ENTHESEAL CHANGES AS A REFLECTION OF ACTIVITY PATTERNS AT 1ST CENTURY BC/AD PETRA, JORDAN

by

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Over the past thirty years, biological anthropologists have attempted to reconstruct human behavioral patterns by analyzing entheseal attachments, the areas where tendons and ligaments attach to the bone. Many researchers hypothesize that biomechanical stress on ligaments and tendons due to repetitive activities will be reflected in bony changes that occur within the attachment site. Therefore, the distribution and characterization of these entheseal changes have been used to illuminate ancient human activity patterns. This research focuses on the pattern of entheseal changes observed in individuals from urban first century BC/AD Petra in order to generate a profile of activity patterns for the non-elite Nabataeans buried along the North Ridge. Assessment of the entheseal attachments was accomplished using the newly formed Coimbra method. This method is considered as an improvement over previous scoring techniques as it is based on the results of clinical research and incorporates refined terminology and descriptions of entheseal changes.

While the multifactorial etiology of entheses hinders identifying specific occupation types, generalized patterns of activity can still be inferred from the collection of these data. The sample of Petra's non-elite experienced only slight entheseal changes compared to other communities assessed here, with little evidence of sexual division of labor. Additionally, the sample did not display bilateral asymmetry as anticipated, however there were higher scores for

the lower limb than the upper limb. During the first century BC and first century AD, Petra was a major urban center and capital of the Nabataean Kingdom. Its economy was based largely on trade and some light manufacturing using local resources. The findings presented here confirm that people who were buried along the North Ridge had been working in the city, possibly involved with civic, administrative, and/or religious duties that would have been present during the height of the city.

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Chapter 1: Introduction

Over the past thirty years, biological anthropologists have attempted to reconstruct human behavioral patterns by analyzing entheseal attachments, the areas where tendons and ligaments attach to the bone. Many researchers hypothesize that biomechanical stress on ligaments and tendons due to repetitive activities will be reflected in bony changes that occur within the attachment site. Therefore, the distribution and characterization of these entheseal changes have been used to illuminate human physical activity (Hawkey and Merbs, 1995). This research focuses on the pattern of entheseal changes observed in individuals from urban first century BC/AD Petra in order to generate a profile of activity patterns based on changes at entheseal attachments associated with particular muscles.

This thesis explores overall patterns of physical activity in a sample of commingled and fragmentary human remains from an ancient urban site by evaluating entheseal changes. Assessment of the entheseal attachments was accomplished using the newly formed Coimbra method. This method is considered as an improvement over previous scoring techniques as it is based on the results of clinical research and incorporates refined terminology and descriptions of entheseal changes (Henderson et al., 2015). Clinical research assessing the *in vivo* biomechanics of entheses have shown a plausible correlation with physical activity. These studies have evaluated the development of entheseal changes seen in sports or similar physical activities, thus supporting the notion that changes at entheses can be caused from biomechanical stress (Rosager et al., 2002; Hansen et al., 2003; Kannus et al., 1995; Kubo et al., 2006). The refined terminology in the Coimbra method is more neutral, which helps to avoid assumptions that underlying causes not related to physical activity would have affected the attachment site and produced the skeletal change.

A first century BC through first century AD skeletal assemblage from Petra recovered in 2012 and 2014 by the Petra North Ridge Project was the sample analyzed in this study. The sample is comprised of the remains of Nabataean urban ‘non-elites’ found in Tombs B.4, B.5, B.6, and B.7. During this period, Petra was known to be an urban community with long-distance trading networks (Parr, 2001; Zayadine, 2001). Urban activities typically involve numerous types of occupations, but the varying levels of physical workload are dependent upon socioeconomic status along with other cultural, environmental, and economic factors (Schrader, 2015). Therefore, the author will be using the degrees of entheseal changes in the Petra sample to identify whether or not the pattern seen here parallels that of other ancient urban and rural contexts (Baker et al., 2012; Havelková et al., 2011; Schrader, 2012, 2015).

This study will provide an example of careful interpretation of entheseal attachments in bioarchaeology and among of the first using the Coimbra method. Analyzing the degrees of entheseal morphologies can give a broader understanding on the lifeways of the ordinary people of Petra. Comparison of the sample-level entheseal patterns of the non-elites from first century BC/AD Petra to other urban and rural populations will determine if the city’s residents maintained a diversity of occupational activities during the city’s height of power. These data can illuminate aspects of the social and economic organization in Petra during the first century BC/AD.

The following chapters will discuss the composition of this research. Chapter 2 will focus on entheses, the characterization of entheseal changes, and their relation to physical activity in medical and clinical contexts as well as archaeological contexts. Additionally, Chapter 2 offers an overview of Nabataean Petra during the first century BC/AD and the burial practices of the non-elites. Materials and methods used for this research are seen in Chapter 4, followed by the results of the research in Chapter 5. Finally, Chapter 6 is comprised of the discussion and Chapter 7 is the concluding remarks.

Chapter 2: Background

The characterization of past human activity from skeletal indicators has faced many methodological and interpretive roadblocks over the past 50 years. Skeletal observations such as patterns of osteoarthritis, cross-sectional geometry, and musculoskeletal markers (MSMs), also referred to as entheses, have each received their fair share of criticism in terms of accurately reflecting ancient human physical behaviors (See Davis et al., 2013; Jurmain, 1999; Jurmain et al., 2012; Meyer et al., 2011; Pearson and Lieberman, 2004). Patterns of osteoarthritis by joint, for example, commonly have been used to illuminate activity since this lesion is ubiquitous across all geological and temporal areas. However, increased age and the effects of sex, genetics, and trauma present important confounding factors in osteoarthritis interpretation, thus a high amount of osteoarthritis present in a sample may not directly result from a high amount of physical activity (Jurmain et al., 2012). Cross-sectional bone geometry also has been used to assess bone morphology for reconstructing past activities (Jurmain et al., 2012). Yet, studies have found that bone geometry is more influenced by biomechanical stress placed on the bone during adolescent development, and thus only represents activity during this period of growth (Pearson and Lieberman, 2004).

However, clinical research has indicated that one indicator actually may reflect habitual human activity – entheseal attachments, or MSMs. In general, entheses are strongly connected with habitual activity, particularly those classified as fibrocartilaginous attachments (Benjamin et al., 2002; Hansen et al., 2003). This growing body of research on entheses focuses on their histological structure, their specific physiological impact on bone based on clinical research, and the confounding, non-activity related factors that also can affect entheseal attachment sites to aid researchers in properly identifying and evaluating entheseal changes. This chapter will discuss the histological makeup of entheses, the clinical background supporting the application of entheses to activity-related bioarchaeological research, and the methodologies used to observe and analyze entheseal changes. Finally, the skeletal sample to which this method will be applied, the bones recovered from the ancient site of Petra, Jordan, will be discussed.

Entheses

Entheses, or entheseal attachments, are insertion sites on the bone for connective tissues, specifically tendons and ligaments (Benjamin et al., 2002). Tendons connect muscle to bone, whereas ligaments connect bone to bone, and both are incorporated within the body to provide stability in the musculoskeletal framework, support in bodily movement, and cushioning for biomechanical stress (Benjamin et al., 2002).

These connective tissues are formed by fibroblast cells encircled by an extracellular matrix (ECM) (Shaw and Benjamin, 2007). The ECM contains both fibrous and non-fibrous structures. Elastin fibers and type I-VI collagen fibers (primarily Type I) make up the fibrous portion, while water, glycoproteins, glycosaminoglycans, and proteoglycans characterize the non-fibrous ground substance portion (Benjamin and Ralphs, 1998; Benjamin and McGonagle, 2001; Schlecht, 2012). Together, these sections are arranged longitudinally along the tendon or ligament to allow for both elasticity and durability during physical movement (Benjamin and Ralphs, 1998).

Tensile strength of the ECM can be increased via adding tropocollagen, which is the basic unit of collagen (Schlecht, 2012). Tropocollagen is aggregated into *fibrils*, and the fibrils are further aggregated to form *fibres* (Benjamin and Ralphs, 1998; Schlecht, 2012).
The *fibres* are then grouped together into *fibre bundles* that house tendon and ligament cells only,

while more *fibre bundles* accumulate into *fascicles*, which are enclosed in loose connective tissue known as the endotenon (Benjamin and Ralphs, 1998). The more bundles a tendon or ligament contains, the greater the support and flexibility of the musculoskeletal system. Tendons and ligaments can easily adapt to changes in mechanical load due to the complex mutli-layering of the fibrous components, which produces a high amount of tensile strength to counter heavy loading that causes failure, including strain and tearing (Benjamin and Ralphs, 1998). However, when this adaptive ability fails, another adaptation can take place at the attachment site on the bone; here, ossification development helps maintain normal soft tissue movement when under biomechanical stress (Benjamin et al., 2006).

Types of Entheseal Attachments

Entheses are the attachment points where ligaments and tendons of the musculoskeletal system interface with bone. The physical properties of these attachment areas can reflect the level of stability provided by a particular ligament or tendon due to biomechanical load and stress. However, ligaments and tendons attach to bone in two different ways, resulting in two different patterns of entheseal response to biomechanical stress. These two different entheses are referred to as fibrous and fibrocartilaginous entheses (Benjamin et al., 2002). Fibrous entheses are located on the diaphyses of long bones, the skull, and the spinous processes and anterior portions of bodies of the vertebrae (Benjamin and McGonagle, 2001; Villotte et al., 2010). They attach ligaments and tendons to the periosteum (periosteal fibrous enthesis) or directly to the bone (bony fibrous enthesis) via Sharpey’s fibers (Benjamin and McGonagle, 2001; Villotte and Knüsel, 2013). These entheses are typically are broad and flat, distributing the tension of the tendon or ligament over a larger area (Benjamin et al., 2002). As the periosteum degrades with age, the periosteal fibrous entheses can turn into bony fibrous entheses (Benjamin and McGonagle, 2001). On dry bone, periosteal fibrous entheses are represented as smooth markings with ill-defined perimeters whereas bony fibrous entheses produce rough patches and ridges (Benjamin et al., 2002).

Fibrocartilaginous entheses, located on the epiphyses of long bones, the medial part of the vertebrae (*ligamenta flava*), and the short bones in hands and feet, attach ligaments or tendons to bone via a patch of fibrocartilage (Benjamin and McGonagle, 2001; Villotte et al., 2010). Aside from the standard functions of entheses for anchoring tissues to bone as well as supporting muscle movement, fibrocartilaginous entheses are thought to aid in endochondral ossification since this bone growth process involves a layering of new fibrocartilage that will later be replaced by ossified bone (Benjamin and McGonagle, 2001; Benjamin et al., 2002). Unlike fibrous entheses, the connective tissue in fibrocartilaginous entheses does not attach to the periosteum; the calcified fibrocartilage is connected directly, albeit irregularly, to the subchondral bone, which is located at the joint surfaces on long bone epiphyses (Benjamin et al., 2002). The architectural support and flexibility of the trabecular web underneath the subchondral bone provides better distribution of biomechanical stress across the enthesis, effectively securing the fibrocartilaginous attachment to the subchondral bone as well as allowing the subchondral bone to deform if needed (Benjamin et al., 2002).

The involvement of different layers of connective tissue in fibrocartilaginous entheses means that four different histological zones can be identified, but only some remain visible on defleshed bone. These include the: 1) connective tissue (tendon or ligament), 2) uncalcified fibrocartilage, 3) calcified fibrocartilage, and 4) subchondral bone (the type of bone found at joint surfaces) (Benjamin and McGonagle, 2001). The uncalcified fibrocartilage is the initial intersection between the elastic connective tissue and the tougher calcified fibrocartilage and subsequent bone (Shaw and Benjamin, 2007). The uncalcified and calcified fibrocartilage contain a feature known as a tidemark, essentially a boundary dividing soft and hard tissues (Benjamin et al., 2002; Odien, 2015). The structure of the calcified and uncalcified fibrocartilage layers allows the connective tissue to retain most of its shape under biomechanical stress since they essentially act as an extension of the bone (Benjamin et al., 2002; Shaw and Benjamin, 2007).

According to Benjamin and McGonagle (2001), fibrocartilaginous entheses have a more intricate morphological structure aside from just the tendon and ligament connections present at the attachment sites than previously considered. The complexity of fibrocartilaginous entheses, involving different types of tissues, suggests to some researchers that they should be referred to as an 'enthesis organ'. This organ not only includes the enthesis itself, but also other supportive and flexible tissues such as sesamoid and periosteal fibrocartilage, synovial folds or fat pads, and bursae that aid in physical movement of the muscle that attaches through a fibrocartilaginous enthesis and dissipates stress over broader areas (Benjamin et al., 2002; Benjamin and McGonagle, 2001). In acknowledging the complexity of entheses, the variation of pathological changes that occur with connective tissues and the associated bone where these tissues insert can be better understood and addressed clinically (Benjamin and McGonagle, 2001; Benjamin et al., 2004).

Entheseal Repair Response Process

A bioarchaeologist interested in documenting ancient human activity through entheses essentially documents the presence and/or level of injury and subsequent repair occurring at attachment sites. Injury to entheses can occur at both the macro and micro levels and results in tears, avulsions (seen as apophysitis in children), strains, and contusions in the soft tissues (Benjamin et al., 2002; Paxton et al., 2012). Macrotraumas, such as sprains, are relatively uncommon considering the strength and flexibility found in the anatomical structure of entheses (Benjamin et al., 2002). Microtrauma is more prevalent and mostly seen as strains on the connective tissue via increase of blood and inflammatory cells, followed by a tissue repair response (Odien, 2015). This microtrauma is what anthropologists primarily utilize to evaluate activity patterns (Hawkey and Merbs, 1995; Mariotti et al., 2007; Henderson et al., 2015).

The repair of connective tissue microtrauma occurs in three stages: inflammatory, proliferative, and remodeling (Paxton et al., 2012). The inflammatory phase involves development of a hematoma by a collection of platelets, vasodilators, and pro-inflammatory chemicals begins just after injury and lasts for a few days. Fibroblasts penetrate the hematoma to help facilitate the formation of capillaries at the wound. The subsequent proliferative phase involves the layering of disorganized type III collagen that fills the wound site. For the next six to ten weeks, the fibers transform into type I collagen to heal the injury. Finally, in the remodeling phase, the number of fibroblasts decreases, the collagen fibers reorganize longitudinally, and type I and type III collagen return to normal amounts. This phase is the longest, taking up to at least a year, though regular tendon function and biomechanics are seldom fully repaired.

