DOI

10.1016/j.ijpp.2019.08.005

International Journal of Paleopathology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Paleopathology

journal homepage: www.elsevier.com/locate/ijpp

Osteoarthritis, entheses, and long bone cross-sectional geometry in the Andes: Usage, history, and future directions

Sara K. Becker*

Department of Anthropology, University of California Riverside, 1334 Watkins Hall Riverside, CA 92521, USA

ARTICLE INFO

Keywords:
Cross-sectional bone geometry
Musculoskeletal stress markers
Activity
Biomechanics
Stress
Multivariate statistical methods

ABSTRACT

Akin to approaches encouraged by Verano (1997) in the Andes, and Ortner (2011, 2012) for general paleopathological studies, this article focuses on accurate descriptions and definitions of osteoarthritis, entheses, and long bone cross-sectional geometry. By evaluating these conditions as part of biological responses to abnormal skeletal changes and biomechanical stress, this research discusses each condition's pathogenesis. Further, this article emphasizes a "small data" approach to evaluating these conditions in ancient culturally and biologically related human populations, where the study samples must have good skeletal preservation, where estimates of age and sex need to be included as major factors, and where abnormalities need to be described and evaluated. This article also discusses global clinical and osteological research on ways scholars are currently trying to establish industry-wide methods to evaluate osteoarthritis, entheses, and long bone cross-sectional geometry. Recent studies have focused on rigorous evaluation of methodological techniques, recording protocols, and inter- and intra-observer error problems. Additionally, scholars have focused on physical intensity of movement using biomechanics, evaluated burials of known occupation, and used complex statistical methods to help interpret skeletal changes associated with these conditions. This article also narrows to focus on these conditions within thematic "small data" areas throughout the Andes. This research concludes with describing future directions to understand skeletal changes, such as more multidisciplinary studies between osteologists and pathologists, collaborations with living people to collect CT, x-rays, or computer-aided motion capture, and a stronger focus on how these conditions correlate with intense biomechanical changes in younger individuals.

1. Introduction

Verano (1997) discussed the depth of human habitation and uniquely varied environments in his foundational article addressing paleopathological advances within Andean South America. These environments change significantly over the varying elevations, but impart generally good levels of human skeletal remains preservation, including mummification. Hence, he has been able to explore the lives of ancient Andean peoples through a variety of diseases and trauma that often coevolve with the development of complex societies (see Verano, 1986, 1995, 2001, 2008, 2013; 2014, and others). Verano (1997) also noted that skeletal diseases are long-term ailments, such as arthritis, chronic infections, and dietary deficiencies. While recent advances on the latter two conditions are covered elsewhere in this special edition (see in this issue, Toyne and Turner; Klaus; Nelson et al.; Gagnon; Blom and Knudson; and Tomasto), this article addresses long-term changes from osteoarthritis (OA), entheses, and long bone cross-sectional geometry (CSG), and describes cases where they have been used to evaluate past Andean lifeways in terms of power, labor, economic activities, and identity.

Early research correlated OA, entheses, and CSG as indicators of past activities, or used them to reconstruct movements associated with things like canoe paddling or spear throwing (e.g., Hawkey and Merbs, 1995; Kennedy, 1989; Merbs, 1983). Jurmain et al. (1999; 2012) have critiqued these approaches as "activity-only myopia," or a "Holy Grail" quest, identifying problems and concerns in description and interpretation with these methods. This has led to a reassessment of OA, entheses, and CSG, and an interrogation of if activity reconstruction in archaeological samples is even possible. Recent research on OA, entheses, and CSG has reevaluated methodological techniques, statistical assessments, recording protocols, inter- and intra-observer error problems, movement and biomechanics, and pathological changes on burials of known occupation, with no one solution (see Becker, 2017; Cardoso and Henderson, 2010; Domett et al., 2017; Pearson and Buikstra, 2006; Perréard Lopreno et al., 2013; Schrader, 2019, and others).

* Corresponding author.
E-mail address: sara.becker@ucr.edu.

https://doi.org/10.1016/j.ijpp.2019.08.005
Received 6 February 2019; Received in revised form 19 August 2019; Accepted 20 August 2019

While this article cannot address all of the problems, nor cover in-depth the prior three decades of research, it does evaluate the biomechanical stress aspects and pathogenesis of OA, entheses, and CSG as skeletal changes from long-term conditions. Following approaches encouraged by both Verano (1997) for research in the Andes, and Ortner (2011, 2012) for general paleopathological studies, this paper focuses on accurate descriptions of pathological responses in bone. Ortner (2011) also supported using a localized approach to bone pathology, where study sample comparisons should be limited to the same, somewhat closed gene pool, where preservation needs to be good enough to estimate age and sex as major factors, and where abnormalities and their distribution need to be described and evaluated. This framework might be called a "small data" approach, as opposed to "big data," because it encourages understanding and evaluating local pathology, while still contributing to the global conversation about past human populations. Thus, this manuscript defines and illustrates biomechanical stressors, abnormalities, and pathogenesis of skeletal changes associated with OA, entheses, and CSG. Methodological and theoretical improvements currently used by scientists in other parts of the world, sometimes in association with activity, to clarify and improve interpretations surrounding these conditions, are also discussed. Focusing on Andean studies of OA, entheses, and CSG in the last 20 years, the article describes these studies and concludes with new approaches and suggested advances that use a small data approach to address future OA, entheses, and CSG research.

2. Skeletal changes noted with OA, entheses, and CSG

2.1. Osteoarthritis (OA)

OA, also known as degenerative joint disease (DJD), occurs with articular cartilage loss and concomitant bone changes. Affecting both cartilage and bone structure and function in a diathrodial joint, OA is a multifactorial process in which mechanical factors play a central role (Hunter and Felson, 2006, 639). Medical studies show that a combination of genetic, systemic, and biomechanical factors may influence OA risk, with genetic predisposition currently under critical scrutiny (Rodriguez-Fontenla and Gonzalez, 2015; Warner and Valdes, 2016; Yucesoy et al., 2015). Typical systemic risk factors include advancing age (e.g., postmenopausal women) and those with lower bone density (e.g., osteoporotic persons). Alternatively, good nutrition with ingestion of items like antioxidants reduces the possibility of OA (Anderson and Loeser, 2010; Brandt et al., 2009; Dieppe, 1995; Felson et al., 2000). Biomechanical factors like previous joint trauma, obesity, mechanical loading, and repeated movements are also part of OA pathogenesis (Dieppe, 1995; Felson, 2004; Felson et al., 2000; Hunter and Felson, 2006; Yucesoy et al., 2015). Thus, a combination of genetics, risk factors, skeletal structure, and movement can all act on OA causation and location in the body.

