Entheseal Changes in an Ancient Egyptian Skeletal Collection

M.A. Thesis Proposal

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Abstract

The purpose of this study is to examine the effects of age, sex, and body size on entheseal changes in an ancient Egyptian skeletal collection. Entheseal changes have been widely considered to reflect past activity patterns. However, recent bioarchaeological and biomedical research has shown biological factors to be correlated with the morphological changes that occur at the entheses (Milella et al. 2015; Nolte and Wilczak 2013; Wilczak 1998; Benjamin et al. 2008; Foster et al. 2014). This study utilizes the Coimbra method (Henderson et al. 2013, 2015) to score six fibrocartilaginous entheses: infra and supraspinatus, subscapularis insertion, common flexor origin, common extensor origin, and biceps brachii insertion.

Introduction

The primary goal of this research is to examine the effects of biological factors on entheseal changes of an ancient Giza, Egypt skeletal collection. This project will build upon previous research that examines the effects of biological factors on entheseal change using the Coimbra method (Henderson et al. 2013, 2015). Effects of age, sex and body size on six fibrocartilaginous entheses will be tested for this project. Previous findings have shown a strong correlation between age and entheseal changes (Villotte and Knusel 2013; Milella et al. 2012; Henderson et al. 2012), as well as a correlation between sex and entheseal changes (Milella et al. 2012; Nolte and Wilczak 2013). Based on those previous studies, it is hypothesized that there will be statistically significant correlations between age, sex and entheseal changes found within this particular skeletal sample. In using a relatively new method for recording entheseal changes, and on a skeletal sample in which entheseal changes has yet to be examined, this research will contribute to the discussion of usability of this particular method across populations and skeletal samples and on which entheseal changes may be more related to biological factors versus mechanical factors.

Recent biomedical research looking at biomechanical effects on enthesis etiology and development has influenced the ways in which bioarchaeologists are examining entheseal changes (Benjamin and McGonagle 2009; Benjamin et al. 2008). Such research is directly applicable to discussions of past activity patterns and occupations that are often expected to be reflected in morphological changes and variation seen on skeletal remains, particularly at the entheses. By incorporating research from biomedicine, bioarchaeolgy, and archaeology, we can glean a better understanding of the multifactorial etiologies of entheses. This research project aims to be beneficial towards future analyses of the human skeletal collection from Giza and to provide insight on biological factors effecting entheseal changes seen on these individuals. Such information can be utilized in further discussions of biomechanical effects on entheseal change, and contribute to bioarchaeological reconstructions of past lifeways.

Background

Entheseal change research in bioarchaeology has been widely applied in reconstruction of past activity patterns and occupational stressors. Early studies examined musculoskeletal stress markers (MSM) and markers of occupational stress (MOS) as being directly reflective of various physical activities and occupations (Kennedy 1983; Lawrence et al. 1987; Kelley and Angel 1987; Hawkey and Merbs 1995; Hawkey 1998).

These studies examined the morphological changes and variation seen at tendon and ligament attachment sites using a variety of qualitative methods to discuss the ways in which bone responds to repeated physical stressors. Kennedy (1983) was among the first to describe MOS and the applicability of forensic methodology in identifying individuals and characteristics such as handedness in bioarchaeological analyses of individuals' physical activities during life. Following Kennedy (1983), Lawrence and colleagues (1987) conducted a study that similarly used morphological changes to describe occupational stressors seen on individuals excavated from the First African Baptist Church in Philadelphia. This paper looked at general variation of a few upper and lower limb tendon and ligament attachment sites, citing Kennedy's (1983) study looking at supinator crest variation.

Hawkey and Merbs (1995) were applied a method that was initially developed by Hawkey (1988) to look at MSM in a Hudson Bay Eskimo population. They looked at three specific characteristics of muscle attachment sites that were separately scored on a scale of 0-3. The variation seen within this population were interpreted as being indicative of gendered division of labor, which continues to be a recurring area of interest for bioarchaeologists looking at MSM, or entheseal changes. These earlier studies evolved from considering general variations or changes observed at muscle attachment sites, to recognizing more specific changes that could be examined as separate features. These changes and variations also began to be viewed as caused by a combination of habitual muscle strain (microtrauma) and possible overuse injuries (macrotrauma). Such research set a foundation for identification of more specific changes and further investigation into the multifactorial etiology of entheseal changes.

Since the Hawkey and Merbs (1995) study, a couple of other methods have been developed to score and record entheseal changes. Mariotti and colleagues (2007) developed a scoring system for 23 different entheses that looked at variations in robusticity, enthesophytes, and enthesopathies. Robusticity has been a commonly observed feature in entheseal change research, which has been considered to be a good indicator of bone remodeling via mechanical stressors and physical activity. However, more recent studies and methods have sought to refine the ways in which entheseal changes are scored, and look closely at more specific features with varying expressions of change. Villotte (2006) developed a method that separated the two different types of entheses, fibrous and fibrocartilaginous. This distinction between types of entheses has been explored in biomedical literature and is important because the two types attach to bone differently, thereby responding to mechanical or biological factors differently as well (Benjamin and Ralphs 1998; Benjamin et al. 2002; Benjamin et al. 2008). Villotte (2006) observed this difference in his method, and further acknowledged two different zones of fibrocartilaginous entheses that is also observed in the Coimbra method.