Bioarchaeologists focus on the bony reflections of the healing process described above when documenting entheseal changes. These healing-related entheseal changes include mineralized tissue formation, surface discontinuity, and complete loss of original morphology (Villotte et al., 2016). Mineralized tissue formation is an osteoblastic (bone building) occurrence that refers to any change in the original surface of the enthesis that can appear anywhere from a rough texture to an obvious protrusion of any shape or size (Slobodin et al., 2015). Surface discontinuity is more osteoclastic (bone resorption) in nature, which involves changes such as depressions and loss of mineralized tissue, and manifests in fibrous entheses as changes to trabecular bone versus the calcification of cartilage and changes to subchondral bone in fibrocartilaginous entheses (Slobodin et al., 2015). Complete loss of original morphology includes both osteoblastic and osteoclastic activities, which can lead to the total malformation of the attachment site.

Entheses as Indicators of Physical Activity

The use of entheses to identify physical activity emerged from the earlier study of so-called “activity-induced pathology” (Merbs, 1983), later labelled “occupational stress markers” (Kennedy, 1989), or alterations in the skeleton thought to emerge from specific activities (e.g. “clay shoveler’s disease”, “kayaker’s clavicle”). Earlier clinical research linked physical stress to changes at specific ligament and tendon insertion sites, indicating some type of relationship between activity and changes at insertion sites (see Tipton, 1975). During the 1980s, there was significant interest for understanding entheseal attachments and how they relate to physical activity in both medical and anthropological literature (see Merbs, 1983; Benjamin et al., 1986; Dutour, 1986; Larsen, 1987; Hawkey, 1988; Kennedy, 1989).

Charles F. Merbs’ 1983 publication became one of the first to comprehensively connect known occupation types to specific musculoskeletal changes. His work was heavily supported with ethnographic reports, first-hand historical accounts, and the archaeological record about the now extinct Inuit cultural group known as the Sadlermiut. Merbs later partnered with Diane

Hawkey, who focused on MSMs in her PhD dissertation (Hawkey 1988) to develop the first standardized scoring system to evaluate the degrees of change of fibrous and fibrocartilaginous entheses (Hawkey and Merbs, 1995). It is one of the first known documents to include the term "musculoskeletal stress markers" (MSMs), instead of the term "markers of occupational stress" Kennedy (1989) had used. The more general term MSMs, which later transformed into "entheseal changes" or "enthesopathies" (the terms used here), does not imply that the skeletal changes directly relate to occupation or work, but physical activity in general (Jurmain and Villotte, 2010; Odien, 2015; Stirland, 1998).

The "Hawkey and Merbs" method focuses on three distinct observations of musculoskeletal stress markers (MSMs): robusticity, stress lesions, and ossification exostoses. Robusticity is defined as a reflection of daily 'wear and tear' on the muscle attachment site, which results in changes ranging from a rugged texture to pointed crests on the bone, demonstrating both osteoblastic and osteoclastic occurrences. The stress lesions are expressed by pitting and porosity that comes from osteoclastic bone resorption at the attachment site. Ossification exostoses are the macrotrauma from major injuries between connective tissue and bone that results in notable bony projections, or 'exostoses'. For all categories, the grading scale follows a degree of change from 0 to 3, with 0 being the absence of a marker, 1 is a faint degree of change, 2 is a moderate change and 3 being a strong change. However, intermediate scores, for example 1.5, can also be used (Hawkey and Merbs, 1995).

After Hawkey and Merbs' methodology was published in the mid-1990s, bioarchaeological interest in entheseal changes accelerated through the 2010s. Some of these included applying Hawkey and Merbs' method to other skeletal samples (see Peterson, 1994; Steen and Lane, 1998; Eshed et al., 2004; Doying, 2010; Schrader, 2012), while others sought to refine the method by developing their own scoring systems (see Robb, 1998; Crubézy, 1988; Mariotti et al, 2004, 2007; Villotte, 2006; Henderson et al., 2013, 2015). At the same time these newer methods were being developed, clinical research on the histological structure of entheses (see Benjamin and Ralphs, 1998; Benjamin et al., 2002; Benjamin et al., 2004) and how fibrocartilaginous entheses are affected by physical stress (see Benjamin et al., 2006; Shaw and Benjamin, 2007) greatly facilitated the development of medically-sound scoring methods and explanatory models of entheseal change. Clinical laboratory studies on human athletes in the last decade have illuminated how biomechanical loading affects the connective tissues and skeleton *in vivo*, and the development of enthesopathies, the pathological changes to entheses (Benjamin et al., 2006). In many cases, tendon size and tendon and muscle elasticity (as opposed to stiffness) have been linked to bony changes at the tendon/muscle attachment site in clinical studies (Benjamin et al., 2000; Benjamin et al., 2007; Shaw et al., 2007).

However, other conditions besides tendon stiffness and muscle damage have been linked to enthesopathies. Rheumatologic diseases such as spondyloarthritis (SpA; specifically, ankylosing spondylitis, AS, and psoriatic arthritis, PsA), and rheumatoid arthritis (RA) also result in significant enthesopathy formation as either primary or secondary features (Rossini et al., 2016; Slobodin et al., 2010). In addition, degenerative joint diseases resulting in excessive bone growth and ossification of joint structures, like diffuse idiopathic skeletal hyperostosis (DISH) and osteoarthritis (OA), affect development of enthesopathies at attachment sites in close proximity to affected joints (Cammisa et al., 1998; Slobodin et al., 2010). Similarly, conditions causing soft tissue inflammation, such as fibromyalgia and Crohn’s disease, can stimulate the development of enthesopathies in the vertebral column, arms, hands, legs, and feet (Ozkan et al., 2013; Van den Bosch et al., 2000). Finally, development of enthesopathies also increases with age, and thus this variable should be considered when assessing activity-related changes in a sample (Mariotti et al., 2007). Therefore, in order to illuminate human behavior through enthesopathies, the presence of confounding variables such as age, sex, and other pathologies known to impact enthesopathy development need to be controlled for.

As a result of increased clinical research that links muscle use to bony changes at their attachment sites, and other factors that can affect entheseal changes, researchers started to move away from the Hawkey and Merbs method to develop a more physiologically- and clinically-sound approach. First, the terminology used by Hawkey and Merbs to describe entheseal changes was transformed to better reflect the underlying processes resulting in their development. "Robusticity" was still used to refer to the topography of the attachment site, but "osteophytic" and "osteolytic", terms referring to bone formation and erosion respectively, were used instead of the vaguer "ossification exostoses" and "stress lesions" (Mariotti et al.2004).

In addition, further clinical research on the histological changes seen at attachment sites and variation in types and consistency of changes at fibrous versus fibrocartilaginous entheses pushed some researchers to completely revamp the categories observed and the scores attributed to changes within these categories (Villotte 2006, 2009, 2012). First, this new approach distinguished between different entheseal attachments based on clinical studies of insertion site morphology and remodeling processes, and the fact that the contours and centers are more easily distinguished in some types of entheses over others (Villotte, 2006). Group 1 includes appendicular fibrocartilaginous entheses, where changes to the contour of insertion site are difficult to observe, Group 2 encompasses appendicular fibrocartilaginous entheses with easy-to-measure contour changes, Group 3 refers to the yellow ligament (*ligamenta flava*) along the vertebral column, which is fibrocartilaginous but the centers and contours are indistinguishable from each other, and Group 4 includes only fibrous entheses which tend to have nearly indistinguishable centers and contours. These four groups should be scored separately in order to reflect their varied responses to activity and ligament and tend strain.

The new method also increased the type of entheseal changes to six from Hawkey and Merbs' three: 1) cyst development, 2) surface irregularity, 3) atypical foramina, 4) cortical bone production, 5) osteoclastic and osteoblastic processes, and 6) erosion. A cyst is a circular opening >1 mm in diameter that leads to a cavity. Irregularity is simply the overall granular or uneven surface at the insertion site. Atypical foramina are at least three small, rounded holes that can be the result of atypical vascularization. Bone production is exostoses or 'enthesophytes', sharp projections of bone built up on the cortical surface. Osteoclastic and osteoblastic processes act in tandem and refer to the bone remodeling process that occurs when bone is damaged. Erosion is loss of bone within a localized area on the attachment site. In addition, because the inner and outer sectors of the entheseal attachment undergo slightly different changes, they should be scored separately. Both the outer surface, or contour, and the inner surface should be scored as 0, 1, and 2, with 0 being no change and 2 representing extensive changes. For the inner surface, or center, a score of 1 is broken down into two subcategories, 1a (the entire surface exhibits non-specific change) and 1b (less than half of the surface exhibits a specific type of change, e.g., bone production, cysts). The scores for inner and outer surfaces for each type of change are then summed to provide an overall score: A if the sum of scores is 0, B if the sum of scores is 1 or 2, and C if the sum of scores is 3 or 4.

Villotte's method underwent continued refinement through testing for interobserver error and recording issues. Havelková and Villotte (2007) found that definitive changes at the attachment sites of fibrous entheses are more difficult to observe, leading to discrepancies in the results. They then recommended to only include fibrocartilaginous entheses in activity-related research. Further refinement of the method by Villotte and Perréard Lopreno (2012) combined Stages B and C into one score to improve the method's reproducibility.

Villotte suggested that biomechanical and histological connections existed between physical stress and entheseal changes, but this needed further evaluation and education across multiple academic professionals. In 2009, Villotte and other osteologists interested in activity-related skeletal changes organized a workshop at the University of Coimbra in Portugal to explore three main issues surrounding entheseal scoring systems: 1) the variation and ambiguity of enthesis terminology used in bioarchaeological literature, 2) the re-standardization of recording methods, and 3) the classification of physical activity patterns and possible occupations in the past using entheses (Henderson et al., 2013; Villotte et al., 2016). The 2009 Coimbra conference was the first to suggest the more neutral term "entheseal changes" instead of musculoskeletal markers (MSMs) since it avoids the assumption that confounding causes would have affected the attachment site and produced the skeletal change (Jurmain and Villotte, 2010).

Restandardization of scoring methodology at the Coimbra conference essentially combined Mariotti (Marriotti et al. 2004) and Villotte's (Villotte, 2006, 2009, 2012) original methods described previously, while improving the terminology and descriptions of entheseal changes (Henderson et al., 2013). The first iteration of the Coimbra method followed Mariotti's grading scale of 0 to 3 (from least to greatest change) and marking any enthesis with less than 50% preserved as NR, "not recordable" (Henderson et al., 2013). However, a revision of the method altered the grading scale to 0 to 2 as an attempt to decrease interobserver error (Henderson et al., 2015). Retained from the first iteration to the revised method is Villotte's delineation of the morphological features found at insertion sites, the contour and center, now identifying them as Zone 1 and Zone 2, respectively. These zones also received more precise definitions, with Zone 1 as “the margin of the entheses at which [connective tissue] fibers attach most obliquely to the bone” and Zone 2 as the rest of that margin and surface of the attachment site (Henderson et al., 2015). The revised method furthermore included Villotte and colleagues’ (2010) suggestion that only fibrocartilaginous entheses be recorded using this system since clinical evidence has suggested that they have a stronger association with muscle use and fewer discrepancies between observations. The revision proved to be rather effective and gave an overall repeatability range of approximately 80-85% (Henderson et al., 2015).

The final results include the original observations of bone formation, erosion, fine porosity, macroporosity, and cavitation, but also included a new category, textural change. Bone formation is present on an enthesis if it has somewhere between a rough surface and distinct bony projections, as long as they are not smooth or mound-like. Erosions include depressions or excavations wider than they are deep, and to be scored as present they must be greater than 1mm in maximum width in Zone 1, and greater than 2mm wide in Zone 2. Textural change refers to having a rough, grain-like texture comparable to fine-grained sandpaper over at least some extent of the surface. The presence of fine porosity refers to small, smooth-edged circular perforations less than 1mm in diameter, while macroporosity indicates holes larger than 1mm in diameter. Cavitations are present if they are openings within the subchondral bone with a visible floor and an opening larger than 2mm in diameter. Henderson and colleagues (2015) also incorporate the original Villotte grading scale into the Coimbra method. All categories except for textural change follow the scoring system 0 (absence of change), 1 (slight change), and 2 (high degree of change), and textural change only is scored as 0 (no change) to 1 (greater than 50% of the surface has an irregular texture). For a more detailed description of each score based on entheseal change for the Coimbra method, as well as the methods discussed earlier, see Appendix A.

This project therefore will utilize the Coimbra method based on its repeatability range of 80-85%, as well as its clinically-informed background regarding entheses and entheseal changes. This method should illuminate activity patterns of non-elite Nabataeans at the turn of the millennium based on an excavated sample of commingled and fragmentary skeletal remains from Petra. Currently, the Coimbra method has not been applied to a commingled and/or fragmented assemblage, so this analysis will be informed by limitations identified by other studies focusing on commingled assemblages, such as inaccurate MNI representation as well as loss of pairing bilateral elements (Nikita and Lahr, 2011).

Research Area: First Century BC/AD Petra, Jordan

Location and Significance

The site of Petra, Jordan, is located on the southern end of the country (Figure 2.1). The ancient city is nestled within a mountainous valley and entered via a 1.3km long water-carved canyon known as the Siq. It is a city partially carved from sandstone that provides a colorful landscape; even its name is from the Greek word for ‘rock’. Petra was the capital city of the Nabataean Kingdom from the third or second century BC to 106 AD, and at its greatest extent spread from southern Syria to northern Saudi Arabia, and across the Negev desert into southern Israel.

Figure 2.1: Map of Jordan showing the location of Petra

During the first century BC/AD, the height of the Nabataean Kingdom, the city was a pre-industrial urbanized environment that was at the center of extensive trading networks and harbored a distinct social hierarchy. The Nabataeans' initial appearance in Arabia is a highly contested topic, though most agree that they were undoubtedly Arab in ancestry and began as nomadic pastoralists (Schmid, 2002). The Nabataeans eventually earned an important place within the Hellenistic world through their sociopolitical and pan-regional economic expertise, learning from surrounding cultures as well as maintaining their own cultural ideals.

The first mention of the Nabataeans comes from Diodorus Siculus' *Bibliotheca Historia*, which describes the attack of Antigonus Monophthalmos, a former general for Alexander the Great, on Petra in 312 BC (2.48-49;19.19-100). Diodorus, writing in the 1st century BC, describes the 4th century BC Nabataeans as nomadic pastoralists who maintained their economic status through overland caravan trading, particularly with spices. Strabo, a Greek historian from Anatolia, described the Nabataeans of the 1st century BC based on information gained from an informant and a close friend (*Geography* 16.4.24-27). At this point they apparently were a sedentary population that had gained momentous wealth by trading in gold, silver, and perfumes. Therefore, it can be implied that between the late fourth century and the beginning of the first century BC, the Nabataean people had shifted from an egalitarian, nomadic lifestyle to living in permanent settlements and relying largely on agricultural production along with pastoral nomadism.