In ancient human populations, causation is harder to address. Subchondral bone changes, such as marginal outgrowths or lipping, osteophyte development, sclerosis, porosity, and/or eburnation, are associated with OA (Fig. 1) (Buikstra and Ubelaker, 1994; Rogers et al., 1987; Schrader, 2019). These usually represent a failed attempt by the body to repair the cartilage and bone joint surfaces (Chen et al., 2017; Loeser et al., 2012; Man and Mologhianu, 2014). Consequently, scholars use any one or a combination of these bone changes to identify the prevalence of this condition in studies of archaeological human remains (see Schrader, 2019 for a comprehensive review). Researchers also suggest multiple techniques to evaluate OA data points collected, and how to analyze these in ways that can be interpreted effectively (see Anderson and Loeser, 2010; Baker and Pearson, 2006; Becker, 2019a; Domett et al., 2017; Klaus et al., 2009; Weiss and Jurmain, 2007, and others). However, interpretation remains in question within paleopathological literature considering OA's multifactorial etiology, and particularly concerning any biomechanical influences. As adjustments,

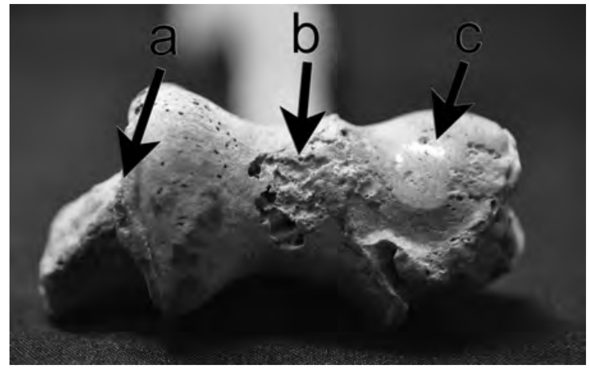

Fig. 1. Distal humerus with evidence of osteoarthritis: (a) evidence of lipping, (b) porosity, and (c) eburnation.

osteologists suggest using methods oriented toward well-contextualized interpretations, population-level comparisons, and strong statistical methods (Becker, 2013, 2017, 2019a, 2019b; Domett et al., 2017; Jurmain et al., 2012; Nikita, 2014; Pearson and Buikstra, 2006; Schrader, 2019; Weiss and Jurmain, 2007). In addition, as Ortner (2011, 2012) suggested, a localized small data approach describing type(s) of bone abnormalities and lesion pattern may provide more accurate knowledge of the incidence, prevalence, and pathology of OA in ancient human skeletal remains.

2.2. Entheseal changes

Musculature can increase in relation to activities performed, and decrease with a lack of movement in the human skeleton. The osseous interfaces where muscles, tendons, and ligaments attach to bone also adjust over a person's lifetime, providing muscle anchorage and stress dissipation (Benjamin et al., 2002, 2006; Schlecht, 2012). These areas, noted as entheses, may be subjected to repeated minor stresses resulting in bone (i.e. microstructural or osteon-level) remodeling (Fig. 2). There are two types of entheses: fibrous and fibrocartilaginous. Fibrous entheses result from intramembranous ossification, where the larger muscles of the body attach to the human skeleton via fibrous attachment points through collagen fibers and connective tissue to bone or to

Fig. 2. Entheseal changes on the inferior view of clavicles from three individuals. At the costoclavicular ligament (a) has mild changes, (b) had moderate changes, and (c) has high evidence of rugosity and bone change. At the conoid tubercle, (d) has a large entheseal growth, while (e) has moderate and (f) shows mild changes.

the periosteum (Apostolakos et al., 2014; Benjamin et al., 2002, 2006). As a person grows into adulthood, these entheses shift to direct bone attachment, resulting in a range of macroscopic changes from smooth bone to larger interruptions or gaps in the surface of the cortical bone. Fibrocartilaginous entheses, defined by the attachment of fibrocartilage to bone in various areas of movement throughout the skeleton at epiphyseal or apophyseal long bone ends, form from endochondral ossification (Benjamin et al., 2006; Schlecht, 2012; Weiss, 2015). Changes in fibrocartilaginous entheses develop as gradient areas of fibrous connective tissue, uncalcified fibrocartilage, calcified fibrocartilage, and bone, and balance bone and tendon elasticity (Benjamin et al., 2002). Further, these regions are part of an “enthesis organ complex,” dissipating stress at the bony interface away from the attachment site. Hence, abnormal changes (e.g., diffuse idiopathic skeletal hyperostosis (DISH), synovitis, bursitis) may also result as part of the complex system of soft and hard tissues within the enthesis organ complex (Benjamin et al., 2002, 2006; Henderson, 2013; Schrader, 2019).

In general, healthy entheseal sites in skeletal remains should be smooth and devoid of vascular foramina (Benjamin et al., 2002; Schrader, 2019; Villotte and Knüsel, 2013). Changes in the structure of entheses may be less regular if there are degenerative changes, such as bone spurs or calcification at the attachment area. Benjamin and colleagues (2002; 2006) also note fibrocartilaginous entheses could show greater skeletal changes because they attach at relatively thin regions of subchondral bone where stress dissipates over a larger region and can leave bony ridges. In contrast, fibrous entheses attach in areas with larger quantities of cortical bone that may better mitigate bone response. Morphological variation in fibrous entheses may also correlate to age and advancing age, instead of providing information on muscle stress and developmental changes (Cardoso and Henderson, 2013; Henderson et al., 2017; Michopoulou et al., 2015; Weiss, 2015). However, biomechanical clinical literature cautions that a variety of factors go into entheseal changes (Benjamin et al., 2002, 2006). Hence, fibrocartilaginous (Henderson et al., 2013, 2015; Henderson et al., 2017; Michopoulou et al., 2017), fibrous (Becker, 2017; Schrader, 2012; Schrader and Buzon, 2017; Yonemoto, 2016), or a combination of both types (Lieverse et al., 2013) have been used in recent osteological studies to understand past populations.

Currently, there is no definitive paleopathological methodology for recording entheseal changes (see Schrader, 2019 for a review). Researchers studying European collections with known textual history have recently provided two ways to standardize fibrocartilaginous entheses data collection: one put forth by Villotte (see Villotte et al., 2010; Villotte and Knüsel, 2013); and from Henderson, the Coimbra method (see Henderson et al., 2013, 2015). While neither has been adopted fully in paleopathological studies, there are concerns about inter- and intra-observer error in the scoring of these muscle attachment points. Researchers encourage strict visual and written definitions of the type of entheseal changes noted (Davis et al., 2013; Henderson et al., 2013; Schrader, 2019). Thus, akin to Ortner’s (2011, 2012) approach, and along with clinical suggestions (Benjamin et al., 2002), presently the best general method to recording any entheseal changes may be descriptive, noting any dry bone patterns (e.g., increases or decreases in robusticity, resorption, marginal irregularity, erosion, calcification, ossification of soft tissues, vascularization, and cavitation) (Schrader, 2019).

2.3. Long bone cross-sectional geometry (CSG)

Lifeways of ancient civilizations may also be understood using CSG (Larsen et al., 2001; Ruff and Hayes, 1983; Ruff, 1999, 2000; Ruff et al., 2006; Ruff and Larsen, 2001). CSG is based on Wolff’s Law, or the idea that bone adapts to the loads under which it is placed. CSG applies the engineering concept of beam theory, a technique that tests a beam or bar’s ability to carry loads in bending and torsion. Long bones, such as the humerus and femur, are modeled as hollow beams and analyzed in the same way as an engineer would model a bridge and test for structural integrity (Runestad et al., 1993). In this model, the further away from a central or neutral axis in a cross-section of a beam, the greater the ability to resist fracture (Ruff and Hayes, 1983; Ruff et al., 2006). As opposed to a beam, bone is a living substance that can adapt to these changes. Thus, in long bones, CSG measures bending and twisting strength of arm and leg bones and compressive strength (weight bearing) of leg bones by examining the cross-sectional shape of long bones at varying distances from the neutral axis. These cross sections may exhibit variations in mechanical loading, as cortical bone thickness and directionality of bone apposition may change in response to mechanical loads (Ruff et al., 2006). Changes in bone shape, from more rounded exterior and interior cortical shape to oblong or directionally oblique, generally indicate reshaping of the cellular matrix of bone to handle non-normal bending and torsion stresses. Hence, differences in these cross sections can help identify mechanical stressors between individuals within the same sample, or larger population-based changes, like chronological transitions from being mobile foragers to a sedentary agricultural way of life (Sládek et al., 2006; Trinkaus and Churchill, 1999; Wescott and Cunningham, 2006). It is also important to note that hormones, diet, age, or genetics may impact normal bone development and cross sectional differences, and these should be accounted for in studies of past populations (Cowgill et al., 2010; Jurmain et al., 2012; Lieberman et al., 2004; Meyer et al., 2011).