In 2009 researchers who had been involved in MSM research met at the University of Coimbra in Portugal to review past research and work towards developing a more effective methodology and terminology for future research. Researchers at this meeting divided up into three working groups: methodology, terminology, and occupation. The methodology working group developed the first phase of the Coimbra method, which was revised during a second meeting in 2013 by altering some definitions and terminology to improve overall usability and rates of inter and intra-observer agreement (Henderson et al. 2013, 2015, 2016; Wilczak et al. 2017). This method looks at a series of features specifically on fibrocartilaginous entheses and was applied in looking for correlations between variations of features and biological factors such as age. The terminology working group concluded that entheseal changes was more appropriate than musculoskeletal stress markers in that musculoskeletal stress markers implies a mechanical, physical activity etiology, which may not necessarily be the case for all changes and variations observed at the entheses. The occupation working group worked towards developing a standard protocol for grouping occupations based on socio-cultural criteria and physical activity criteria.

An important component within past and present entheseal change research in bioarchaeology is the integration of biomedical research to better understand entheses and how the soft tissue interacts with bone. Benjamin and various colleagues have published papers since the 1980s through to 2009 that have been largely informative for bioarchaeologists (Benjamin et al. 1986, 1992, Benjamin and Ralphs 1998; Benjamin and McGonagle 2001, 2009; Benjamin et al. 2002, 2004, 2006, 2008, 2009). Such articles have explored various effects on entheses such as age, disease and different levels of physical activity, as well as described the different ways in which both fibrous and fibrocartilaginous entheses attach to bone. Many other biomedical researchers have published articles that similarly describe entheses and potential factors contributing to enthesis development, all of which have been practical for bioarchaeologists seeking to understand the multifactorial etiology of entheseal changes in the archaeological record (Cooper and Misol 1970; Dorfl 1980; Grant et al. 1981; Hurov 1986; Apostolakos et al. 2014).

In light of this research, my aim will be to apply the most recent research method to characterize entheseal changes in skeletal remains from Giza, Egypt. The archaeological research of George A. Reisner, original collector of this skeletal collection, contributed to the context of the individuals utilized for this study. Reisner conducted excavations in Giza during the early 1900's, known as the "Hearst Expedition of the University of California," (Reisner 1942). These excavations took place over the course of 33 years, and the cultural materials as well as human remains are all currently housed at the University of California, Berkeley.

Methods

The ancient Giza, Egypt skeletal collection housed at the Phoebe A. Hearst Museum ad the University of California, Berkeley will be utilized for this project. It is projected that approximately thirty individuals will be utilized for this analysis. It is currently unknown how many males and females will be represented in this sample, and the sample size is subject to change upon further examination of the collection. Six upper limb fibrocartilaginous entheses will be scored and recorded on each individual: infraspinatus, supraspinatus, subscapularis insertion, biceps brachii insertion, common flexor origin, and the common extensor origin. Age-at-death, sex, and body size to determine sexual dimorphism will also be recorded. Statistical analysis using SPSS software will be performed to test for effects of age and sex on entheseal changes. Other components of this analysis will be looking at asymmetry alongside entheseal change, in order to better assess effects of age and sex and to consider biomechanical effects. Body size effects on entheseal changes will be tested from measurements of the upper limb bones to account for sexual dimorphism.

The Coimbra method will be the primary method employed in this study, and will be used to record entheseal changes. This method is a scoring system that considers features of the fibrocartilaginous entheses individually, and each attachment site is divided into two zones for separate scoring (Henderson et al. 2015; 2013; 2010; Wilczak et al. 2017). Zone 1, or the margin of the enthesis, is defined as the most distant from the acute angle formed by the intersection of tendon and bone, and zone 2 is the remainder of the tendon attachment surface (Villotte 2013). Each zone expresses different characteristics of changes (Henderson et al. 2015; 2016). A series of features on each zone of the enthesis are assessed and assigned a score of 0, 1, or 2 depending on the degree of expression except for textural change, which is scored as 0 or 1. For zone 1, the features that are scored are bone formation and erosion. For zone 2, the features that are scored are textural change, bone formation, erosion, fine porosity, macro-porosity, and cavitation. This researcher has undergone proper training on using the Coimbra method from one of the original developers, Dr. Cynthia Wilczak.

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

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

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

Body size is considered in this study in order to discuss sexual dimorphism and asymmetry in this skeletal sample. These body size values will be determined using body size proxies calculated from osteometric measurements of the upper limb (Nolte and Wilczak 2013; Wilczak 1998). The following osteometric measurements will be taken: maximum length of the humerus; vertical head diameter of the humerus; distal articular breadth of the humerus; maximum length of the radius; and head diameter of the radius using both medial-lateral and anterior-posterior measurements. The body size measurements will be compared against the entheseal change scores in order to test for the strength of a correlation between the body size measurements and entheseal change score.