This sedentism occurred at the same time that the Nabataeans began participating intensively in international trade through routes that linked the Nabataean Kingdom with the Arabian Peninsula and the Mediterranean (Schmid, 2002). Noteworthy items of trade included spices and incense from South Arabia, and precious stones, sugar, and spices from India (Schmid, 2002). Originally, these were distributed via overland routes. However, as the Roman Empire began establishing maritime trade ports in nearby Egypt, the Nabataeans likewise expanded their reach to sea ports, like the one located at Aila, now modern-day Aqaba (Parker, 2014). Trade networks were the main source of economy for the Nabataeans, concentrating on the commodities of frankincense, myrrh, oils, and perfumes. Perfume production became a major export by the later end of the first century BC, transported using Petra-made *unguentaria* (perfume bottles) (Johnson, 1987).

With the wealth and stability provided by trade during the end of the first century BC and into the first century AD, the Nabataeans could expand their main city, Petra. A number of elaborate religious, political, funerary, and residential structures were constructed during this period, including an amphitheater, public bath houses, and complex water storage and drainage systems (Ortloff, 2005; Schmid, 2002). In addition to these monuments, construction of elite or royal tombs that line the cliffs occurred, displaying a variety of sizes and stylistic choices in their facades (Schmid, 2002). The kingdom eventually was annexed as a province of Arabia in 106 AD by Trajan (Schmid, 2002). It is within this pre-Roman annexation social and economic context that the North Ridge tombs were constructed for burial of some of the city's dead.

Burial Spaces of the Non-Elite Nabataeans

Previously, not much was known about the non-elite population of Petra. Much of the archaeological focus has been on architectural features like the monumental structures and the elite/royal façade tombs. However, during the last decade, research based on learning about the non-elite segment of the population has increased (Bikai and Perry, 2001; Perry 2016; Parker and Perry 2013). New research on these burials has yielded a plethora of evidence to piece together the lives of these non-elites, providing a more all-encompassing portrait of life in Petra during the first century BC/AD.

This research focuses on the skeletal remains found in non-elite rock-cut shaft tombs found along the North Ridge during the 2012 and 2014 seasons of the Petra North Ridge Project. The standard style used by non-elite Nabataeans for these tombs incorporates a two- to threemeter shaft carved straight down into bedrock that opens into rectangular burial chambers. The chambers include structural burial features such as wall niches and oblong floor burial receptacles where the individuals were interred (Perry, 2016). Evidence from the tombs suggests that the dead would have likely been buried within wooden coffins occasionally decorated with copper alloy “studs”. During the funerary process, the deceased would be left to decompose into skeletonized remains, most likely inside the tomb in the wall niches and in some of the floor receptacles (Perry, 2016). At some point, some of the burials were impacted by natural and cultural processes, which left the skeletal remains not only commingled, but highly fragmented. Water infiltration during the rainy season, sediment fill, burial practices, looting in antiquity, and the clearing of space in modern times all play a role in the preservation of these remains (Perry 2002; Perry, 2016).

Presently, there is limited bioarchaeological and archaeological information focusing on the non-elites of Petra. Studies of the individuals buried along the North Ridge include paleopathology analysis (Canipe, 2014), assessment of age-related mortality (Propst, 2017), and isotopic investigations of diet (Appleton, 2015). Analysis of the PNRP 2012 remains, as well as the remains from the individuals found under the Ridge Church, has discovered that these people lived healthy, active lives with very few indications of infectious disease or physiological stress (Bikai and Perry, 2001; Canipe, 2014). There are some indications of trauma on the ribs, wrists, and ankles, which may correspond to minor injuries incurred while traversing the rocky landscape outside the city (Perry, 2002). Also, there are a few cases of degenerative joint disease, with approximately 18% of joints in the PNRP 2012 assemblage, though this is significantly lower than contemporary agricultural communities and nomadic groups (Canipe, 2014).

Using entheseal changes as physical activity indicators can provide more insight to the daily lives of the ordinary peoples of Nabataean Petra. This research seeks to determine a generalized pattern of physical activity that the non-elite Nabataeans of Petra experienced, with focuses on overall distribution, bilateral asymmetry, and sex-related differences. Analyzing the level of physical activity offers opportunities towards future anthropological studies regarding these data, including improved understanding of differences in activity patters between socioeconomic strata and gender-based roles.

Chapter 3: Materials and Methods

Materials

The 2012 and 2014 skeletal assemblages from the Petra North Ridge Project (PNRP) were combined to maximize the amount of entheseal attachments recorded for this research. This sample comes from Tombs B.4, B.5, B.6, and B.7, which have a total MNI of 114. Taphonomic and anthropogenic processes have caused fragmentation and commingling of the sample. Thus, observations of entheses could not be assessed by individual, but by fragment. The sample size was reduced further by the poor preservation of bone metaphyses and epiphyses, the location of many ethereal attachments. In addition, in many cases the observations could not be assessed by sex or age, and individuals under the age of 20 are underrepresented in the PNRP sample. However, entheseal reactions generally do not develop in young individuals, thus only adult individuals (i.e., those 20 years and older) were included in this analysis. In addition, since osteoarthritis presents a confounding factor in the assessment of activity-related enthesopathies, fragments that displayed signs of osteoarthritis were not included in the final analysis.

Methods

Entheseal Change Scoring System

Macroscopic observation of entheses in the integrated PNRP 2012/2014 sample utilized the revised Coimbra method as discussed in Chapter 2 (Henderson et al., 2015) As per the recommendations made by Havelková and Villotte (2007) and Henderson and colleagues (2013, 2015), only fibrocartilaginous entheseal attachments were analyzed. This study utilized fifteen separate muscle attachments from thirteen different skeletal elements as recommended by Havelková and Villotte (2007). Furthermore, the revision of the Coimbra method suggested inclusion of the common extensor origin in addition to those recommended by Havelková and Villotte (Henderson et al., 2015). The muscle attachments observed here include: *common extensor origin, subscapularis, supraspinatus, infraspinatus, biceps brachii, triceps brachii, flexor carpi radialis, flexor carpi ulnaris, gluteus medius, gluteus minimus, iliopsoas, quadriceps femoris, biceps femoris,* and *triceps surae*. See Appendix B for the data collection form that was used, which separates each attachment by the delineated Zones 1 and 2 as well as the six types of entheseal changes (bone formation, erosion, textural change, fine porosity, macro-porosity, and cavitation). See Appendix C for pictures of each enthesis by element.

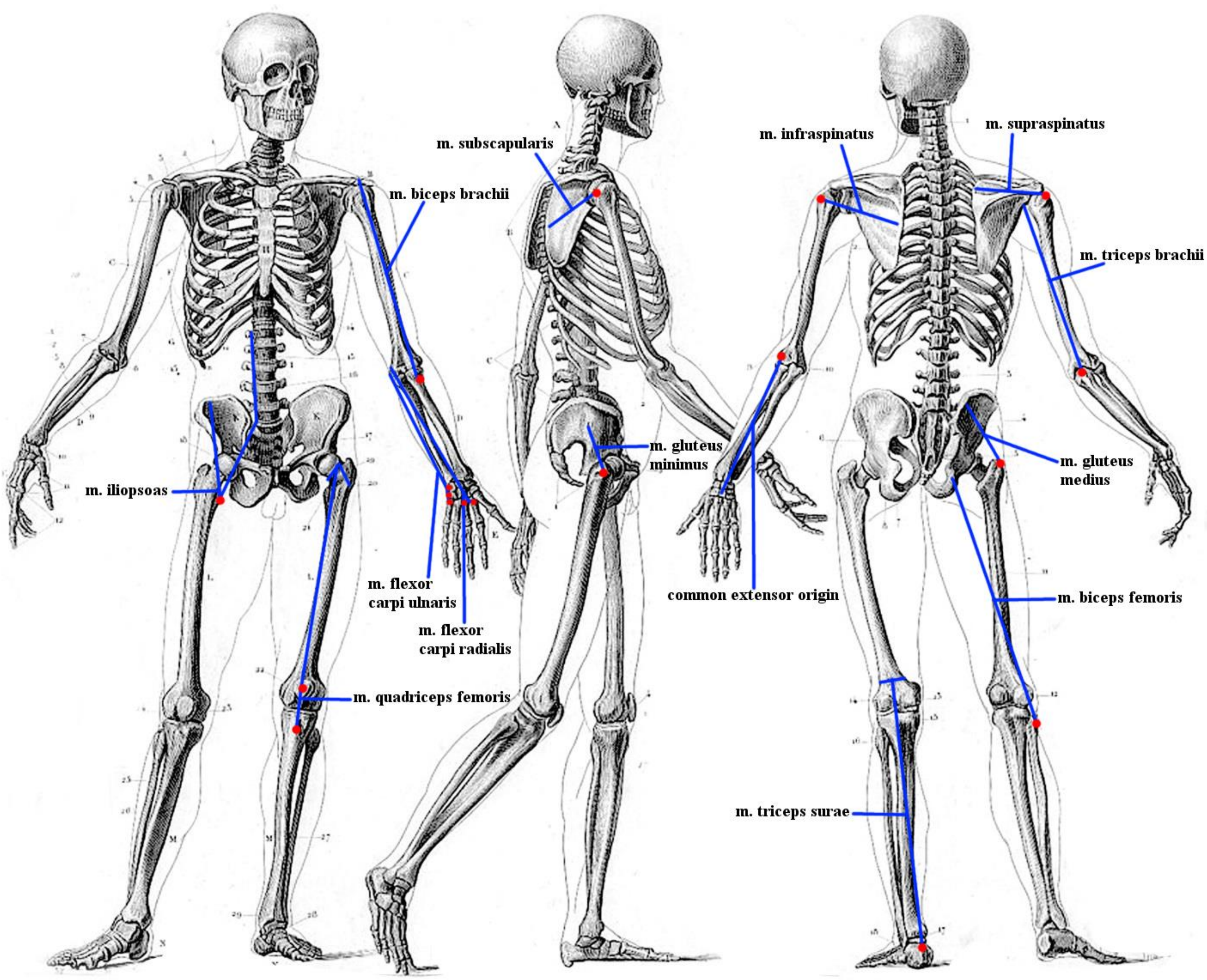

Figure 3.1: Anatomical location of the muscles used in this study. Red dots indicate location of entheses. Image borrowed from https://human-anatomy101.com/skeleton-human-anatomy/skeleton-human-anatomy-full-skeleton-diagram-drawing-tutorials-the-human-skeleton/. Lines and labels added by author.

Sex Determination

Determining sex for a commingled, fragmentary sample is hindered by the inability to use multifactorial techniques. Instead, only fragments or bones that are sexually dimorphic either morphologically or metrically can be assigned a sex estimation. This study utilized a number of metric and morphological techniques to estimate sex (see Appendix B for a list of measurements). Studies using populations geographically close to Jordan were utilized if available, since patterns of sexual dimorphism have been found to be region-specific (Yaşar İşcan et al., 1998). Sex of whole and partial metacarpals was determined following Manolis et al. (2009), who developed their technique using modern Greek populations. Radial head measurements also were used for sex estimation based on Berrizbeitia's (1989) study of U.S. individuals of European and African descent. Sexually-dimorphic distal humerus morphology as discovered by Rogers (1999) was used. Spradley and Jantz (2011) found that the use of certain post-cranial element measurements yields more accurate sex determination of up to 94% than cranial measurements if the pelvis is not present. Sex estimation of the humerus, radius, ulna, femur, tibia, and calcaneus, was accomplished using Spradley and Jantz's technique following the standard measurements from Buikstra and Ubelaker (1994) for each element.

Statistical Analyses

The scores for all enthesis observations were converted to mean scores to demonstrate general patterns of entheseal change across the body, as well as find any possible differences between females and males and the left and right sides. These mean scores were evaluated using Wilcoxon rank sums tests using JMP (version 13, Cary, NC). A Bonferroni correction for multiple comparisons was calculated to adjust the p-value identifying significance. The data was run two ways, first by comparing mean scores for each enthesis by upper/lower limb, sex, and side, and second by comparing the amount of 0's, 1's, and 2's scored for each observation at each enthesis. This second step was broken down by initially comparing the overall counts for the sample by upper/lower limb, sex, and side, then followed by doing comparisons for each enthesis by sex and by side. The results of both analyses were the same, and only the mean score comparisons are reported here.

Variation by Sex

Previous research has found that gender-linked labor roles can result in differences in enthesopathy development by sex (Palmer et al., 2016; Schrader, 2012; Villotte et al., 2010). Variation of enthesopathies by sex was assessed through comparing the mean score for each entheseal attachment and the mean score of all entheseal attachments by sex. Differential patterning within the body by sex was tested by comparing mean scores from the left and right sides by sex and upper and lower limbs by sex. There are three null hypotheses for this analysis:

$\boldsymbol{H_O}$**:** There are no differences between males and female mean scores of each entheses

$\boldsymbol{H_O}$**:** There are no differences in overall upper limb mean scores between males and females, and in overall lower limb mean scores between males and females

$\boldsymbol{H_O}$**:** There are no differences in overall left mean scores between males and females, and in overall right mean scores between males and females

Bilateral Asymmetry

Evidence for bilateral asymmetry was identified through comparison of left and right side frequencies and means scores overall and within the lower and upper limbs. There are three null hypotheses for this analysis:

$\boldsymbol{H_O}$**:** There are no differences in mean scores between left and right sides

$\boldsymbol{H_O}$**:** There are no differences in upper limb mean scores between left and right sides

$\boldsymbol{H_O}$**:** There are no differences in lower limb mean scores between left and right sides

Summary

Evaluating and analyzing the degrees of entheseal changes present on the non-elite Nabataeans aids in understanding the biomechanical workload of the population. This research will expound on the typical activity patterns of the non-elite, and if this group was conducting light- or heavy-labor activities in Petra during the first century BC/AD. Moreover, accounting for sex allows for sample-wide comparison to determine whether males and females had experienced similar or different physical stress. In turn, this will clarify if a sexual division of labor was present for the non-elite Nabataeans. A cross-examination with related studies from other non-industrial urban sites will then be conducted to bring further context and analysis to these results (see Chapter 5).