3. Prior uses of OA, entheses, and CSG

Osteologists once used OA, entheses, and CSG to discern patterns that could identify specific jobs and forms of labor. The expectation was that all “weavers” would have a similar pattern of activity, representing a blueprint to identify that specific occupation in archaeological skeletal remains. The hope was to recognize economically productive activities in communities with little historic evidence of tasks people performed. Certain activities were also given names for movements with which they were associated, like “atlatl elbow” (elbow OA associated with throwing), or “fruit-picker’s cervical spine” (lipping on the fourth through seventh cervical vertebrae) (Angel, 1966; Capasso et al., 1998; Kennedy, 1989). During the 1980s and early 1990s, identifying archaeological groups who may have performed distinct activities or been engaged in specific occupations was common when discussing activity evidence in human skeletal remains. However, by the late 1990s and early 2000s, various authors (Buikstra and Beck, 2006; Jurmain, 1999; Pearson and Buikstra, 2006; Stirland, 1998) suggested that OA, entheses, and CSG may not provide clear examples of past labor and activity.

From these concerns, human skeletal studies began collecting OA, entheses, or CSG in conjunction with other indicators of skeletal stress or isotopic studies. Clinically oriented animal studies of disease on bone associated with biomechanical changes were also performed to address skeletal changes with movement (cf. Carlson and Judex, 2007; Morimoto et al., 2011; Niinimäki and Salmi, 2016; Schalkwyk et al., 2004; Wallace et al., 2017, and others). Analyses of human arm and leg bone morphological CSG changes were also correlated within archaeological collections, indicating long bones change across cross sections as a result of biomechanical stressors (e.g., Davies et al., 2012; Ruff, 2000; Weiss, 2005, and others). In addition, studies of OA and entheses began to factor estimates of age at death, sex, and body size, along with noting that genetics could play an invisible role in the prevalence of OA or entheseal changes in skeletal collections. Hence, the focus shifted to a wider array of skeletal stress and disease pathogenesis (Bendele, 2001; Milella, 2014; Schlecht, 2012; Villotte and Knüsel, 2013; Wallace et al., 2017). Weiss and Jurmain (2007) also suggested that a missing element in any study of biomechanical changes, especially those associated with OA, is subadult risk, with an interest in establishing juvenile age of onset, injury, and activity intensity. Thus, most recent research on OA, entheseal changes, and CSG was careful to use population-oriented approaches, factor in age at death and sex, and note if subadults were affected (Austin, 2017; Becker, 2017; Becker and Goldstein, 2017; Cheverko and Bartelink, 2017; Domett et al., 2017; Palmer et al., 2016; Schrader and Buzon, 2017).

4. Prior Andean research on OA, entheses, and CSG

Akin to the larger history of research on OA, entheses, and CSG, some of the earliest Andean studies of these skeletal changes identified specific activities. Allison and Gerszten (1982) evaluated prehistoric mummies from Peru who had cervical OA. They suggested this was evidence of tumpline use (i.e., a sling across the forehead for carrying loads on the back). In other cases, Andean evidence of "atlatl elbow" was identified (Neves, 1984; Wise et al., 1994). However, recent scholarship employs multiple lines of evidence, population-based approaches, and strong statistical methods to study prehistoric South American populations. What follows are descriptions of prior studies based on each's thematic approach to understanding these conditions within the Andes.

4.1. Economic activities

Focusing on economic activities from some of the earliest human settlements in the Andes, Rhode (2006) evaluated entheseal changes in Archaic (7800–4700 BC) southern Andean coastal fishing populations (Fig. 3, area E). He compared them to inland, high-elevation Archaic (3000–1500 BC) through Late Intermediate Period (LIP) (AD 900–1450) farmers from Peru and Chile (Fig. 3, areas E and F). His research was well-grounded in the biomechanics of entheseal development. He also identified how various coastal and farming activities were performed in the pre-contact Andes. Overall, Rhode found that fishing populations had greater upper body musculature, while farmers had greater lower body musculature.

Also in the southern Andes, Ponce (2010b, 2012) evaluated two Chinchorro occupational groups from northern Chile, coastal fisher folk (3000–1000 BC) and inland agriculturalists (AD 1–1000) (Fig. 3, area F). She used entheseal changes, OA, spondylolysis, os acromiale, osteochondritis dissecans, and osteometric measurements to characterize skeletal changes. Akin to prior research from Rhode, Ponce's research stated that marine resource procurement was more mechanically demanding and physically stressful when compared to the inland agriculturalists. Ponce (2010a, 2010b) also described gendered divisions of labor with coastal males having significantly higher skeletal indicators of activity than coastal females. However, lifeways for inland agriculturalists showed little to no division of labor for males and females.

In the North Coast of Peru (Fig. 3, area A), Titelbaum (2012) evaluated 159 adults for OA and entheses at the El Brujo site in the Chicama Valley in order to understand transitions in economic lifeways in this region. Changing from more mobile, egalitarian fisherfolk to sedentary farmers in a stratified state-level society over the *longue durée* at this site, skeletal remains studied were primarily from three temporal periods: the Late Preceramic (3000–1800 BC), the Early Intermediate Period (100 BC-AD 700), and the LIP (AD 950–1375). She found that OA and entheseal data indicated biomechanical differences between fisher-foragers and farmers. There was also a division of labor by sex among fisher-foragers with females likely exploiting terrestrial resources and males focused on underwater resources. Hence, at El Brujo, there were skeletal differences between fishing and farming, as was seen in the prior studies in the southern Andes. In the agricultural-only populations, there were few OA and entheseal differences between males and females. However, later agricultural farming populations at El Brujo demonstrate similar entheseal changes and OA to early

Fig. 3. Map of the Andean area: (A) North Coast region of Peru, (B) central coastal area near present-day Lima, Peru, (C) southern highland region near present-day Cusco, Peru, (D) high altitude flat plain near present-day La Paz, Bolivia; (E) lower elevation inland and coastal region of southern Peru, (F) lower elevation coastal and inland region of northern Chile, (G) highland San Pedro de Atacama oasis in Chile.

farmers, but with greater prevalence, suggesting agricultural intensity increased.

Evaluating specialized occupational groups, Toyne (2002, 2004, 2008) recorded paleopathological changes in various North Coast populations. Her (2002) research at Túcume, Peru primarily evaluated entheseal changes from 19 Inka period potentially elite females and compared these to other burials at the site. She tested the idea that these females were *aqllacuna* (specialized Inka weavers), but she was unable to show that any skeletal changes supported this hypothesis. Similarly, using entheseal changes her work (2004) at nearby Punta Lobos (AD 1250–1300) explored the idea that male burials from the site were fishermen. She found that males exhibited high rates of age-related, but not necessarily occupational, entheseal changes. Toyne (2008) returned to Túcume at the Templo de la Piedra Sagrada site, primarily to evaluate trauma and violence, but average entheseal scores were also recorded. The 40 male burials evaluated showed that entheses increased with age, akin to her previous 2004 research.