Several statistical procedures have been used to analyze data recorded using the Coimbra method. The methodology group from the original Coimbra workshop is currently reviewing the best strategies for these analyses (pers. comm. Wilczak). All statistical analyses will be undertaken upon consultation with the methodology working group.

Expected Findings

The hypothesis of this study is that there will be statistically significant effects of age and sex on entheseal change. This is to say that individuals of older ages will exhibit higher rates of normal, non-pathological change to the entheses. It is also expected that males will show higher rates of entheseal change than females. It is possible that age and sex correlations will differ between features of the entheses. For example, recent studies in historic European populations have shown strong correlations between bone formation and age (Henderson et al. 2015; Henderson et al. in press.). However, given that this is an entirely different population used in this study, there may be correlations seen with different features and biological factors.

It is hypothesized that this skeletal sample will show evidence of asymmetry, which may indicate that mechanical stressors and levels of physical activity could be effecting entheseal change. The results will provide information as to what types biomechanical factors are effecting entheseal change within this ancient Egyptian population, and will further be compared against past studies that have used the Coimbra method to discuss potential population differences.

Schedule

May 2017	**June 2017**	**July 2017**	**August 2017**	**Sept. 2017**	**Oct. 2017**	**Nov. 2017**	**Dec. 2017**	**Jan. 2018**	**Feb. 2018**
Submit final draft of Methods chapter	Submit finished 1st draft of Literature Review chapter	Submit 2nd draft of Lit. Review Chapter	Submit 1st draft of Intro. chapter	Begin statistical analysis of data	Continue work on data analysis	Submit Results chapter	Submit 1st draft of complete thesis	Submit 2nd draft of complete thesis	Submit 3rd draft of thesis
Continue work on first draft of Lit. Review chapter	Data collection at Phoebe A. Hearst Museum	Begin work on Intro. chapter	Submit final draft of Literature Review chapter	Add in statistical analysis section to Methods chapter	Submit final draft of Intro. chapter	Submit Discussion chapter			
			Submit Materials section	Submit second draft of Intro. chapter					

Committee

Chair: Dr. Cynthia Wilczak

Second Committee Member: Dr. Mark Griffin

LITERATURE CITED

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

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

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

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

Alves Cardoso, F., Henderson, C. 2013. The Categorisation of Occupation in Identified Skeletal Collections: A Source of Bias? *International Journal of Osteoarchaeology* 23(2):186-196.

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

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

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

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

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

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

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

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

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

Benjamin, M., H. Toumi, J.R. Ralphs, G. Bydder, T.M. Best, S. Milz. 2006. Where tendons and ligaments meet bone: attachment sites ('entheses') in relation to exercise and/or mechanical load. *Journal of Anatomy* 208(4): 471-490.

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

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

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

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

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

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

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

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

Chen, XP, ZY Zhang, GY Zhu, and LY Tao. 2011. Determining the Age at Death of Females in the Chinese Han Population: Using Quantitative Variables and Statistical Analysis From Pubic Bones. *Forensic Science International* 210 (1-3): 278.
Chew, ML and BM Giuffre. 2005. Disorders of the Distal Biceps Brachii Tendon. *RSNA RadioGraphics* 25(5):1227-1237.

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

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

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

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

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

Eshed, V, A Gopher, E Galili, and I Hershkovitz. 2007. Musculoskeletal stress markers in Natufian hunter-gatherers and Neolithic farmers in the Levant: The upper limb. *American Journal of Physical Anthropology* 123(4): 303-315.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Henderson CY, Mariotti V, Santos F, Villotte S, Wilczak C. (in press) The new Coimbra method for recording entheseal changes and the effect of age-at-death. Bulletins et Mémoires de la Société d'Anthropologie de Paris.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Milner, G. Transition Analysis Scoring Procedures Version 1.01. Fordisc documentation. Downloaded from: http://math.mercyhurst.edu/~sousley/Software/
Milz, S, R Putz, JR Ralphs, and M Benjamin. 1998. Fibrocartilage in the extensor tendons of the human metacarpophalangeal joints. *The Anatomical Record* 256(2):139-145.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Todd, TW and DW Lyon Jr. 1925. Cranial Suture Closure, Its Progress and Age Relationship Part II. Ectocranial Suture Closure in Adult Males of White Stock. *American Journal of Physical Anthropology* 8: 23-45
Ubelaker, D and C Volk. 2002. A Test of the Phenice Method for the Estimation of Sex. *Journal of Forensic Sciences* 47(1): 19-24.
Villotte, S. Assis, S. Alves Cardoso, F. Henderson, C. Mariotti, V. Milella, M. Pany Kucera, D. Speith, N. Wilczak, C. and Jurmain, R. 2016. In search of consensus: terminology for entheseal changes (EC). *International Journal of Paleopathology* 13: 49-55.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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