Chapter 4: Results

A total of 322 observations of 14 different entheses were utilized for this research. Tables 4.1 and 4.2 report the frequency of scores given for each attachment for all eight observations. These fibrocartilaginous entheseal attachments are the same as those selected by Villotte (2012) because of the strong clinical evidence that they reflect with particular muscles. Only a few entheseal attachments could be observed for *subscapularis* (n=5), *supraspinatus* (n=2), *infraspinatus* (n=3), *gluteus medius* (n=5), *gluteus minimus* (n=2), *iliopsoas* (n=1), and *biceps femoris* (n=9), likely due to the poor preservation of the associated skeletal elements. These insertion sites are located at the epiphyses of the long bones where the thin cortical bone is highly susceptible to taphonomic damage (Todd and Rapson, 1988). The metacarpals and carpals were the most complete and well preserved. In addition, entheseal attachment scores for 11 out of the total 14 entheses observed only could be linked with a sex estimation of 77 female observations and 15 male observations (Tables 4.3, 4.4, and 4.5). Similar to the entire sample, the metacarpals were the best preserved in the sample, and thus the *flexor carpi radialis* generated the most observations for females and males. See Appendix D for the list of measurements used for sex determination.

The breakdown of observation score frequencies show a general trend that all entheses, regardless of side or sex, display higher percentages for a score of 0 than 1 or 2. This might indicate that the sample did not engage in strenuous physical activity. Another trend is that the lower limbs exhibit greater instances of scores indicating change, i.e. 1 and 2, than the upper limb; it could be assumed that there was more physical use of the lower limbs than the upper limbs for this sample. However, this trend could be due to the uneven amount of observations between upper and lower limbs (226 versus 96, respectively). These trends are only initial observations when reviewing the frequency breakdowns, therefore further analyses using mean scores will aid in either refuting or accepting these claims.

Table 4.1: Overall breakdown of observation scores by enthesis of the Petra North Ridge tombs. Each enthesis was scored for eight different observations following Henderson et al. (2015), and thus the score sample sizes are larger than the sample size of the entheses observed. '# of OBS' refers to the number of observations receiving each score.

		Frequency of score within sample					
		0		**1**		**2**	
Enthesis	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**
m. subscapularis	5	28	77.8	7	19.40	1	2.8
m. supraspinatus	2	15	93.8	1	6.3	0	0
m. infraspinatus	3	22	100	0	0	0	0
m. biceps brachii	39	231	77.0	47	15.7	22	8.3
m. triceps brachii	52	332	83.4	54	13.6	12	3.0
Common extensor origin	17	105	83.3	17	13.5	4	3.2
m. flexor carpi radialis	56	372	88.2	49	11.6	1	0.2
m. flexor carpi ulnaris	52	333	80.4	72	17.4	9	2.2
Upper Limb Total	226	1438	83.0	247	14.2	49	2.8
m. gluteus medius	5	27	75.0	9	25.0	0	0
m. gluteus minimus	2	7	50.0	7	50.0	0	0
m. iliopsoas	1	6	75.0	2	25.0	0	0
m. quadriceps femoris	56	309	73.6	96	22.8	15	3.6
m. biceps femoris	9	48	66.7	20	27.8	4	5.5
m. triceps surae	23	118	67.1	46	26.1	12	6.8
Lower Limb Total	96	515	70.9	180	24.8	31	4.3

Table 4.2: Breakdown of observation scores by enthesis and side of the Petra North Ridge tombs. Each enthesis was scored for eight different observations following Henderson et al. (2015), and thus the score sample sizes are larger than the sample size of the entheses observed. '# of OBS' refers to the number of observations receiving each score.

		Left Frequencies							**Right Frequencies**					
		0		**1**		**2**			**0**		**1**		**2**	
Enthesis	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**
m. subscapularis	3	19	86.36	2	9.09	1	4.55	2	9	64.3	5	35.7	0	0
m. supraspinatus	1	8	100	0	0	0	0	1	7	87.5	1	12.5	0	0
m. infraspinatus	1	6	100	0	0	0	0	2	16	100	0	0	0	0
m. biceps brachii	23	134	77.0	27	15.5	13	7.5	16	97	77.0	20	15.9	9	7.1
m. triceps brachii	19	128	83.1	23	14.9	3	2.0	33	204	83.6	31	12.7	9	3.7
Common extensor origin	8	50	83.3	8	13.30	2	3.3	9	55	83.3	9	13.7	2	3.0
m. flexor carpi radialis	28	196	88.3	25	11.2	1	0.5	33	176	88.0	24	12.0	0	0
m. flexor carpi ulnaris	28	184	82.9	32	14.4	6	2.7	28	149	77.6	40	20.8	3	1.6
Upper Limb Total	111	725	83.5	117	13.5	26	3.0	124	713	82.3	130	15.0	23	2.7
m. gluteus medius	4	22	78.6	6	21.4	0	0	1	5	62.5	3	37.5	0	0
m. gluteus minimus	2	7	50.0	7	50.0	0	0	0	--	--	--	--	--	--
m. iliopsoas	0	--	--	--	--	--	--	1	6	75.0	2	25.0	0	0
m. quadriceps femoris	32	179	74.0	55	22.7	8	3.3	24	130	73.0	41	23.0	1	3.9
m. biceps femoris	5	30	75.0	7	17.5	3	7.5	4	18	56.3	13	40.6	1	3.1
m. triceps surae	14	70	66.1	26	24.5	10	6.4	9	48	68.6	20	28.5	2	2.9
Lower Limb Total	57	308	71.6	101	23.5	21	4.9	39	207	71.4	79	27.2	4	1.4

Table 4.3: Breakdown of observation scores by enthesis and sex of the Petra North Ridge tombs. Each enthesis was scored for eight different observations following Henderson et al. (2015), and thus the score sample sizes are larger than the sample size of the entheses observed. '# of OBS' refers to the number of observations receiving each score.

	Female							Male						
		0		1		2			0		1		2	
Enthesis	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**
m. subscapularis	2	12	85.7	2	14.3	0	0	0	--	--	--	--	--	--
m. supraspinatus	2	15	93.8	1	6.3	0	0	0	--	--	--	--	--	--
m. infraspinatus	2	14	100	0	0	0	0	0	--	--	--	--	--	--
m. biceps brachii	5	30	75.0	5	12.5	5	12.5	1	4	50.0	3	37.5	1	12.5
m. triceps brachii	0	--	--	--	--	--	--	1	7	87.5	1	12.5	0	0
Common extensor origin	5	41	85.4	5	10.4	2	4.2	2	12	75.0	3	18.8	1	6.3
m. flexor carpi radialis	39	234	88.0	31	11.7	1	0.3	4	26	86.7	4	13.3	0	0
m. flexor carpi ulnaris	7	48	85.7	7	12.5	1	1.8	6	41	85.4	6	12.5	1	2.1
Upper Limb Total	62	394	86.8	51	11.2	9	2.0	14	90	81.8	17	15.5	3	2.7
m. gluteus medius	2	11	78.6	3	21.4	0	0	0	--	--	--	--	--	--
m. quadriceps femoris	1	3	50.0	3	50.0	0	0	0	--	--	--	--	--	--
m. triceps surae	12	58	69.0	21	25.0	5	6.0	1	4	66.7	2	33.3	0	0
Lower Limb Total	15	72	69.2	27	26.0	5	4.8	1	4	66.7	2	33.3	0	0

Table 4.4: Breakdown of observation scores by enthesis and side for females only of the Petra North Ridge tombs. Each enthesis was scored for eight different observations following Henderson et al. (2015), and thus the score sample sizes are larger than the sample size of the entheses observed. '# of OBS' refers to the number of observations receiving each score.

	Left							Right						
		0		1		2			0		1		2	
Enthesis	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**
m. subscapularis	1	6	100	0	0	0	0	1	6	75.0	2	25.0	0	0
m. supraspinatus	1	8	100	0	0	0	0	1	7	87.5	1	12.5	0	0
m. infraspinatus	1	6	100	0	0	0	0	1	8	100	0	0	0	0
m. biceps brachii	3	17	70.8	4	16.7	3	12.5	2	13	81.3	1	6.3	2	12.5
m. triceps brachii	0	--	--	--	--	--	--	0	--	--	--	--	--	--
Common extensor origin	3	25	78.1	5	15.6	2	6.3	2	16	100	0	0	0	0
m. flexor carpi radialis	17	97	86.6	14	12.5	1	0.9	22	137	89.0	17	11.0	0	0
m. flexor carpi ulnaris	3	23	95.8	1	4.2	0	0	4	25	78.1	6	18.8	1	3.1
Upper Limb Total	29	182	85.8	24	11.3	6	2.8	33	212	87.6	27	11.2	3	1.2
m. gluteus medius	2	11	78.6	3	21.4	0	0	0	--	--	--	--	--	--
m. quadriceps femoris	0	--	--	--	--	--	--	1	3	50.0	3	50.0	0	0
m. triceps surae	7	36	69.2	13	25.0	3	5.8	5	22	68.8	8	25.0	2	6.3
Lower Limb Total	9	47	71.2	16	24.2	3	4.5	6	25	65.8	11	28.9	2	5.3

Table 4.5: Breakdown of observation scores by enthesis and side for males only of the Petra North Ridge tombs. Each enthesis was scored for eight different observations following Henderson et al. (2015), and thus the score sample sizes are larger than the sample size of the entheses observed. '# of OBS' refers to the number of observations receiving each score.

	Left							**Right**						
		0		**1**		**2**			**0**		**1**		**2**	
Enthesis	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**	**Total N**	**# of OBS**	**%**	**# of OBS**	**%**	**# of OBS**	**%**
m. subscapularis	0	--	--	--	--	--	--	0	--	--	--	--	--	--
m. supraspinatus	0	--	--	--	--	--	--	0	--	--	--	--	--	--
m. infraspinatus	0	--	--	--	--	--	--	0	--	--	--	--	--	--
m. biceps brachii	0	--	--	--	--	--	--	1	4	50.0	3	37.5	1	12.5
m. triceps brachii	0	--	--	--	--	--	--	1	7	87.5	1	12.5	0	0
Common extensor origin	1	6	75.0	2	25.0	0	0	1	6	75.0	1	12.5	1	12.5
m. flexor carpi radialis	3	21	87.5	3	12.5	0	0	1	5	62.5	1	12.5	0	0
m. flexor carpi ulnaris	3	20	83.3	3	12.5	1	4.2	3	21	87.5	3	12.5	0	0
Upper Limb Total	7	47	83.9	8	14.3	1	1.8	7	43	79.6	9	16.7	2	3.7
m. gluteus medius	0	--	--	--	--	--	--	0	--	--	--	--	--	--
m. quadriceps femoris	0	--	--	--	--	--	--	0	--	--	--	--	--	--
m. triceps surae	0	--	--	--	--	--	--	1	4	66.7	2	33.3	0	0
Lower Limb Total	0	--	--	--	--	--	--	1	4	66.7	2	33.3	0	0

Out of the 322 total observations, only 267 observations were included in assessing the mean scores (Table 4.6). 55 observations had scores missing in Zone 1 categories (bone formation 1 and erosion 1), but had scores for Zone 2, thus more than 50% of the entire enthesis surface (Zones 1 and 2 combined) were recordable. Therefore, observations missing Zone 1 scores were not included in the mean score calculations. The highest upper limb score is *m. biceps brachii*, and the highest lower limb score is *m. gluteus minimus*. However, this enthesis, along with five others (*subscapularis*, *supraspinatus*, *infraspinatus*, *gluteus medius*, and *iliopsoas*) had very few observations, and the high mean scores may be due to sampling bias. Therefore, the mean scores of the upper and lower limbs were recalculated without including these entheses (Table 4.7). The deletion of these entheses did not result in any change in overall means scores of the upper and lower limbs with the exception of a 0.1 increase in left lower limb mean score of the reduced sample. Both the complete sample and the reduced sample show a trend for greater mean scores in the lower limb.

Table 4.6: Overall mean scores by enthesis and side for the Petra North Ridge sample.

	Total		Left		Right	
Enthesis	**N**	**Mean Score**	**N**	**Mean Score**	**N**	**Mean Score**
m. subscapularis	3	2.0	2	2.0	1	2.0
m. supraspinatus	2	0.5	1	0.0	1	1.0
m. infraspinatus	2	0.0	--	--	2	0.0
m. biceps brachii	33	2.7	18	2.8	15	2.5
m. triceps brachii	43	1.6	17	1.5	26	1.7
Common extensor origin	12	1.9	6	2.0	6	1.8
m. flexor carpi radialis	49	1.0	27	1.0	22	1.0
m. flexor carpi ulnaris	48	1.8	27	1.6	21	2.0
Upper Limb Total	192	1.7	98	1.7	94	1.7
m. gluteus medius	3	2.3	2	2.0	1	3.0
m. gluteus minimus	1	4.0	1	4.0	0	--
m. iliopsoas	1	2.0	0	--	1	2.0
m. quadriceps femoris	42	2.6	25	2.6	17	2.7
m. biceps femoris	9	3.1	5	2.6	4	3.8
m. triceps surae	19	3.3	11	3.6	8	2.8
Lower Limb Total	75	2.8	44	2.8	31	2.8

Table 4.7: Overall mean scores for the upper and lower limbs without *subscapularis*, *supraspinatus*, *infraspinatus*, *gluteus medius*, *gluteus minimus*, and *iliopsoas* for the Petra North.

	Total		Left		Right	
	N	**Mean Score**	**N**	**Mean Score**	**N**	**Mean Score**
Upper Limb	185	1.7	95	1.7	90	1.7
Lower Limb	70	2.8	41	2.9	29	2.8

Mean scores were also calculated for the observations with a determined sex (Table 4.8). For female observations, 66 out of 77 observations and for male observations, 13 out of 15 were included in the assessment of mean scores. Similar to the circumstance presented above, 13 observations had scores missing in Zone 1 categories but still had scores for Zone 2, resulting in more than 50% of the entire enthesis surface (Zones 1 and 2 combined) as recordable. Thus, observations missing Zone 1 scores were not included in the mean score calculations. Only two lower limb entheses had observations that could be attributed to a particular sex, and none were identified as male, greatly limiting comparisons of the lower limb by sex. In addition, three entheses in the upper limb had no male observations. In general, the data are heavily skewed toward females, which may result from bias in the sex estimation techniques used in this study. In general, the Nabataeans tend to be more gracile and smaller in size than modern populations, and thus even using some techniques developed in the modern Mediterranean, most individuals were identified as female.

Again, the mean scores were recalculated by removing the entheses with the lowest observations: *subscapularis, supraspinatus, infraspinatus,* and *gluteus medius*. Similar to the overall mean scores, there was little to no change in the mean scores for both females and males. Male upper limb and female lower limb mean scores became only marginally higher. For females, the muscles that show the highest means scores from reliable observations are *triceps surae, biceps brachii*, right *flexor carpi ulnaris*, and left common extensor origin; all of which coincide with the general pattern seen in the overall distribution of mean scores. For males, the highest mean scores from reliable observations are common extensor origin and *flexor carpi ulnaris*, which is similar to females.