4.2. Labor and power structures

Located at the cemetery of Villa El Salvador (100 BC–AD 100) near present-day Lima, Peru, Pechenkina and Delgado (2006) evaluated 64 skeletal remains to understand social structure at this site (Fig. 3, region B). All burials were associated with the same ceramic tradition, thus were likely part of the same overarching cultural ideology. However, as supported by differences in cranial modification, these burials may have comprised two moieties: a coastal group and a high-elevation group. The authors used markers of stress and diet, along with bone changes in elbows, knees, and the spine associated with OA to test for wellbeing, assuming that traits covaried with archaeological indicators of social differentiation. Overall, Pechenkina and Delgado used multivariate statistics and were able to find two geographically defined groups at Villa El Salvador from the skeletal indicators of stress. They attributed these to different diets and pathogenic exposure during childhood. The authors also noted that along with burial wealth of some of the males, higher OA rates in the joints of the elbows, knees, and spine of males buried with fewer grave goods suggest a labor hierarchy among men within this community.

In southern Peru and highland Bolivia, Becker and colleagues (Becker, 2013, 2016, 2017, 2019a, 2019b; Becker and Goldstein, 2017; Blom et al., 2016) have studied the state-level Tiwanaku culture (AD 500–1100) using entheseal changes and OA. This research used a large sample (approximately 2500 individuals) with good skeletal preservation from the high-altitude core (Fig. 3, area D) and near-perfect bone preservation from colony sites near Moquegua, Peru in the Atacama Desert (Fig. 3, area E) (Becker, 2013). Using precise age at death and sex estimates and controlling for these within OA and entheseal comparisons, researchers found labor levels similar between highland regions, but a lower prevalence in the colony that was growing maize for export to the heartland capital city of Tiwanaku (Becker, 2013, 2017; Becker and Goldstein, 2017). These differences were interpreted as reciprocal labor within the heartland of the state, reinforcing that Tiwanaku colonists were not conscripted for the benefit of the state, as had been observed later during the Inka period (AD 1476–1532). Becker (2013, 2019b) also reported differences within the city of Tiwanaku's individual neighborhoods for OA and entheses, which supported archaeological interpretations of embedded, guild-like groups living around the ceremonial center of the city (Janusek, 1999, 2004, 2008). Becker and Goldstein's (2017) research on Tiwanaku colonists identified sex and age-related differences in OA, including evidence of this condition in individuals 14 years and younger. In addition, these Tiwanaku studies used individually recorded data points for each entheseal change or articular surface within a joint for each individual, but compared data at a population level using the Generalized Estimating Equations (GEE) approach. Hence, Becker (2012, 2013, 2019a) suggests using a strong statistical methodology like GEE to evaluate and describe OA and entheseal changes in past populations.

Contemporaneous to the Tiwanaku civilization, the Wari state (AD 700–1000) of the Central Andes also had high levels of organized labor. Juengst and Skidmore (2016) studied skeletal remains from 41 individuals buried at Hatun Cotuyoc in Huaro, Peru who were agriculturalists, but also possibly low-level elite peoples (Fig. 3, area C). They evaluated OA, skeletal stressors, diet, and trauma, noting evidence of OA with lipping, eburnation, and DJD in the lower back, hip, and knee joints. Overall, Juengst and Skidmore found that people were well fed, but also labored strenuously. In addition, the authors note that individuals from Hatun Cotuyoc had a varied diet, likely exporting much of the corn they grew for export to the state capital in Ayacucho, Peru. Thus, people were maize-focused in both the Wari and Tiwanaku states with laboring colonies to produce maize sent back to heartland cores.

A diachronic comparison of CSG skeletal changes associated with trade in and around San Pedro de Atacama, Chile (AD 500–1450), especially after the collapse of the Tiwanaku state, was researched by Pomeroy (2013) (Fig. 3, area G). She characterized San Pedro de Atacama as a trading hub during the Tiwanaku state. Her expectations were that those involved in trade would show skeletal evidence of that mobility through greater long bone robusticity and less circular limb bone cross sections. She noted that lower limb CSG during the Middle Horizon (MH) / Tiwanaku period (AD 500–1000) was less robust, and therefore women, men, elites, and non-elites were less mobile than those who lived during the LIP (AD 1000–1450). Hence, with Tiwanaku's decline, the population may have become more actively involved in long distance travel. Also, her findings do not support the idea that MH non-elites were more actively involved in long distance trade under the control of the elites. Instead, Pomeroy suggests these differences could correlate with changes in camelid herding activities after the collapse of the Tiwanaku polity. Finally, individuals from various areas during the LIP had similar CSG measurements, which may indicate similar mobility and trading activities after the collapse of this state.

Also after the collapse of the Tiwanaku state and within their former maize growing colony in the Moquegua Valley of Peru (Fig. 3, area E), Lowman (2017) studied two groups of post-Tiwanaku descendants at the Tumilaca la Chimba site (AD 950–1476). She evaluated the anemic responses, oral pathology, and OA from these individuals. Her thesis found evidence of dental caries, dental abscess, porotic hyperostosis, cribra orbitalia, and OA changes in the spine. Overall, Lowman interpreted these changes chronologically, noting that people who lived closer to the collapse of the Tiwanaku civilization were affected more often by these conditions.

During Inka times in the central Andes (Fig. 3, area C), research by Andrushko (2007) and collaborators (Andrushko et al., 2006) studied skeletal stress indicators and OA in and around Cuzco during this Empire. The *mit'a* (labor rotation) for public construction, army service, and toiling in state-owned fields, required by Inka rulers may have increased physical labor demands, leading to an increase in OA. Andrushko (2007) observed that there were more degenerative OA skeletal changes in the periphery compared to the core, as would be expected in a typical hierarchical state system in service to a heartland. Hence, the Inka Empire required arduous labor tribute from commoners who lived around the core city of Cuzco.

In the North Coast of Peru, OA evidence was evaluated for indigenous Mochica peoples by Klaus (2008) and Klaus et al. (2009). They assessed local precontact and postcontact groups (AD 1536–1751) using odds ratios statistical comparisons across four age classes for the joints of the shoulder, elbow, wrist, and knee. Overall, OA increased immediately following European contact in this region, and by sex, males experienced more OA than females. Using well-contextualized data, they interpreted these changes as sociopolitical alterations, local environmental changes, and regional economic intensification due to the colonial Spanish political economy.

4.3. Osteobiography and individual identity

The last four studies evaluated individual burials to understand what life was like for specific people within the southern and north coastal Andes. Within the Tiwanaku neighborhood of Ch'iji Jawira, which was associated archaeologically with ceramics manufacture, Becker (2016) evaluated a skeleton of an older female for patterns of OA and entheses. She found that the musculature of the woman, especially in the hands and feet, could indicate a lifetime spent as a craftsperson. During a similar time period at the Solcor 3 site (ca. AD 500–900) in San Pedro de Atacama, Chile (Fig. 3, area G), Torres-Rouff and Knudson (2007) examined an adult male (individual 1978) who possessed non-local childhood strontium signatures. They note that even though he was not local, mortuary evidence and temporomandibular OA made him similar in death and burial to his peers at this site. In the North Coast of Peru at the San Jose de Moro site during the Lambayeque period (AD 1000–1350), Nelson et al. (2000) took an osteobiography approach to understand a female burial in tomb M-U508. Evaluating entheseal changes in this burial that had textile related mortuary goods, they found that she was an elderly craftswoman who probably spun thread on a daily basis. Additionally, in the Lambayeque Valley of north coastal Peru, Klaus and Ortner (2014) describe a female (U4 05–32) buried during the Early Colonial Period at Mórrope. She had osteophyte responses in her shoulder and elbow joints, but also rare evidence of treponemal infection for this region indicating her uniqueness.

