	0	0	1	0	0
			R	COM. FLEX	99	99	99	99	99	99	99	99
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	0	0	0	0	0	1	0	0
			L	INFRA/SUPRA	99	99	0	0	0	1	0	0
			L	COM. FLEX	0	0	0	0	0	1	0	0
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	0	0	0	0	0	0	0
			L	BB	0	0	0	0	0	0	0	0
*12-5156	31-50	1	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	0	0	0	0	0	1	0	0
			R	COM. EXT	0	0	0	1	0	0	0	0
			L	SS	0	0	0	1	0	1	0	0
			L	INFRA/SUPRA	0	0	0	0	0	0	0	1
			L	COM. FLEX	99	99	0	0	0	1	0	0
			L	COM. EXT	0	0	0	0	0	1	0	0
			R	BB	99	99	99	99	99	99	99	99
			L	BB	99	99	99	99	99	99	99	99
*12-5153	31-50	2	R	SS	0	0	0	0	0	0	0	0

			R	BB	1	0	0	1	0	0	1	0
			L	BB	99	99	99	99	99	99	99	99
*12-5199	> 50	2	R	SS	99	99	0	0	0	0	1	0
			R	INFRA/SUPRA	0	0	0	0	0	0	0	0
			R	COM. FLEX	99	99	0	0	0	0	0	0
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	0	0	0	0	0	0	0	0
			L	COM. EXT	1	0	0	0	0	0	0	0
			R	BB	99	99	99	99	99	99	99	99
			L	BB	99	99	99	99	99	99	99	99
*12-5228	31-50	1	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	99	99	99	99	99	99	99	99
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	0	0	0	0	0	0	0	0
			L	COM. EXT	0	0	0	0	1	0	0	1
			R	BB	99	99	99	99	99	99	99	99
			L	BB	0	0	0	0	0	0	0	0
*12-5159	< 30	2	R	SS	0	0	0	0	0	0	0	0
			R	INFRA/SUPRA	99	99	0	0	0	0	0	0
			R	COM. FLEX	0	0	0	0	0	0	0	0
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	99	99	99	99	99	99	99	99
			L	COM. EXT	99	99	99	99	99	99	99	99
			R	BB	0	0	0	0	0	1	0	0
			L	BB	0	0	0	0	1	1	0	0
*12-5222	31-50	2	R	SS	99	99	0	0	0	0	0	0
			R	INFRA/SUPRA	0	0	0	0	0	0	0	0
			R	COM. FLEX	99	99	0	0	0	0	0	0
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	99	99	99	99	99	99	99	99

			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	0	0	0	0	0	0	0	0
			L	COM. EXT	99	99	99	99	99	99	99	99
			R	BB	99	99	99	99	99	99	99	99
			L	BB	0	0	0	0	0	0	0	0
*12-5160	> 50	2	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	99	99	99	99	99	99	99	99
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	0	0	0	1	0	0	0	0
			L	COM. EXT	0	0	0	1	0	0	1	0
			R	BB	99	99	99	99	99	99	99	99
			L	BB	0	0	1	0	0	0	0	0
*12-5150	> 50	1	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	0	0	0	0	1	0	0	0
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	99	99	99	99	99	99	99	99
			L	COM. EXT	0	0	0	0	0	0	0	0
			R	BB	0	0	1	0	0	0	0	0
			L	BB	99	99	99	99	99	99	99	99
*12-5147	> 50	2	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	99	99	0	0	0	0	0	0
			R	COM. EXT	0	0	0	0	0	0	0	0
			L	SS	0	0	0	0	0	0	0	0
			L	INFRA/SUPRA	99	99	0	0	0	0	0	0
			L	COM. FLEX	99	99	0	0	0	0	0	0
			L	COM. EXT	0	1	0	0	0	0	0	0
			R	BB	99	99	99	99	99	99	99	99
			L	BB	99	99	99	99	99	99	99	99

			R	INFRA/SUPRA	99	99	0	0	0	1	0	0
			R	COM. FLEX	99	99	0	0	0	0	0	0
			R	COM. EXT	99	99	0	0	0	0	0	0
			L	SS	0	0	0	1	0	0	0	0
			L	INFRA/SUPRA	0	0	0	0	0	1	0	0
			L	COM. FLEX	99	99	0	0	0	0	0	0
			L	COM. EXT	99	99	0	1	0	0	0	0
			R	BB	0	0	0	0	0	1	0	0
			L	BB	0	0	0	0	0	1	0	0
*12-5145	> 50	2	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	1	0	0	0	1	0	0	0
			R	COM. EXT	0	0	0	1	0	1	0	0
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	99	99	99	99	99	99	99	99
			L	COM. EXT	99	99	99	99	99	99	99	99
			R	BB	99	99	99	99	99	99	99	99
			L	BB	1	0	0	0	0	1	2	0
*12-5152	> 50	1	R	SS	99	99	0	0	0	1	0	0
			R	INFRA/SUPRA	99	99	0	0	0	0	0	0
			R	COM. FLEX	99	99	99	99	99	99	99	99
			R	COM. EXT	99	99	99	99	99	99	99	99
			L	SS	99	99	0	0	0	0	0	1
			L	INFRA/SUPRA	0	0	0	0	0	0	0	0
			L	COM. FLEX	99	99	99	99	99	99	99	99
			L	COM. EXT	99	99	0	0	0	0	0	0
			R	BB	99	99	1	0	0	1	0	0
			L	BB	0	0	1	0	0	1	0	0
*12-5190	31-50	2	R	SS	99	99	99	99	99	99	99	99
			R	INFRA/SUPRA	99	99	99	99	99	99	99	99
			R	COM. FLEX	99	99	99	99	99	99	99	99
			R	COM. EXT	1	0	0	1	0	0	1	1
			L	SS	99	99	99	99	99	99	99	99
			L	INFRA/SUPRA	99	99	99	99	99	99	99	99
			L	COM. FLEX	1	0	0	1	0	0	0	0
			L	COM. EXT	99	99	99	99	99	99	99	99