Table 4.8: Overall mean scores by enthesis, side, and sex of the Petra North Ridge sample.

	Females						Males					
	Total		Left		Right		Total		Left		Right	
Enthesis	**N**	**Mean Score**	**N**	**Mean Score**	**N**	**Mean Score**	**N**	**Mean Score**	**N**	**Mean Score**	**N**	**Mean Score**
m. subscapularis	1	2.0	0	--	1	2.0	0	--	0	--	0	--
m. supraspinatus	2	0.5	1	0.0	1	1.0	0	--	0	--	0	--
m. infraspinatus	1	0.0	--	--	1	0.0	0	--	0	--	0	--
m. biceps brachii	5	3.0	3	3.3	2	2.5	1	5.0	0	.	1	5.0
m. triceps brachii	0	--	0	--	0	--	1	1.0	0	--	1	1.0
Common extensor origin	5	1.6	3	2.7	2	0.0	2	2.5	1	2.0	1	3.0
m. flexor carpi radialis	35	0.9	17	0.9	18	0.8	3	1.0	3	1.0	0	--
m. flexor carpi ulnaris	7	1.3	3	0.3	4	2.0	6	1.3	3	1.7	3	1.0
Upper Limb Total	56	1.2	27	1.3	29	1.1	13	1.7	7	1.4	6	2.0
m. gluteus medius	1	2.0	1	2.0	0	--	0	--	0	--	0	--
m. triceps surae	9	3.0	5	3.0	4	3.0	0	--	0	--	0	--
Lower Limb Total	10	2.9	6	2.9	4	3.0	0	--	0	--	0	--

Table 4.9: Overall mean scores for females and males of the Petra North Ridge sample without *subscapularis*, *supraspinatus*, *infraspinatus*, and *gluteus medius*.

	Total		**Left**		**Right**	
Sex	**N**	**Mean Score**	**N**	**Mean Score**	**N**	**Mean Score**
Female						
Upper	52	1.2	26	1.3	26	1.1
Lower	9	3.0	5	3.0	4	3.0
Male						
Upper	11	1.7	6	1.3	5	2.2
Lower	0	--	0	--	0	--

The presence of any significant patterns within the sample were demonstrated using a Wilcoxon rank sums tests comparing mean scores in the upper versus lower limbs, by side, and by sex (Table 4.10). Only the lower limb has a significantly higher mean score than the upper limb overall and bilaterally. Separating out females from the sample also show that they have a higher mean score in their lower limb (males could not be compared due to lack of lower limb observations). These tests were rerun after removing entheses with the lowest number amounts (*subscapularis*, *supraspinatus*, *infraspinatus*, *gluteus medius*, *gluteus minimus*, and *iliopsoas*) with similar results (Table 4.11). Table 4.12 shows a breakdown of the Wilcoxon rank sums test results by enthesis, comparing left versus right, female versus male, female left versus right, and male left versus right. No significant differences were found.

Table 4.10: Results of overall statistical comparisons of mean scores in the Petra North Ridge sample using the Wilcoxon rank sums test (significance determined by Bonferroni-corrected p-value = 0.003).

Comparison		**Z score**	**P value**
Upper v. Lower	Total	6.25158	**<.0001**
	Left	4.94333	**<.0001**
	Right	3.88303	**<.0001**
	Females	3.5439	**0.0004**
	Males	--	--
Left v. Right	Total	0.25889	0.7657
	Upper	0.30639	0.7593
	Lower	-0.03347	0.9733
	Females	1.04748	0.2949
	Males	0.95157	0.3413
Male v. Female	Total	0.98809	0.3231
	Left	-0.63836	0.5232
	Right	1.12611	0.2601

Table 4.11: Results of overall statistical comparisons of mean scores in the Petra North Ridge sample using the Wilcoxon rank sums test without *subscapularis*, *supraspinatus*, *infraspinatus*, *gluteus medius*, *gluteus minimus*, and *iliopsoas* (significance determined by Bonferroni-corrected p-value = 0.003).

Comparison		**Z score**	**P value**
Upper v. Lower	Total	5.96208	**<.0001**
	Left	4.7865	**<.0001**
	Right	3.64105	**0.0003**
	Females	3.36827	**0.0008**
	Males	--	--
Left v. Right	Total	-0.05737	0.9542
	Upper	0.46534	0.6417
	Lower	0	1.000
	Females	-1.04761	0.2948
	Males	0.95157	0.3413
Male v. Female	Total	0.27091	0.7865
	Left	-0.70239	0.4824
	Right	1.08063	0.2799

Table 4.12: Results of statistical comparisons of means scores in the Petra North Ridge sample by enthesis using the Wilcoxon rank sums test (significance determined by Bonferroni-corrected p-value=0.002).

	Left v. Right		**Female v. Male**		**Female Left v. Right**		**Male Left v. Right**	
Enthesis	**Z score**	**P value**	**Z score**	**P value**	**Z score**	**P value**	**Z score**	**P value**
m. subscapularis	0	1.000	--	--	--	--	--	--
m. supraspinatus	--	--	--	--	--	--	--	--
m. infraspinatus	--	--	--	--	--	--	--	--
m. biceps brachii	-0.05138	0.6074	0.90453	0.3657	0	1.000	--	--
m. triceps brachii	-0.64788	0.5171	--	--	--	--	--	--
Common extensor origin	0	1.000	0.78591	0.4319	--	--	--	--
m. flexor carpi radialis	0.05523	0.956	0.16656	0.8677	0.49256	0.6223	--	--
m. flexor carpi ulnaris	0.93913	0.3477	0.3052	0.7602	-1.11144	0.2664	0	1.000
Upper Limb Total	0.30639	0.7593	0.98809	0.3231	0.88396	0.3767	0.95157	0.3413
m. gluteus medius	--	--	--	--	--	--	--	--
m. gluteus minimus	--	--	--	--	--	--	--	--
m. iliopsoas	--	--	--	--	--	--	--	--
m. quadriceps femoris	0	1.000	--	--	--	--	--	--
m. biceps femoris	1.02805	0.3039	--	--	--	--	--	--
m. triceps surae	-1.60088	0.1094	--	--	0	1.000	--	--
Lower Limb Total	-0.03347	0.9733	--	--	0.22588	0.8213	--	--

The general pattern of results indicates that this sample did not show significant amounts of entheseal change. The majority of observed scores are 0 or 1, indicating little to no entheseal change, including accounting for side and for sex. Mean scores were significantly different between total upper and lower limbs, with lower limbs having marginally higher scores than upper limbs, a pattern also seen in females. Female observations and male observations did not have significant differences in mean scores, and or by left or right sides. Thus, the following null hypotheses were accepted:

***H_O*:** There are no differences between males and female mean scores of each entheses

***H_O*:** There are no differences in overall upper limb mean scores between males and females, and in overall lower limb mean scores between males and females

H_O: There are no differences in overall left mean scores between males and females, and in overall right mean scores between males and females

When assessing the data for bilateral asymmetry, there were no significant differences found between the left and right mean scores. Therefore, the following null hypotheses were accepted:

H_O: There are no differences in mean scores between left and right sides

H_O: There are no differences in upper limb mean scores between left and right sides

H_O: There are no differences in lower limb mean scores between left and right sides

When evaluating the results by entheses, there is a general pattern for overall observations and for observations by sex. *Biceps brachii*, common extensor origin, *flexor carpi ulnaris*, *quadriceps femoris*, *biceps femoris*, and *triceps surae* all have reliable sample sizes and show slightly more entheseal change than the other entheses based on score frequencies and mean scores. This could be an indication of muscle groups being used in tandem to execute biomechanical movements, though this will be addressed in the following chapter. These general patterns of physical activity for the non-elite Nabataeans of Petra will be further analyzed by comparing the results with those found from other non-industrial urban sites in Chapter 5, focusing on the societal elements of hierarchical status and variance of physical activity by sex.

Chapter 5: Discussion

As concluded by this research, the non-elite Nabataeans buried along the North Ridge of Petra during the 1st century BC/AD did not exhibit intensive biomechanical stress as evident from the slight degree of entheseal change present on the skeletal remains. There is no significant difference in entheseal change between the left and right sides overall and by sex, nor is there any significant difference in entheseal change between females and males. The only difference identified is between different parts of the body, with the lower limb having significantly higher mean scores than the upper limb in the overall sample and broken down by sex. Any parallels or differences between this pattern of physical activity and other pre-industrial urban and rural contexts will be determined through comparative analysis (Baker et al., 2012; Havelková et al., 2011; Schrader, 2012, 2015). One of the difficulties comparing the results of this study to previous research is that it utilizes a relatively new method. Scores from different entheseal scoring systems cannot be directly compared. However, the general body patterning of entheseal changes seen at Petra can be assessed within the context of regional studies or patterns seen at other preindustrial urban sites.

Only one contemporary site from the region has produced results on the development of enthesopathies, at the 2nd century AD agricultural town of Salkhad in southern Syria (Baker et al. 2012). The same fourteen fibrocartilaginous entheses used in this study were analyzed at Salkhad, in addition to two fibrous entheses that will not be considered here for comparison. These entheses were scored using the Villotte method. In general, the Salkhad sample shows significant entheseal change to the most extreme degree in the *biceps brachii, triceps brachii, quadriceps femoris, iliopsoas,* and *triceps surae* (Table 5.1). This may indicate that rural

Nabataean populations strained the muscles associated with these entheses more than the urban capital of Petra.

Table 5.1: Comparison of score frequencies between Salkhad and Petra with scores indicating any entheseal change.

	Salkhad[a]		Petra	
Enthesis	**N**	**Stage B + C %**	**N**	**Score 1 + 2 %**
m. biceps brachii	97	46	39	24
m. triceps brachii (ulna attachment)	165	25	52	16.6
m. iliopsoas	117	38	1	25
m. quadriceps femoris	236	44	56	26.4
m. triceps surae	175	54	23	32.9

[a] Baker et al., 2012.

Unlike the Petra sample, the Salkhad sample experienced notable bilateral asymmetry on the upper limb with more entheseal changes occurring on right side limbs than left. In contrast, there was no significant bilateral asymmetry present in the lower limb attachments in the Salkhad sample, similar to Petra. Baker and colleagues (2012) assert that the physical activity the Salkhad individuals were likely executing related to masonry and agricultural work, which can lead to significant bilateral asymmetry on the upper limb. Osteoarthritis, another skeletal indicator nominally linked with activity as noted in Chapter 2, was the most observed pathology at Petra. However, the frequency of osteoarthritis seen in the North Ridge tombs was significantly lower than agricultural villages, which had the highest prevalence of osteoarthritis (Canipe, 2014). This may support the hypothesis that communities relying on agriculture general show skeletal signs of greater activity than at urban sites such as Petra. However, the patterns seen at Salkhad with the greatest modifications seen in the *biceps brachii, triceps surae*, and the *quadriceps femoris* parallels that seen at Petra. This may indicate that while the Petra population buried on the North Ridge was not as active as that at Salkhad, the types of biomechanical movements they were engaged in were similar.

To get a broader temporal perspective from elsewhere in the region, the pattern of entheseal changes seen at Petra also were compared to the 2nd to 1st millennium urban Nubian sites of Tombos and Kerma (Schrader 2012, 2015). These studies utilized the Hawkey and Merbs method. At Tombos Schrader observed 12 fibrocartilaginous attachments and four fibrous attachments, and calculated mean scores by joint location (i.e., shoulder, elbow, wrist, hip, and knee). The Tombos sample had low levels of entheseal change in muscle attachments associated with the shoulder and knee and greater changes with the wrist and elbow based on mean scores. Petra also experienced low levels of entheseal change but instead had higher involvement in the lower limb entheses. Entheseal changes were also strongly influenced by sex in the Tombos sample, with males having a higher mean score at all joints than females. However, Petra showed little sexual dimorphism with no significant difference in mean scores between females and males. Schrader (2012) asserts that those buried at Tombos participated in less strenuous activities that relate to civic or political work, as the city had probably been an administrative center. Petra was also an urban center of trade and politics; therefore, it is possible the non-elite may have engaged in such activities.

The Kerma sample, however, did not represent the larger population but only chiefs and human sacrifices (Schrader 2015). Some of these sacrifices were interred near the graves of the chiefs, whereas others were located farther away in the mortuary context, within corridors. At Kerma, Schrader assessed 14 fibrocartilaginous entheses and five fibrous entheses using the Hawkey and Merbs method and compared the sacrificial burials (corridor and subsidiary) to the chief burials. The corridor sacrificial burials had higher mean scores than the subsidiary sacrificial burials. For both corridor and subsidiary sacrificial burials, males had higher mean scores than females. However, the male subsidiary sacrifices had mean scores similar to the chiefs. Schrader (2015) concluded that the subsidiary sacrifices were likely individuals that were high-ranking officials with a close sociopolitical relationship to the chief. Conversely, the corridor sacrifices were people of lower social status who had performed more labor-intensive tasks such as farming, construction, and trade transportation. The physical workload experienced by the non-elite of Petra is relatively similar to that conducted by the subsidiary sacrifices and chiefs of Kerma, rather than the corridor sacrificial burials. This could imply that those buried along the North Ridge held at least some considerable social standing in Petra.

The Petra pattern of entheseal changes also was compared to a site containing both urban and extra-urban components, the 9th century Great Moravian site of Mikulčice in the Czech Republic (Havelková et al., 2011). The site includes a fortified castle with at least ten churches with a hinterland surrounding the fortification. Individuals used for this study were buried near the churches and within the hinterland. It is considered an “extensive settlement agglomeration” that was a regional administrative hub (Havelková et al., 2011). The Villotte method was used to score 11 fibrocartilaginous attachments. The sample was divided between individuals buried in the hinterland, likely engaged in agriculture, and those buried within and around a church in the castle, containing not only the elite but also individuals involved in the maintenance and upkeep of the fortified settlement. Similar to Salkhad in Syria, the researchers found instances of more entheseal change in the upper limbs than lower limbs overall, in contrast to Petra’s pattern of higher mean scores in the lower limbs. In addition, sexual dimorphism in the scores varied based on burial location, with females buried in the castle having higher scores than males buried in the castle, yet males buried outside of the city had higher mean scores than females buried outside the city. The males buried at the castle exhibited the lowest levels of entheseal change.

Table 5.2: Comparison of score frequencies between females in Petra and the Mikulčice hinterland and castle by enthesis and side. Frequencies based on scores of any change.