5. Conclusion and future directions

This research advocates for taking a "small data" approach where bone abnormalities and their pattern of distribution are described in skeletally well preserved, culturally related, and potentially genetically closedsample populations. This is similar to approaches called for by Ortner (2011) for all paleopathological research, and for by Verano (1997) for research in the South American Andes. Beyond reporting frequencies, making any interpretations from OA, entheses, or CSG data collected must come with methods that include age and sex, use strong statistical methods, and justify interpretation by contextualizing within the archaeological and skeletal population data.

In addition to these approaches, one future research direction often previously noted by osteologists is to engage further with clinical literature (Cardoso and Henderson, 2010; Jurmain, 1999; Jurmain et al., 2012; Pearson and Buikstra, 2006; Schlecht, 2012; Stirland, 1998; Villotte et al., 2010; Weiss, 2007; Weiss and Jurmain, 2007). Since this scholarship is vast and is rapidly updated by clinicians working with living people, it may be wise to engage more often with medical doctors who have an interest in paleopathology, akin to the Ortner (paleopathologist) and Ragsdale (medical doctor/pathologist) partnership (Buikstra and Roberts, 2012; Buikstra, 2019; Grauer, 2018; Miller et al., 1996).

Beyond creating partnerships, another future direction is to establish industry-wide data collection methods for OA and entheses. While CSG has more direct approaches and various methods (Davies et al., 2012; Michopoulou et al., 2015; Ruff and Hayes, 1983; Stock and Shaw, 2007), OA and entheses have no established recording procedures that are accepted by all human osteologists. For example, published literature on OA describes the various methodological approaches: by individual, by joint, or by population. From this, a percentage of individuals affected can be calculated, or an average rate of OA is provided for the population, but many of these methods do not account for multiple articular surfaces within each joint, or the distinctions if many or few surfaces show evidence of skeletal changes associated with OA. Thus, if data from all articular surfaces were collected and multivariate statistical methods were standard analytical assessors in osteology, such as GEE, generalized linear modelling, or Bayesian modeling, results would provide more detailed information on bone abnormality and skeletal lesion patterning beyond what simple bivariate statistics can measure (Becker, 2017, 2019a; McCullagh and Nelder, 1989; Nikita, 2014; Nikita et al., 2013; Schrader, 2019).

Other specific directions may be to consider OA, entheses, and CSG in younger individuals. While the first two conditions are strongly associated with age, both osteological and clinical research show that biomechanical patterns (e.g., athletics, injury) of skeletal changes may be influenced by young people's diet, movement, and activity intensity (Becker and Goldstein, 2017; Chen et al., 2017; DiVasta et al., 2007; Karakostis et al., 2018; Macintosh et al., 2017; Miller et al., 2018; Nicholson et al., 2009; Schrader, 2019; Spahn et al., 2017; Wallace et al., 2017). Three-dimensional scans of long bones could also be included as a future research method, from both skeletal collections and CT or MRI scans from various ages of living people with varying levels of physical activity, to create a global database of individual bone changes. In addition, scholars could perform more controlled case studies on living populations using biomechanical recreations using computerized motion capture. Working with modern people, researchers could observe movement to understand the skeletal kinematics (i.e., movement of the body) and kinetics (i.e., force behind the bodily movements) involved in a variety of activities. For example, by looking at individuals who are experts at certain tasks (e.g., ceramics production in the region), these people could be recorded for movement in bones and joints. When combined with CT scans, X-rays, or MRIs, comparisons could be performed to look for any visible skeletal pathological changes.

In sum, inspired by Verano's (1997) description of the environment, ecology, and paleopathology of the South American Andes, this article has defined and described the best-known etiology and pathogenesis of OA, entheses, and CSG in order to explore the lives of ancient peoples. This article has also described the prior 20 years of Andean research on these conditions, as well as methodological and theoretical improvements currently used by scientists in other parts of the world. While studies on these conditions sometimes were used as a one-to-one comparison with past activity, modern research is more circumscript about how OA, entheses, and CSG are used. Much exploration has gone into understanding and improving methods and analyses of these data (e.g., Becker, 2017, 2019b; Cardoso and Henderson, 2010, 2013; Davis et al., 2013; Henderson and Cardoso, 2013; Milella et al., 2015; Pearson and Buikstra, 2006; Perréard Lopreno et al., 2013; Schlecht, 2012; Schrader, 2019; Villotte and Knüsel, 2013, and others). However, more studies are needed on these conditions as biomechanical stressors, abnormalities, and the pathogenesis of their skeletal changes.

Acknowledgements

I wish to thank the editors of this special edition journal for their invitation to participate and Celeste Gagnon for early proof reading on this manuscript. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Allison, M.J., Gerszten, E., 1982. Paleopathology in South American Mummies: Application of Modern Techniques. Medical College of Virginia, Richmond.

Anderson, A.S., Loeser, R.F., 2010. Why is osteoarthritis an age-related disease? Best Pract. & Res. Clin. Rheumatology 24, 15–26. https://doi.org/10.1016/j.berh.2009.08.006.

Andrushko, V.A., 2007. The Bioarchaeology of Inca imperialism in the Heartland: an Analysis of Prehistoric Burials From the Cuzco Region of Peru. PhD Dissertation. Department of Anthropology, University of California at Santa Barbara, Santa Barbara.

Andrushko, V.A., Torres Pino, E.C., Bellifemine, V., 2006. The burials at Sacsahuaman and Chokepukio: a bioarchaeological case study of imperialism from the capital of the Inca empire. Ñawpa Pacha 28, 63–92. https://doi.org/10.1179/naw.2006.28.1.005.

Angel, J.L., 1966. Early Skeletons From Tranquility, California. Smithsonian Contributions to Anthropology 2. https://repository.si.edu/bitstream/handle/10088/1319/SCtA-0002.1-Lo_res.pdf?sequence=2&isAllowed=y.

Apostolakos, J., Durant, T.J.S., Dwyer, C.R., Russell, R.P., Weinreb, J.H., Alaee, F., Beitzel, K., McCarthy, M.B., Cote, M.P., Mazzocca, A.D., 2014. The enthesis: a review of the tendon-to-bone insertion. Muscles Ligaments Tendons J. 4, 333–342. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4241425/.

Austin, A.E., 2017. The cost of a commute: a multidisciplinary approach to osteoarthritis in New Kingdom Egypt. Int. J. Osteoarchaeol. 27, 537–550. https://doi.org/10.1002/oa.2575.

Baker, J., Pearson, O.M., 2006. Statistical methods for bioarchaeology: applications of age-adjustment and logistic regression to comparisons of skeletal populations with differing age-structures. J. Archaeol. Sci. 33, 218–226. https://doi.org/10.1016/j.jas.2005.07.019.

Becker, S.K., 2012. Using generalized estimating equations to evaluate activity in human skeletal remains. Presentation in' Anthropological Applications' Symposium at the International Conference on Advances in Interdisciplinary Statistics and Combinatorics 5–7.

Becker, S.K., 2013. Labor and the Rise of the Tiwanaku State (AD 500-1100): a Bioarchaeological Study of Activity Patterns. PhD Dissertation. Department of Anthropology, University of North Carolina, Chapel Hill, Chapel Hill, NC.

Becker, S.K., 2016. Skeletal evidence of craft production from the Ch'iji Jawira site in Tiwanaku. Bolivia. J. Archaeol. Sci. Reports 9, 405–415. https://doi.org/10.1016/j.jasrep.2016.08.017.