		Petra		Mikulčice Hinterland Females[a]		Mikulčice Hinterland Males[a]		Mikulčice Castle Females[a]		Mikulčice Castle Males[a]	
Enthesis	**Side**	**N**	**Score 1 + 2 %**	**N**	**Stage B + C %**	**N**	**Stage B + C %**	**N**	**Stage B + C %**	**N**	**Stage B + C %**
HSC (*m. subscapularis*)	L	2	18.8	45	50.0	35	64.7	49	50.0	68	39.5
	R	1	25.0	45	45.0	35	75.0	49	54.5	68	33.3
HSI (*m. supraspinatus, m. infraspinatus*)	L	1	0	45	22.2	35	33.3	49	35.5	68	9.1
	R	3	4.2	45	5.6	35	60.0	49	42.9	68	35.5
RBB (*m. biceps brachii*)	L	18	26.4	45	50.0	35	72.7	49	46.4	68	52.8
	R	15	24.2	45	65.2	35	72.7	49	57.7	68	44.4
HEL (*common extensor origin*)	L	6	20.8	45	58.8	35	63.6	49	52.6	68	27.8
	R	6	18.8	45	38.5	35	63.6	49	55.0	68	35.3
FMF (*m. gluteus medius*)	L	2	25.0	45	30.0	35	25.0	49	29.2	68	25.0
	R	1	37.5	45	14.3	35	10.0	49	28.6	68	28.6
FPF (*m. gluteus minimus*)	L	1	50.0	45	6.7	35	50.0	49	33.3	68	21.9
	R	0	--	45	0	35	25.0	49	42.3	68	9.1
FIP (*m. iliopsoas*)	L	0	--	45	4.5	35	41.7	49	30.0	68	16.7
	R	1	25.0	45	14.3	35	36.4	49	17.9	68	23.7

[a] Havelková et al., 2011.

Since the methodology used for this study relies on a different scoring system, mean scores cannot be directly compared. As a consideration, it is difficult to properly compare the females and males from Petra against the Mikulčice sample because there is a large difference in sample size. The Petra sample has 76 female observations and 15 male observations, whereas Mikulčice has 94 females and 103 males with hinterland and castle combined (Table 5.2). Note, the sample sizes listed for Mikulčice are an assumption based on the article by Havelková et al. (2011), as samples per attachment site were not provided. Overall, Petra females exhibit less instances of entheseal change than both the castle and hinterland females, and the frequencies for Petra males lie either between the castle and hinterland males, or less than the castle and hinterland males. Havelková et al. (2011) note that females were likely not viewed equally with males in terms of social status during the 9th century, hence why the castle females and hinterland females exhibit similar distributions of entheseal change. On the other hand, Petra displays less discrepancy between females and males, which might lend towards the 1st century BC/AD Nabataeans females and males engaging in the same activities.

Therefore, the predominance of lower limb entheseal changes at Petra does not follow the typical patterns seen at more rural sites, particularly where people are involved in agriculture. As noted above, skeletal indicators of osteoarthritis made up the greatest frequency of lesions seen in the PNRP sample, however these individuals from Petra and other urban sites had lower overall frequencies than the pastoral nomads or the agricultural villagers. Osteoarthritis prevalence and severity cannot be linked directly to activity, as discussed in Chapter 2, as other factors such as age of the sample, genetics, injury, and sex all play a role in development of degeneration.

Observations of entheseal changes at Petra did not include individuals with osteoarthritis, as the presence of OA is a confounding factor and linked to development of enthesopathies. However, the patterns of osteoarthritis severity in the body does not quite parallel those of the enthesopathies, suggesting that different factors led to their development. For instance, the wrist was the most common location of osteoarthritic changes, affecting 43% of observable articular surfaces associated with this area (the distal radius and ulna, carpals, and the proximal metacarpal joint surfaces) (Canipe, 2014). Two entheseal attachments involving the hand and wrist, the *flexor carpi ulnaris* (involving the pisiform, hamate, and fifth metacarpal) and *flexor carpi radialis* (involving the second and third metacarpals), and their upper attachment point on the humerus, and the common extensor origin have rather average mean scores for the lower limb (Upper limb total means score = 1.7, *flexor carpi ulnaris* mean score = 1.8, *flexor carpi radialis* mean score = 1.0, common extensor origin mean score = 1.9). The entheses included in this study do not include those on elements showing joint degeneration, and thus if there is a common factor (i.e., activity) in the development of osteoarthritis and enthesopathies, then the mean scores of these attachment sites likely would increase with the inclusion of elements showing joint degeneration. However, the osteoarthritis frequencies in lower limb joints fall slightly above the upper limb joints (Canipe, 2014), a pattern seen in the enthesopathies. In addition, the pattern of lower limbs having greater entheseal changes than the upper limb at Petra is not seen in the other agricultural and urban populations used for comparison.

Summary

Assigning specific occupation types to entheseal changes should be avoided since one biomechanical movement can be used for multiple activities. However, providing insight into habitual biomechanical movements can reflect general patterns of physical activity. For this sample of 1st century BC/AD Nabataeans in Petra, the muscles with the highest mean scores are the *biceps brachii* in the upper limb, and the *triceps surae* in the lower limb (not including the entheses with small sample sizes). However, none of the entheseal attachments show dramatic changes, and even the ones with the highest mean scores are not notably higher than the other entheses. The upper limb entheses relate to the extension and flexion of the arm and wrist joints, while the lower limb entheses relates to the flexion of the knee and ankle joints. The entheseal changes present in the upper limb can be an indication of individuals lifting and carrying objects (Ibáñez-Gimeno et al., 2014). Those buried along Petra's North Ridge were not likely involved in maneuvering large and/or weighted objects. The entheseal changes seen in the lower limb probably coincide with habitual bipedal locomotion. Petra's landscape could lend to the lower limbs showing greater amounts of entheseal change, with its rocky and hilly terrain. There is evidence of non-elite Nabataeans sustained minor trauma to the ankles, wrists, and ribs that is related to falling (Perry, 2002). Entheseal changes on the leg likely occurred due to the individual's body adapting to traversing the rugged environment of the city. Considering that there were no significant differences in entheseal changes between the left and right sides overall and by sex, it can be asserted that the non-elite Nabataeans were not involved in activities that utilized one side of the body over the other.

There is little difference between female observations and male observations in terms of patterns of entheseal change, which is possibly due to the Nabataean cultural perspective of equal social status between men and women (Anderson, 2005). The physical activities conducted by the first century BC/AD Petra non-elite were being executed by men and women alike.

At the height of its power, Petra was an urban city of trade with political and religious authority (Schmid, 2002). Regarding the results of this research in comparison with other similar studies, it is plausible to assert that the non-elite population of 1st century BC/AD Nabataean Petra had engaged in civil, economic, or religious related activities without distinction between men and women. The non-elite, ordinary Nabataeans were not involved in heavy labor activities, only light labor at most. The legs were being used the most frequently, likely in part to habitual bipedal movement in combination with the uneven landscape. Women and men performed similar physical activities considering the cultural view of gender equality.

Chapter 6: Conclusions

Entheseal changes have been found to reflect levels of physical activity on a clinical level and have been utilized to reconstruct past human behaviors with some success. While the multifactorial etiology of entheses hinders identifying specific occupation types, generalized patterns of activity can still be inferred from the collection of these data. The sample of Petra's non-elite experienced only slight entheseal changes compared to other communities assessed here, with little evidence of sexual division of labor. In comparison to four other sites, three pre-industrial urban centers from different circum-Mediterranean contexts and one from an agricultural village in Syria (Havelková et al., 2011; Baker et al., 2012; Schrader, 2012, 2015), the Petra individuals were not participating in heavy-labor activities. The Petra sample did not display bilateral asymmetry as anticipated, however there were higher scores for the lower limb than the upper limb. The higher lower limb mean scores may be due in part to the small sample size of lower limb entheseal attachments observed compared to the upper limb.

The limited sample size of the PNRP tombs limits any interpretations made here. The largest problem stems from fragmentation of the remains, particularly at the articular ends where entheses are located. Degradation of subchondral bone at epiphyses lends to non-recordable entheses that are missing more than 50% or more of their surface area. Skeletal fragmentation also can hinder sex estimation, decreasing the sample size for assessment of sexual dimorphism. The commingling of the remains also made it difficult to provide individual-level analyses or any relationship between entheseal attachments and age.

More female observations than male observations were identified in the sample of bones that could be assessed for sex. While studies utilizing populations closer genetically and geographically to Jordan were preferred in selecting sex estimation techniques, in most cases the sex estimation techniques utilized here were based on U.S. populations. Past Middle Eastern populations tend to be more gracile and shorter than those in the modern U.S. (see Fryar et al., 2016; Rosenstock et al., 2015; Ruff et al., 2012), and thus any method based on measurements of U.S. populations may over-identify females within Middle Eastern samples.

Inter- and intra-observer error may also impact the scoring frequencies seen here. Several studies have found that inter- and intra-observer error can affect the subjective process of scoring of enthesopathies (Davis et al. 2013). The Coimbra method at this point divides the entheses space between two zones based solely on a description, although the zones for the *biceps brachii* have been published (Henderson et al., 2016) and publication denoting the zones for all fibrocartilaginous attachments is planned (Henderson et al., 2015; Henderson et al., 2016). Having a visual aid when scoring entheses will significantly decrease any inter- and intra-observer error.

Future research can include increasing the sample size by analyzing the skeletal remains recovered in the 1999 and 2016 seasons of the Petra North Ridge Project. In addition, further development of the Coimbra method may involve its application to commingled and fragmented remains, and the publication of more studies utilizing this method that can be compared to the Petra sample.

Reconstructing physical activity patterns are significant in understanding the social and economic dynamics of past societies. During the first century BC and first century AD, Petra was a major urban center and capital of the Nabataean Kingdom. Its economy was based largely on trade and some light manufacturing using local resources. The findings presented here confirm that people who were buried along the North Ridge had been working in the city, possibly involved with civic, administrative, and/or religious duties that would have been present during the height of the city. The daily lives of the non-elites of Petra can be better established with the continued analyses on the PNRP assemblages, whether the focus is on entheseal changes, physical activity patterns, or otherwise.

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APPENDIX A

Description of the Hawkey and Merbs method, adopted from Hawkey and Merbs (1995).

Musculoskeletal Stress Marker	**Definition**	**Score**
Robusticity	Rugged markings; most extreme expression as sharp ridges, or crests, of bone	0 = absent R1 = faint R2 = moderate R3 = strong
Stress lesion	Pitting, or 'furrow', into the cortex	0 = absent S1 = faint S2 = moderate S3 = strong
Ossification exostosis	Due to abrupt macrotrauma; results in an exostosis, or bony 'spur'	0 = absent OS1 = faint OS2 = moderate OS3 = strong

Description of the Mariotti method, adopted from Mariotti et al., (2004).

Enthesopathies	Definition	Score
Osteophytic formation (OF)	Characterized by the presence of enthesophytes	0 = absent 1 = minimal exostosis (<1mm) 2 = clear exostosis (1-4mm) 3 = substantial exostosis (>4mm) nr = not recordable
Osteolytic formation (OL)	Characterized by pitting or eroded areas	0 = absent 1 = presence of fine porosity (<1mm in diameter) 2 = diffuse porosity (1mm in diameter) or small area of erosion 3 = presence of several small areas of erosion (at least 4mm in diameter) or one extensive and deep osteolytic area (>4mm in diameter) nr = not recordable

Description of the Villotte method, adopted from Villotte (2006, 2009, 2012).

Enthesis Features	Definition	Types of Entheseal Change	Score
Outer Part	The margin the most distant from the acute angle formed by the tendon and the bone	Regular margin, salient or irregular, or enthesophyte(s)	0 = absent, regular margin 1 = minor, salient or irregular 2 = major, enthesophyte(s)
Inner Part	The remaining surface of the enthesis	Cyst, irregularity, foramina, bone production, osteoclastic and osteoblastic processes, erosion	0 = absent, regular surface, no foramina or cysts 1a = minor, the entire surface presents a slight irregularity 1b = minor, less than the half of the surface is affected by another type of change (bone production, erosion, etc.) 2 = major, more than half of the surface is affected by major changes

Description of Coimbra method, adopted from Henderson et al. (2015).

Zone	Feature	Abbreviation	Definition	Degrees of expression
Zone 1	Bone formation	BF (Z1)	See degrees of expression. Normal morphological smooth-rounded or mound-like (check by touching) margins, even if the margin is elevated, should be scored as 0	1 = distinct sharp demarcated new bone formation along the margin or other enthesophyte which does not meet the criteria for stage 2 in terms of size or extent 2 = distinct sharp demarcated new bone formation along the margin or other enthesophyte ≥1mm in elevation and ≥50% of margin affected by new bone formation
	Erosion	ER (Z1)	Depressions or excavations of any shape and involving discontinuity of the floor of the lesion greater in width than depth with irregular margins. Only erosions >1 mm, where you can clearly see the floor, were recorded. This does not include pores (i.e. rounded margins). Score erosions if they occur on bone formation.	1 = <25% of margin 2 = ≥25% of margin
Zone 2	Textural change	TC	A non-smooth, diffuse granular texture (with the appearance of fine grained sandpaper)	1 = covering >50% of surface
	Bone formation	BF (Z2)	Any bone production from roughness of surface to true exostoses (e.g. distinct bone projections of any form, like bony spurs, bony nodules and amorphous bone formation).	1 = distinct bone formation >1mm in size in any direction and affecting <50% of surface 2 = distinct bone formation >1mm in size in any direction and affecting ≥50% of surface
	Erosion	ER (Z2)	Depressions or excavations of any shape (but not covered by the definition of macro-porosity) and involving discontinuity of the floor of the lesion greater in width than depth with irregular margins. Only erosions >2mm were	1 = <25% of surface 2 = ≥25% of surface

		recorded. MPO or FPO occurring within an erosion should not be recorded separately. Bone formation is only scored if it exceeds the height of the depression (do not score woven bone). Score erosions if they occur on bone formation.	
Fine Porosity	FPO	Small, round to oval perforations with smooth, rounded margins <1 mm. These should be visible to the naked eye and be in a localized area. Do not score if they are at the base of an erosion or if they occur as part of woven bone.	1 = <50% of surface 2 = ≥50% of surface
Macro-porosity	MPO	Small, round to oval perforations with smooth, rounded margins about 1mm or larger in size with the appearance of a channel, but the internal aspect is rarely visible. Do not score if they are at the base of an erosion.	1 = one or two pores 2 = >2 pores
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

APPENDIX B

Sample of the data collection form used for this study, created by author.

Observer: ___________________________________ Date: _______________

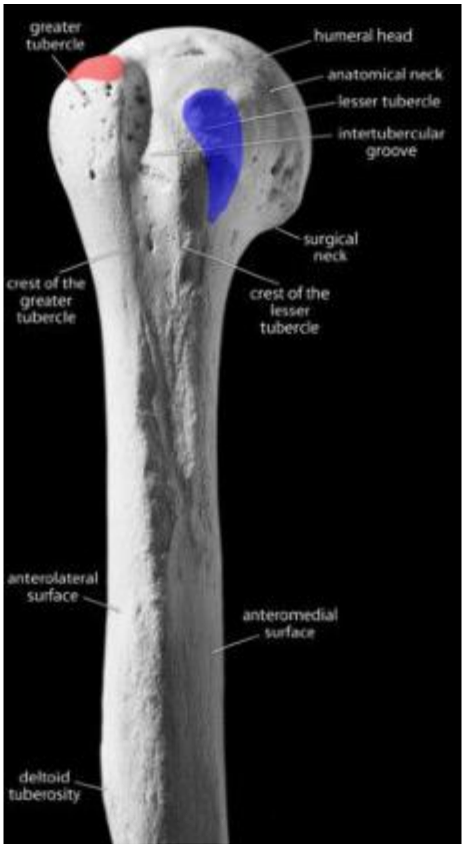
Site Number: ____________________ Burial Number: ____________________________________

Element: _______________________ Muscle Attachment: _________________________________

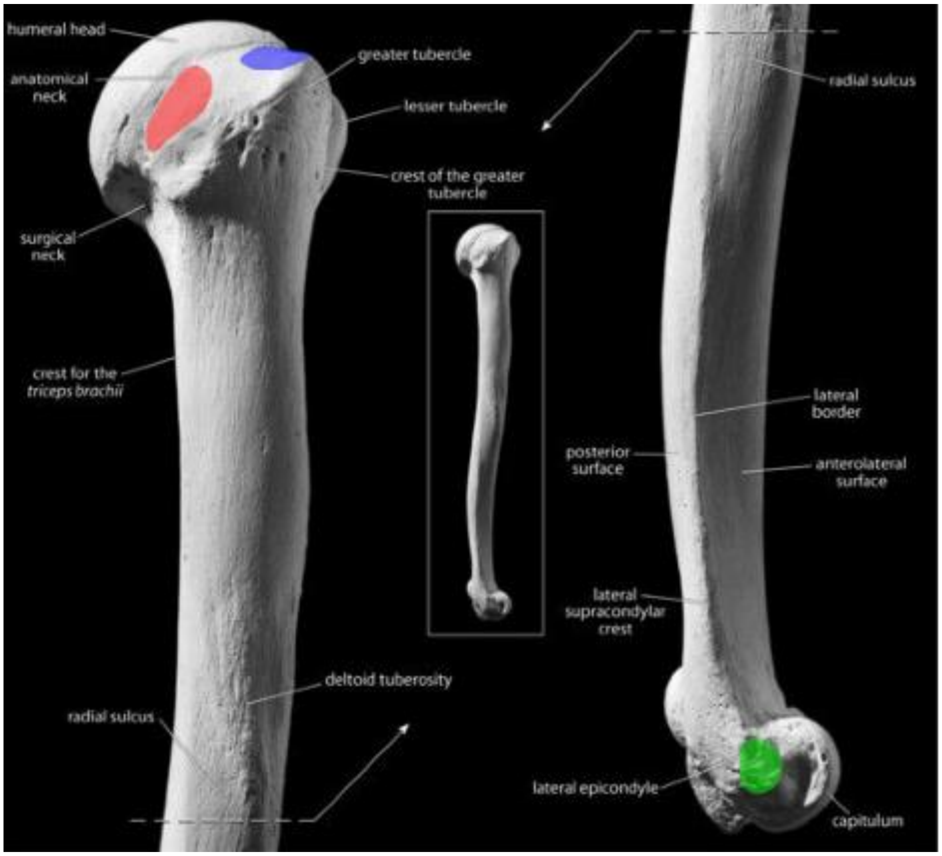
Zone	**Feature**	**Degree of Expression**
Zone 1	Bone formation (BF)	
	Erosion (ER)	
Zone 2	Textural Change (TC)	
	Bone formation (BF)	
	Erosion (ER)	
	Fine porosity (FPO)	
	Macro-porosity (MPO)	
	Cavitation (CA)	

APPENDIX C

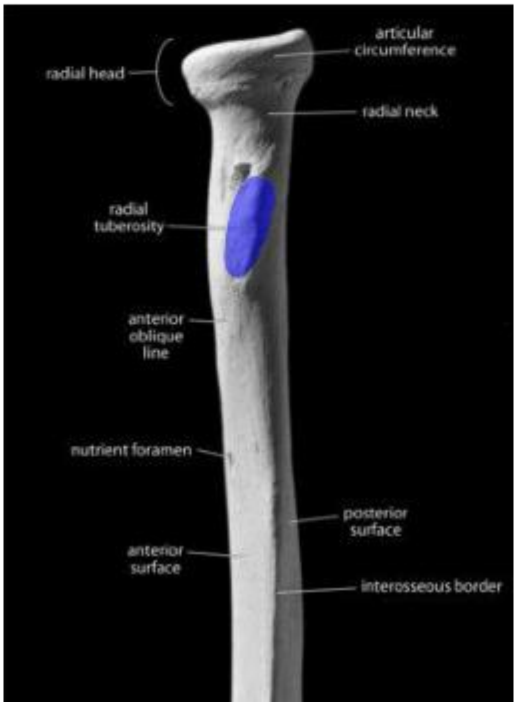
Presented here are images that display each enthesis used in this research by element. Original images are from: White TD, Black MT, Folkens PA. 2011. Human osteology, third edition. United States: Academic Press. Modifications are made by the author.



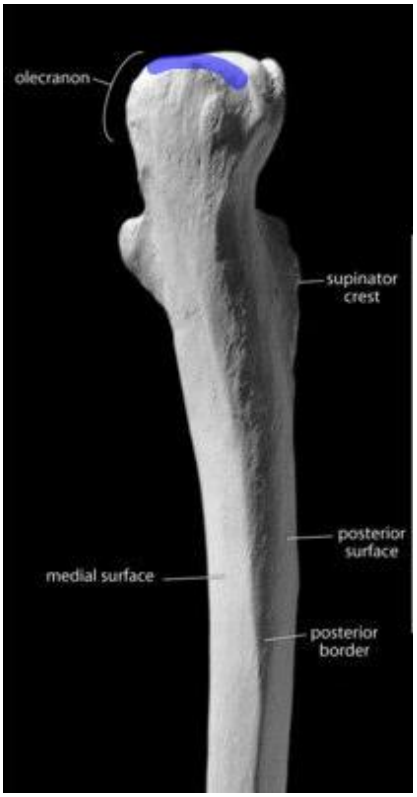
Right humerus, anterior view, proximal. Blue: *m. subscapularis*; red: *m. supraspinatus*.



Right humerus, lateral view, proximal and distal. Blue: *m. supraspinatus*; red: *m. infraspinatus*; green: common extensor origin.

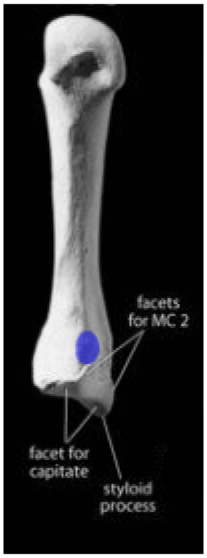


Right radius, medial view, proximal. Blue: *m. biceps brachii*.

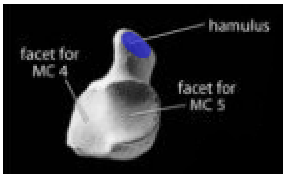


Right ulna, posterior view, proximal. Blue: *m. triceps brachii*.

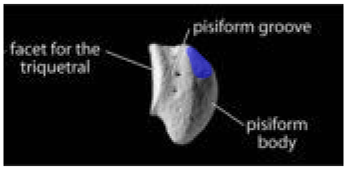
Right MC2, anterior view, distal end is up. Blue: *m. flexor carpi radialis*.



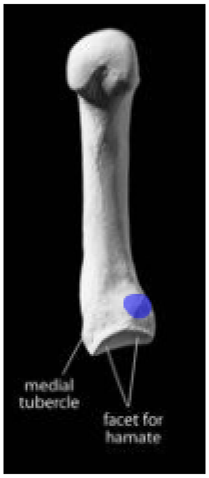
Right MC3, anterior view, distal end is up. Blue: *m. flexor carpi radialis*.



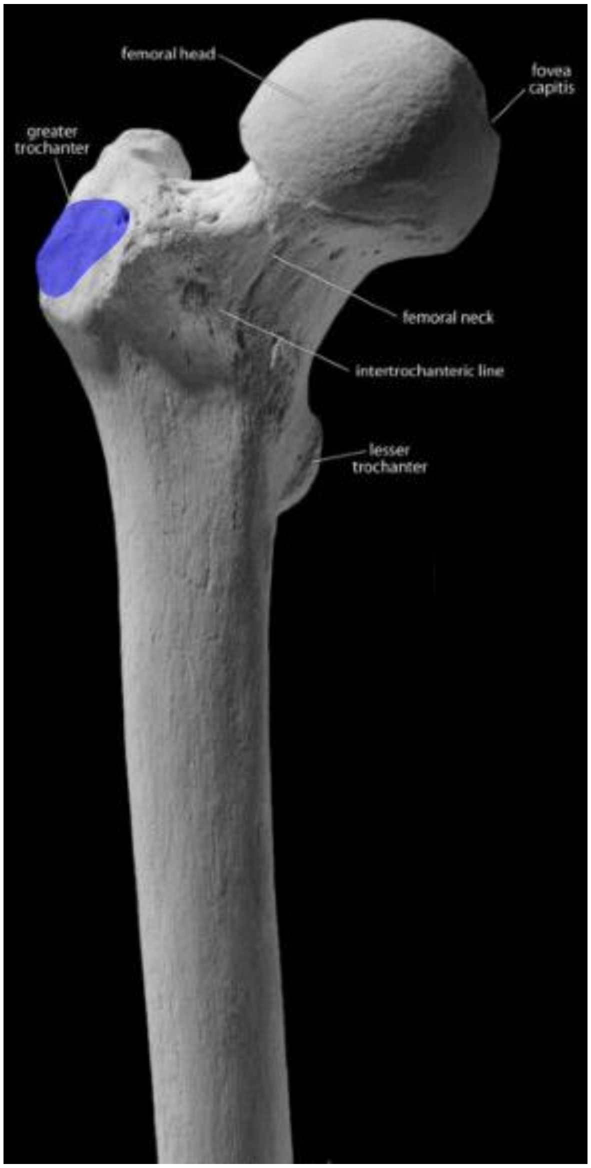
Right hamate, distal view. Blue: *m. flexor carpi ulnaris*.



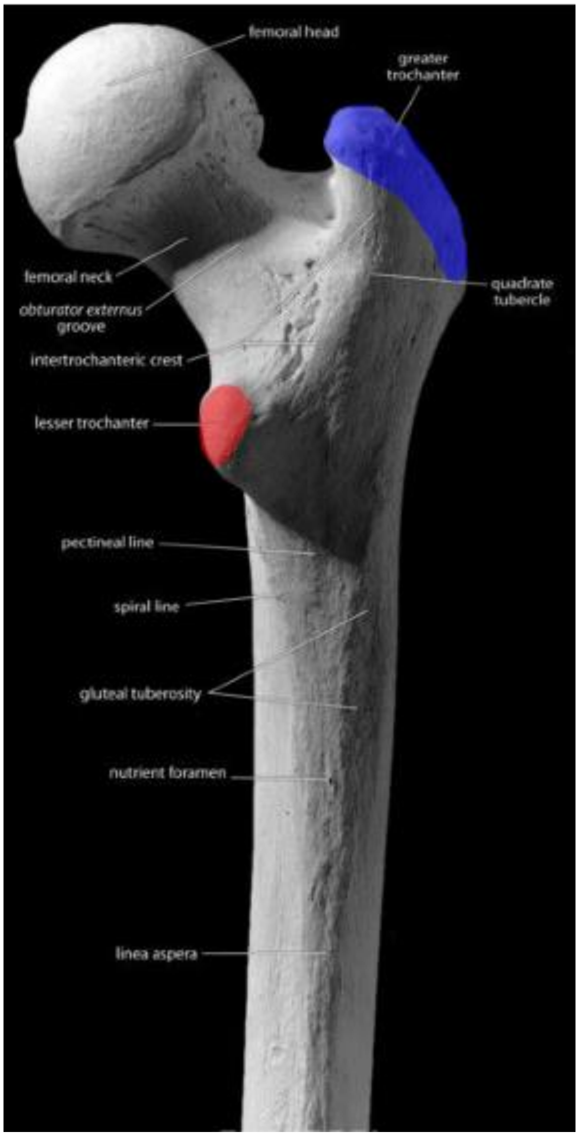
Right pisiform, lateral view. Blue: *m. flexor carpi ulnaris*.



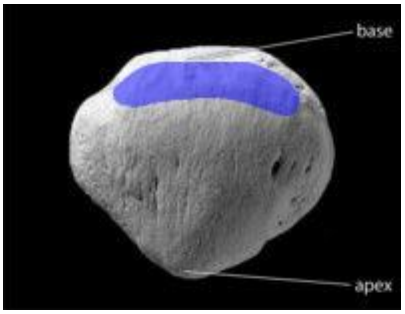
Right MC5, anterior view, distal end is up. Blue: *m. flexor carpi ulnaris*.