Becker, S.K., 2017. Community labor and laboring communities within the Tiwanaku state (C.E. 500-1100). Archaeol. Pap. Am. Anthropol. Assoc 28, 38–53. https://doi.org/10.1111/apaa.12087.

Becker, S.K., 2019a. Evaluating elbow osteoarthritis within the prehistoric Tiwanaku state using generalized estimating equations (GEE). Am. J. Phys. Anth. 169, 186–196. https://doi.org/10.1002/ajpa.23806.

S.K. Becker. Labor across an occupational and gendered taskscape: bones and bodies of the Tiwanaku state (AD 500-1100). Bioarchaeol. Int., in press.

Becker, S.K., Goldstein, P.S., 2017. Evidence of osteoarthritis in the Tiwanaku colony, Moquegua, Peru (AD 500–1100). Int. J. Osteoarchaeol. 28, 54–64. https://doi.org/10.1002/oa.2634.

Bendele, A.M., 2001. Animal models of osteoarthritis. J. Musculoskelet. Neuronal Interact. 1, 363–376.

Benjamin, M., Kumai, T., Milz, S., Boszczyk, B.M., Boszczyk, A.A., Ralphs, J.R., 2002. The skeletal attachment of tendons—tendon 'entheses'. Comp. Biochem. Physiol. Part A: Molec. Integr. Physiol. 133, 931–945. https://doi.org/10.1016/S1095-6433(02)00138-1.

Benjamin, M., Toumi, H., Ralphs, J., Bydder, G., Best, T., Milz, S., 2006. Where tendons and ligaments meet bone: attachment sites ("entheses") in relation to exercise and/or mechanical load. J. Anat. 208, 471–490. https://doi.org/10.1111/j.1469-7580.2006.00540.x.

Blom, D.E., Knudson, K.J., Janusek, J.W., Becker, S.K., Bowen, C.M., 2016. Formation and transformation of identities in the Andes: the constructions of childhood among the Tiwanaku. Presentation in the 'On the Move: Archaeological Approaches to Children and Childhood' Symposium.

Brandt, K.D., Dieppe, P., Radin, E.L., 2009. Commentary: is it useful to subset "primary" osteoarthritis? A critique based on evidence regarding the etiopathogenesis of osteoarthritis. Semin. Arthritis & Rheumatism 39, 81–95. https://doi.org/10.1016/j.semarthrit.2009.06.001.

Buikstra, J., Roberts, C., 2012. The Global History of Paleopathology: Pioneers and Prospects. Oxford University Press, New York.

Buikstra, J.E., 2019. Chapter 2 - a brief history and 21st century challenges. In: Buikstra, J.E. (Ed.), Ortner's Identification of Pathological Conditions in Human Skeletal Remains, third edition. Academic Press, San Diego, pp. 11–19.

Buikstra, J.E., Beck, L.A., 2006. Bioarchaeology: the Contextual Analysis of Human Remains. Academic Press, Burlington, MA.

Buikstra, J.E., Ubelaker, D.H., 1994. Standards for data collection from human skeletal remains. Research Series, No. 44. Arkansas Archaeological Survey.

Capasso, L., Kennedy, K.A., Wilczak, C.A., 1998. Atlas of Occupational Markers on Human Remains. Edigrafital SpA, Teramo, Italy.

Cardoso, F.A., Henderson, C.Y., 2010. Enthesopathy formation in the humerus: data from known age-at-death and known occupation skeletal collections. Am. J. Phys. Anth. 141, 550–560. https://doi.org/10.1002/ajpa.21171.

Cardoso, F.A., Henderson, C.Y., 2013. The categorisation of occupation in identified skeletal collections: A source of bias? Int. J. Osteoarchaeol. 23, 186–196. https://doi.org/10.1002/oa.2285.

Carlson, K.J., Judex, S., 2007. Increased non-linear locomotion alters diaphyseal bone shape. J. Exp. Biol. 210, 3117–3125. http://jeb.biologists.org/content/210/17/3117.

Chen, D., Shen, J., Zhao, W., Wang, T., Han, L., Hamilton, J.L., Im, H.J., 2017. Osteoarthritis: toward a comprehensive understanding of pathological mechanism. Bone Res. 5, 16044. https://www.nature.com/articles/boneres201644.

Cheverko, C.M., Bartelink, E.J., 2017. Resource intensification and osteoarthritis patterns: changes in activity in the prehistoric Sacramento-San Joaquin delta region. Am. J. Phys. Anthropol. 164, 331–342. https://doi.org/10.1002/ajpa.23272.

Cowgill, L.W., Warrener, A., Pontzer, H., Ocobock, C., 2010. Waddling and toddling: the biomechanical effects of an immature gait. Am. J. Phys. Anth. 143, 52–61. https://doi.org/10.1002/ajpa.21289.

Davies, T.G., Shaw, C.N., Stock, J.T., 2012. A test of a new method and software for the rapid estimation of cross-sectional geometric properties of long bone diaphyses from 3D laser surface scans. Archaeol. Anthropol. Sci. 4, 277–290. https://link.springer.com/article/10.1007/s12520-012-0101-8.

Davis, C.B., Shuler, K.A., Danforth, M.E., Herndon, K.E., 2013. Patterns of interobserver error in the scoring of entheseal changes. Int. J. Osteoarchaeol. 23, 147–151. https://doi.org/10.1002/oa.2277.

Dieppe, P., 1995. The classification and diagnosis of osteoarthritis. In: Kuettner, K.E., Goldberg, V. (Eds.), Osteoarthritic Disorders. American Academy of Orthopaedic Surgeons, Rosemont, IL, pp. 5–12.

DiVasta, A.D., Beck, T.J., Petit, M.A., Feldman, H.A., LeBoff, M.S., Gordon, C.M., 2007. Bone cross-sectional geometry in adolescents and young women with anorexia nervosa: a hip structural analysis study. Osteoporos. Int. 18, 797–804. https://link.springer.com/article/10.1007%2Fs00198-006-0308-6.

Domett, K., Evans, C., Chang, N., Tayles, N., Newton, J., 2017. Interpreting osteoarthritis in bioarchaeology: highlighting the importance of a clinical approach through case studies from prehistoric Thailand. J. Archaeol. Sci: Reports 11, 762–773. https://doi.org/10.1016/j.jasrep.2016.12.030.

Felson, D., 2004. Risk factors for osteoarthritis. Clin. Orthoped. Rel. Res 427S, S16–S21. https://doi.org/10.1097/01.blo.0000144971.12731.a2.

Felson, D.T., Lawrence, R.C., Dieppe, P.A., et al., 2000. Osteoarthritis: new insights. Part 1: the disease and its risk factors. Ann. Int. Med. 133, 635–646.

Grauer, A.L., 2018. A century of paleopathology. Am. J. Phys. Anth. 165, 904–914. https://doi.org/10.1002/ajpa.23366.

Hawkey, D.E., Merbs, C.F., 1995. Activity-induced musculoskeletal stress markers (MSM) and subsistence strategy changes among ancient Hudson Bay Eskimos. Int. J. Osteoarchaeol. 14, 7–17. https://doi.org/10.1002/oa.1390050403.

Henderson, C.Y., 2013. Do diseases cause entheseal changes at fibrous entheses? Int. J. Paleopath. 3, 64–69. https://doi.org/10.1016/j.ijpp.2013.03.007.

Henderson, C.Y., Cardoso, F.A., 2013. Special issue entheseal changes and occupation: technical and theoretical advances and their applications. Int. J. Osteoarchaeol. 23, 127–134. https://doi.org/10.1002/oa.2298.

Henderson, C.Y., Mariotti, V., Pany-Kucera, D., Villotte, S., Wilczak, C.A., 2013. Recording specific entheseal changes of fibrocartilaginous entheses: initial tests using the Coimbra method. Int. J. Osteoarchaeol. 23, 152–162. https://doi.org/10.1002/oa.2287.

Henderson, C.Y., Mariotti, V., Pany-Kucera, D., Villotte, S., Wilczak, C.A., 2015. The new 'coimbra method': a biologically appropriate method for recording specific features of fibrocartilaginous entheseal changes. Int. J. Osteoarchaeol. 26 (5), 925–932. https://doi.org/10.1002/oa.2477.

Henderson, C.Y., Mariotti, V., Santos, F., Villotte, S., Wilczak, C.A., 2017. The new Coimbra method for recording entheseal changes and the effect of age-at-death. BMSAP 29, 140–149. https://link.springer.com/article/10.1007/s13219-017-0185-x.

Hunter, D.J., Felson, D.T., 2006. Osteoarthritis. BMJ : British Med. J. 332, 639–642.

Janusek, J.W., 1999. Craft and local power: embedded specialization within Tiwanaku cities. Latin Am. Antiq 10, 107–131. https://www.jstor.org/stable/972198.

Janusek, J.W., 2004. Identity and Power in the Ancient Andes: Tiwanaku Cities Through Time. Routledge, New York.

Janusek, J.W., 2008. Ancient Tiwanaku. Cambridge University Press, New York.

Juengst, S.L., Skidmore, M., 2016. Health at the Edge of the Wari Empire: an Analysis of Skeletal Remains From Hatun Cotuyoc, Huaro, Peru. Andean Past 12, Article 7. https://digitalcommons.library.umaine.edu/cgi/viewcontent.cgi?article=1002&context=andean_past.

Jurmain, R., 1999. Stories From the Skeleton: Behavioral Reconstruction in Human Osteology. Gordon and Breach, Amsterdam.

Jurmain, R., Alves Cardoso, F., Henderson, C., Villotte, S., 2012. Bioarchaeology's holy grail: the reconstruction of activity. In: Grauer, A.L. (Ed.), A Companion to Paleopathology. Wiley-Blackwell, Malden, MA, pp. 531–552.

Karakostis, F.A., Hotz, G., Scherf, H., Wahl, J., Harvati, K., 2018. A repeatable geometric morphometric approach to the analysis of hand entheseal three-dimensional form. Am. J. Phys. Anth. 166, 246–260. https://doi.org/10.1002/ajpa.23421.

Kennedy, K.A.R., 1989. Skeletal markers of occupational stress. In: Iscan, Y., Kennedy, K. (Eds.), Reconstruction of Life From the Skeleton. Alan R. Liss, Inc., New York, pp. 129–160.

Klaus, H., Larsen, C.S., Tam, M.E., 2009. Economic intensification and degenerative joint disease: life and labor on the postcontact North Coast of Peru. Am. J. Phys. Anth. 139, 204–221. https://doi.org/10.1002/ajpa.20973.

Klaus, H.D., 2008. Out of Light Came Darkness: Bioarchaeology of Mortuary Ritual, Health, and Ethnogenesis in the Lambayeque Valley Complex, North Coast Peru (AD 900-1750). PhD Dissertation. Department of Anthropology, The Ohio State University, Columbus.

Klaus, H.D., Ortner, D.J., 2014. Treponemal infection in Peru's early colonial period: a case of complex lesion patterning and unusual funerary treatment. Int. J. Paleopathol. 4, 25–36. https://doi.org/10.1016/j.ijpp.2013.12.001.

Larsen, C.S., Griffin, M.C., Hutchinson, D.L., Noble, V.E., Norr, L., Pastor, R.F., Ruff, C.B., Russell, K.F., Schoeninger, M.J., Schultz, M., Simpson, S.W., Teaford, M.F., 2001. Frontiers of contact: bioarchaeology of spanish Florida. J. World Prehist. 15, 69–123. https://link.springer.com/article/10.1023/A:1011180303211.

Lieberman, D., Polk, J., Demes, B., 2004. Predicting long bone loading from cross-sectional geometry. Am. J. Phys. Anthropol. 123, 156–171. https://doi.org/10.1002/ajpa.10316.

Lieverse, A.R., Bazaliiskii, V.I., Goriunova, O.I., Weber, A.W., 2013. Lower limb activity in the cis-baikal: entheseal changes among Middle Holocene Siberian foragers. Am. J. Phys. Anth. 150, 421–432. https://doi.org/10.1002/ajpa.22217.

Loeser, R.F., Goldring, S.R., Scanzello, C.R., Goldring, M.B., 2012. Osteoarthritis: a disease of the joint as an organ. Arthritis Rheum. 64, 1697–1707. https://doi.org/10.1002/art.34453.

Lowman, S.A., 2017. A Bioarchaeological Approach to Social Transition in the Pre-hispanic Andes: A Diachronic Study of Health at Tumilaca La Chimba, Peru. MA Thesis. Department of Anthropology, Georgia State University, Atlanta.

Macintosh, A.A., Pinhasi, R., Stock, J.T., 2017. Prehistoric women's manual labor exceeded that of athletes through the first 5500 years of farming in Central Europe. Sci. Adv. 3. http://advances.sciencemag.org/content/3/11/eaao3893.

Man, G.S., Mologhianu, G., 2014. Osteoarthritis pathogenesis - a complex process that