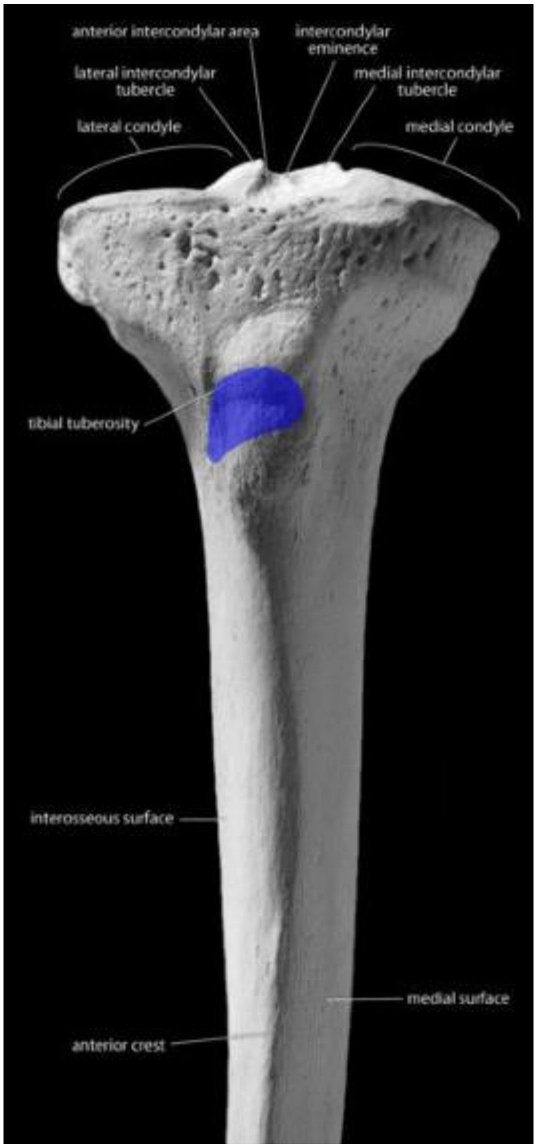
Right femur, anterior view, proximal. Blue: *m. gluteus minimus*.



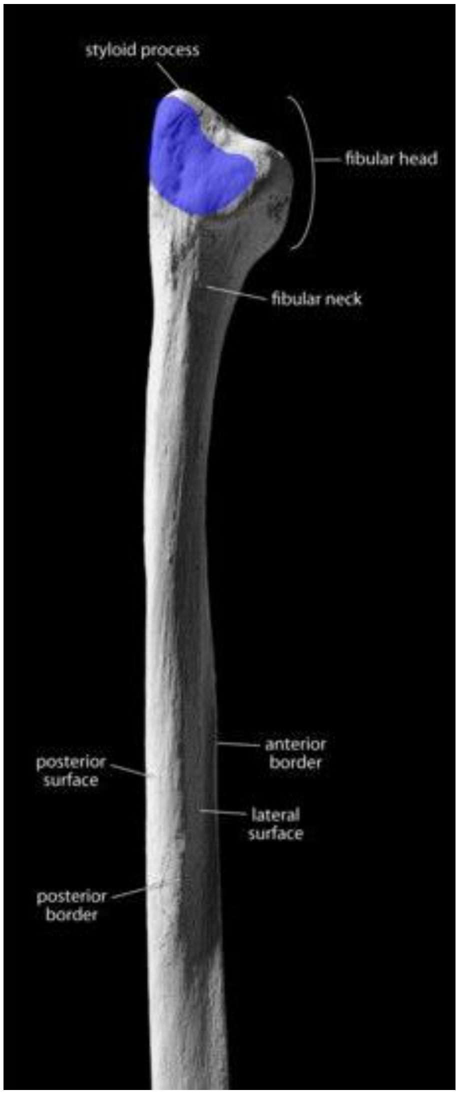
Right femur, posterior view, proximal. Blue: *m. gluteus medius*; red: *m. iliopsoas*.



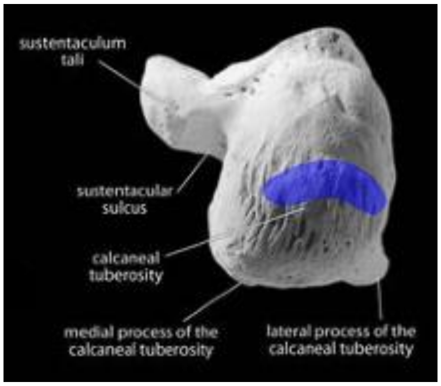
Right patella, anterior view. Blue: *m. quadriceps femoris*.



Right tibia, anterior view, proximal. Blue: *m. quadriceps femoris*.



Right fibula, lateral view, proximal. Blue: *m. biceps femoris*.



Right calcaneus, posterior view. Blue: *m. triceps surae*.

APPENDIX D

Measurements on the humerus for sex determination.

Sex	Burial Number	Side	Enthesis	Trochclear Constriction (Rogers, 1999)	Trochclear Symmetry (Rogers, 1999)	Olecranon Fossa (Rogers, 1999)	Angle of Medial Epicondyle (Rogers, 1999)	Epicondylar Breadth	Transverse Head Diameter	Vertical Head Diameter
Female	B.6:39	L	Common extensor origin	constricted	symmetrical	oval	tilt	60mm		
Female	B.6:39	R	Common extensor origin	constricted	symmetrical	oval	tilt	56mm		
Female	B.6:43	L	m. subscapularis, m. supraspinatus, m. infraspinatus						37.77mm	45.30mm
Female	B.6:43	L	Common extensor origin	constricted	symmetrical	oval	tilt	57mm		
Female	B.6:44	L	Common extensor origin	constricted	symmetrical	oval	tilt	55m		
Female	B.7:25	R	Common extensor origin					56mm		
Female	B.7:33 Skel #1	R	m. subscapularis, m. supraspinatus, m. infraspinatus						42.12mm	45.42mm
Male	B.5:32	R	Common extensor origin	not constricted	asymmetrical	triangular	parallel	61mm		
Male	B.7:34	L	Common extensor origin	not constricted	asymmetrical			61mm		

Measurements on the radius for sex determination.

Sex	Burial Number	Side	Enthesis	Maximum Radial Head Diameter (Berrizbeitia, 1989)	Minimum Radial Head Diameter (Berrizbeitia, 1989)	Maximum Length	Anterior-Posterior Diameter at Midshaft	Medial-Lateral Diameter at Midshaft
Male	B.6:28	R	m. biceps brachii	23.86mm	22.96mm			
Female	B.6:37	R	m. biceps brachii	19.69mm	17.96mm			
Female	B.6:39	L	m. biceps brachii	20.32mm	18.67mm			
Female	B.6:41	L	m. biceps brachii	18.68mm	18.43mm			
Female	B.7:20	L	m. biceps brachii	20.80mm				
Female	B.7:20	R	m. biceps brachii	20.20mm		235mm	11.11mm	13.78mm

Measurements for sex determination on the ulna.

Sex	Burial Number	Side	Enthesis	Anterior-Posterior Diameter at Midshaft	Medial-Lateral Diameter at Midshaft	Minimum Circumference
Male	B.6:43	R	m. triceps brachii	13.52mm	13.75mm	
Female	B.7:20	R	m. triceps brachii	12.05mm	16.79mm	38mm

Measurements on the hand (MC2, MC3, MC5) for sex determination.

Sex	Burial Number	Element	Side	Enthesis	Maximum Length	Medio-Lateral Diameter of Distal Epiphysis	Antero-Posterior Diameter of Distal Epiphysis	Medio-Lateral Diameter at Midshaft	Antero-Posterior Diameter at Midshaft	Medio-Lateral Diameter of Proximal Epiphysis	Antero-Posterior Diameter of Proximal Epiphysis
Female	B.7:20	MC2	L	m. flexor carpi radialis	68.86mm	11.22mm	13.47mm	7.89mm	8.67mm	16.43mm	11.69mm
Female	B.7:33	MC2	L	m. flexor carpi radialis	64.88mm	10.47mm	12.72mm	8.02mm	7.83mm	14.09mm	10.77mm
Female	B.6:23	MC2	L	m. flexor carpi radialis						12.69mm	8.27mm
Female	B.5:34	MC2	L	m. flexor carpi radialis						17.15mm	12.33mm
Female	B.5:35	MC2	L	m. flexor carpi radialis						12.16mm	9.28mm
Female	B.5:35	MC2	L	m. flexor carpi radialis						16.33mm	10.58mm
Female	B.6:41	MC3	L	m. flexor carpi radialis						7.63mm	13.96mm
Female	B.5:32	MC3	L	m. flexor carpi radialis						7.62mm	16.35mm
Female	B.5:35	MC3	L	m. flexor carpi radialis						11.83mm	16.29mm
Female	B.6:23	MC3	L	m. flexor carpi radialis						8.91mm	16.47mm
Female	B.6:23	MC3	L	m. flexor carpi radialis	54.31mm	7.91mm	11.04mm	6.09mm	6.85mm	7.87mm	13.22mm
Female	B.5:32	MC3	L	m. flexor carpi radialis						7.91mm	14.98mm
Female	B.5:35	MC3	L	m. flexor carpi radialis						11.84mm	16.39mm
Female	B.5:35	MC3	L	m. flexor carpi radialis						9.65mm	16.03mm
Female	B.6:39	MC5	L	m. flexor carpi ulnaris						10.14mm	9.61mm
Female	B.7:33 Skel#1	MC5	L	m. flexor carpi ulnaris						10.61mm	10.12mm
Female	B.7:33 Skel#1	MC5	L	m. flexor carpi ulnaris	58.47mm	9.91mm	12.27mm	7.09mm	7.38mm		8.84mm
Female	B.7:20	MC2	R	m. flexor carpi radialis	70.12mm	13.38mm	13.02mm	8.08mm	8.79mm	15.93mm	9.35mm
Female	B.7:33	MC2	R	m. flexor carpi radialis	66.03mm	10.93mm	13.03mm	8.47mm	8.77mm	15.21mm	10.87mm
Female	B.5:34	MC2	R	m. flexor carpi radialis						17.17mm	12.16mm
Female	B.6:27	MC2	R	m. flexor carpi radialis						12.14mm	9.52mm

Female	B.7:34	MC2	R	m. flexor carpi radialis						15.51mm	10.24mm
Female	B.5:35	MC2	R	m. flexor carpi radialis						12.84mm	13.72mm
Female	B.5:35	MC2	R	m. flexor carpi radialis						15.02mm	12.04mm
Female	B.5:32	MC2	R	m. flexor carpi radialis						17.04mm	13.68mm
Female	B.7:20	MC3	R	m. flexor carpi radialis	67.89mm	11.28mm	12.99mm	9.03mm	9.13mm	9.66mm	13.97mm
Female	B.5:32	MC3	R	m. flexor carpi radialis						10.39mm	17.51mm
Female	B.6:34	MC3	R	m. flexor carpi radialis						9.21mm	12.76mm
Female	B.7:33	MC3	R	m. flexor carpi radialis	62.51mm	9.61mm		8.53mm	8.46mm	9.52mm	13.76mm
Female	B.5:35	MC3	R	m. flexor carpi radialis	64.11mm	10.14mm	14.17mm	8.10mm	9.79mm	8.89mm	
Female	B.6:23	MC3	R	m. flexor carpi radialis						9.48mm	14.70mm
Female	B.6:44	MC3	R	m. flexor carpi radialis						10.28mm	15.10mm
Female	B.5:35	MC3	R	m. flexor carpi radialis	60.09mm	10.91mm	13.61mm	7.83mm	9.01mm	7.68mm	17.23mm
Female	B.6:23	MC3	R	m. flexor carpi radialis						10.77mm	17.35mm
Female	B.5:35	MC3	R	m. flexor carpi radialis						8.44mm	14.66mm
Female	B.6:23	MC3	R	m. flexor carpi radialis						8.59mm	12.11mm
Female	B.6:23	MC5	R	m. flexor carpi ulnaris						13.27mm	8.34mm
Female	B.6:31	MC5	R	m. flexor carpi ulnaris	47.35mm	8.24mm		6.51mm	5.87mm	9.58mm	7.23mm
Female	B.7:20	MC5	R	m. flexor carpi ulnaris						11.86mm	11.52mm
Female	B.5:19	MC5	R	m. flexor carpi ulnaris						12.85	9.66
Female	B.4:23	MC2	L	m. flexor carpi radialis						17.09	16.32
Female	B.5:19	MC2	L	m. flexor carpi radialis						14.87	17.16
Female	B.4:23	MC3	L	m. flexor carpi radialis						14.19	16.09
Male	B.7:20	MC3	L	m. flexor carpi radialis	67.72mm	10.51mm	13.17mm	9.05mm	9.28mm	10.25mm	15.11mm
Male	B.5:32	MC5	L	m. flexor carpi ulnaris	57.62mm	12.48mm	14.18mm	7.60mm	7.10mm	12.84mm	10.13mm
Male	B.6:23	MC5	L	m. flexor carpi ulnaris	51.44mm	9.56mm	11.03mm	7.47mm	6.47mm	13.52mm	8.58mm
Male	B.7:20	MC5	L	m. flexor carpi ulnaris	54.81mm	8.74mm	10.61mm	9.29mm	6.60mm	11.97mm	11.11mm
Male	B.5:33	MC5	L	m. flexor carpi ulnaris	50.55mm	11.59mm	12.89mm	9.16mm	8.77mm	14.07mm	11.21mm
Male	B.4:23	MC2	L	m. flexor carpi radialis						18.93	15.43
Male	B.4:23	MC3	L	m. flexor carpi radialis						14.77	17.59

Male	B.4:22	MC3	R	m. flexor carpi radialis	61.58	13.99	14.42	9.14	10.89	13.54	15.76
Male	B.4:17	MC5	R	m. flexor carpi ulnaris	57.06	12.21	12.55	7.97	7.64	15.89	11.97
Male	B.4:17	MC5	R	m. flexor carpi ulnaris						15.62	13.23

Measurements on the femur for sex determination.

Sex	Burial Number	Side	Enthesis	Maximum Head Diameter
Female	B.5:35	L	m. gluteus medius	42.11mm
Female	B.6:28	L	m. gluteus medius	38.89mm

Measurements on the tibia for sex determination.

Sex	Burial Number	Side	Enthesis	Maximum Diameter at Nutrient Foramen	Medial-Lateral Diameter at Nutrient Foramen	Circumference at Nutrient Foramen
Female	B.5:34	R	m. quadriceps femoris	28.09mm	19.84mm	78mm

Measurements on the calcaneus for sex determination.

Sex	Burial Number	Side	Enthesis	Maximum Length	Middle Breadth
Male	B.6:28	R	m. triceps surae	88.95mm	41.80mm
Female	B.5:32	L	m. triceps surae	69.85mm	38.83mm
Female	B.6:23	R	m. triceps surae	72.62mm	38.53mm
Female	B.6:28	L	m. triceps surae	75.26mm	43.33mm
Female	B.6:28	L	m. triceps surae	78.55mm	36.47mm
Female	B.6:28	L	m. triceps surae	76.97mm	40.35mm
Female	B.6:28	R	m. triceps surae	79.05mm	35.43mm
Female	B.7:34	L	m. triceps surae	76.89mm	39.08mm
Female	B.5:32	L	m. triceps surae	80.25mm	
Female	B.5:32	R	m. triceps surae	72.30mm	
Female	B.6:28	L	m. triceps surae	81.77mm	
Female	B.7:33 Skel #1	R	m. triceps surae		37.49mm