involves the entire joint. J. Med. Life 7, 37–41. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3956093/.
McCullagh, P., Nelder, J.A., 1989. Generalized Linear Models, 2nd ed. Chapman &Hall/CRC Press, Boca Raton, FL.
Merbs, C.F., 1983. Patterns of Activity-induced Pathology in a Canadian Inuit Population. University of Ottawa Press.
Meyer, C., Nicklisch, N., Held, P., Fritsch, B., Alt, K.W., 2011. Tracing patterns of activity in the human skeleton: an overview of methods, problems, and limits of interpretation. HOMO 62, 202–217. https://doi.org/10.1016/j.jchb.2011.03.003.
Michopoulou, E., Nikita, E., Henderson, C.Y., 2017. A test of the effectiveness of the Coimbra method in capturing activity-induced entheseal changes. Int. J. Osteoarchaeol. 27, 409–417. https://doi.org/10.1002/oa.2564.
Michopoulou, E., Nikita, E., Valakos, E.D., 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. Am. J. Phys. Anth. 158, 557–568. https://doi.org/10.1002/ajpa.22822.
Milella, M., 2014. The influence of life history and sexual dimorphism on entheseal changes in modern humans and african great apes. PLoS One 9, e107963. https://doi.org/10.1371/journal.pone.0107963.
Milella, M., Cardoso, F.A., Assis, S., Lopreno, G.P., Speith, N., 2015. Exploring the relationship between entheseal changes and physical activity: a multivariate study. Am. J. Phys. Anth 156, 215–223. https://doi.org/10.1002/ajpa.22640.
Miller, E., Ragsdale, B.D., Ortner, D.J., 1996. Accuracy in dry bone diagnosis: a comment on palaeopathological methods. Int. J. Osteoarchaeol. 6, 221–229. https://doi.org/10.1002/(SICI)1099-1212(199606)6:3 < 221::AID-OA267 > 3.0.CO;2-2.
Miller, M.J., Agarwal, S.C., Aristizabal, L., Langebaek, C., 2018. The daily grind: sex- and age-related activity patterns inferred from cross-sectional geometry of long bones in a pre-Columbian Muisca population from Tibanica, Colombia. Am. J. Phys. Anth. 167, 311–326. https://doi.org/10.1002/ajpa.23629.
Morimoto, N., De León, M.S.P., Zollikofer, C.P.E., 2011. Exploring femoral diaphyseal shape variation in wild and captive chimpanzees by means of morphometric mapping: a test of Wolff's Law. Anatom. Rec. 294, 589–609. https://doi.org/10.1002/ar.21346.
Nelson, A., Nelson, C., Castillo, L.J., MacKey, C., 2000. Osteobiografía de una hilandera precolombina. Iconos. Revista Peruana de Conservación y Arqueología 4, 30–43.
Neves, W., 1984. Incidência e distribuição de osteoartrites em grupos coletores do litoral do paraná: uma abordagem osteobiográfica. CLIO 6, 47–62.
Nicholson, S., Dickman, K., Maradiegue, A., 2009. Reducing premature osteoarthritis in the adolescent through appropriate screening. J. Ped. Nurs. 24, 69–74. https://doi.org/10.1016/j.pedn.2008.03.009.
Niinimäki, S., Salmi, A.K., 2016. Entheseal changes in free-ranging versus zoo reindeer—observing activity status of reindeer. Int. J. Osteoarchaeol. 26, 314–323. https://doi.org/10.1002/oa.2423.
Nikita, E., 2014. The use of generalized linear models and generalized estimating equations in bioarchaeological studies. Am. J. Phys. Anth. 153, 473–483. https://doi.org/10.1002/ajpa.22448.
Nikita, E., Mattingly, D., MirazónLahr, M., 2013. Methodological considerations in the statistical analysis of degenerative joint and disc disease. Int. J. Paleopath. 3, 105–112. https://doi.org/10.1016/j.ijpp.2013.03.002.
Ortner, D.J., 2011. Human skeletal paleopathology. Int. J. Paleopath. 1, 4–11. https://doi.org/10.1016/j.ijpp.2011.01.002.
Ortner, D.J., 2012. Differential diagnosis and issues in disease classification. In: Grauer, A.L. (Ed.), A Companion to Paleopathology. Blackwell, Malden, MA, pp. 250–267.
Palmer, J.L.A., Hoogland, M.H.L., Waters-Rist, A.L., 2016. Activity reconstruction of post-medieval Dutch rural villagers from upper limb osteoarthritis and entheseal changes. Int. J. Osteoarchaeol. 26, 78–92. https://doi.org/10.1002/oa.2397.
Pearson, O.M., Buikstra, J.E., 2006. Behavior and the bones. In: Buikstra, J.E., Beck, L.A. (Eds.), Bioarchaeology: The Contextual Analysis of Human Remains. Elsevier, Amsterdam, pp. 207–225.
Pechenkina, E.A., Delgado, M., 2006. Dimensions of health and social structure in the Early Intermediate Period cemetery at Villa el Salvador. Peru. Am. J. Phys. Anth. 131, 218–235. https://doi.org/10.1002/ajpa.20432.
Perréard Lopreno, G., Alves Cardoso, F., Assis, S., Milella, M., Speith, N., 2013. Categorization of occupation in documented skeletal collections: its relevance for the interpretation of activity-related osseous changes. Int. J. Osteoarchaeol. 23, 175–185. https://doi.org/10.1002/oa.2301.
Pomeroy, E., 2013. Biomechanical insights into activity and long distance trade in the South-central Andes (AD 500–1450). J. Archaeol. Sci. Rep. 40, 3129–3140. https://doi.org/10.1016/j.jas.2013.04.019.
Ponce, P.V., 2010a. Biosocial aspects of sexual division of labour among prehistoric chinchorro people. Soc. Bio. Hum. Affairs 75, 41–65.
Ponce, P.V., 2010b. A Comparative Study of Activity-related Skeletal Changes in 3rd-2nd Millennium Bc Coastal Fishers and 1st Millenium Ad Inland Agriculturists in Chile, South America,. PhD Dissertation. Department of Archaeology, Durham University, Durham, UK.
Ponce, P.V., 2012. A comparative study of markers of occupational stress in coastal fishers and inland agriculturalists from northern chile. In: Mitchell, P.D., Buckberry, J. (Eds.), Proceedings of the Twelve Annual Conference of the British Association for Biological Anthropology and Osteoarchaeology - British Archaeological Reports International Series 2380. Archaeopress, Oxford, pp. 71–85.
Rhode, M.P., 2006. Habitual Subsistence Practices Among Prehistoric Andean Populations: Fishers and Farmers. PhD Dissertation. Department of Anthropology, University of Missouri-Columbia, Columbia, MO.
Rodriguez-Fontenla, C., Gonzalez, A., 2015. Genetics of osteoarthritis. Reumatología Clínica (English Edition) 11, 33–40.
Rogers, J., Waldron, T., Dieppe, P., Watt, I., 1987. Arthropathies in palaeopathology: the basis of classification according to most probable cause. J. Archaeol. Sci. Rep. 14, 179–193. https://doi.org/10.1016/0305-4403(87)90005-7.
Ruff, C., Hayes, W., 1983. Cross-sectional geometry of pecos pueblo femora and tibiae - a biomechanical investigation: I. Method and general patterns of variation. Am. J. Phys. Anthropol. 60, 359–381. https://doi.org/10.1002/ajpa.1330600308.
Ruff, C.B., 1999. Skeletal structure and behavior patterns of prehistoric great basin populations. In: Hemphill, B., Larsen, C. (Eds.), Understanding Prehistoric Lifeways in Great Basin Wetlands: Bioarchaeological Reconstruction and Interpretation. University of Utah Press, Salt Lake City, pp. 290–320.
Ruff, C.B., 2000. Biomechanical analyses of archaeological human skeletons. In: Katzenberg, M., Saunders, S. (Eds.), Biological Anthropology of the Human skeleton. Wiley-Liss, New York, pp. 71–102.
Ruff, C.B., Holt, B., Trinkaus, E., 2006. Who's afraid of the big bad Wolff?: "Wolff's law" and bone functional adaptation. Am. J. Phys. Anthropol. 129, 484–498. https://doi.org/10.1002/ajpa.20371.
Ruff, C.B., Larsen, C.S., 2001. Reconstructing behavior in spanish florida. In: Larsen, C. (Ed.), Bioarchaeology of Spanish florida: The Impact of Colonialism. University Press of Florida, pp. 113–145.
Runestad, J., Ruff, C., Nieh, J., Thorington, R., Teaford, M., 1993. Radiographic estimation of long bone cross-sectional geometric properties. Am. J. Phys. Anth. 90, 207–213. https://doi.org/10.1002/ajpa.1330900207.
Schalkwyk, O.Lv., Skinner, J.D., Mitchell, G., 2004. A comparison of the bone density and morphology of giraffe (*giraffa camelopardalis*) and buffalo (*syncerus caffer*) skeletons. J. Zool. 264, 307–315. https://doi.org/10.1017/S0952836904005795.
Schlecht, S.H., 2012. Understanding entheses: bridging the gap between clinical and anthropological perspectives. Anat. Rec. 295, 1239–1251. https://doi.org/10.1002/ar.22516.
Schrader, S.A., 2012. Activity patterns in New Kingdom Nubia: an examination of entheseal remodeling and osteoarthritis at Tombos. Am. J. Phys. Anth. 149, 60–70. https://doi.org/10.1002/ajpa.22094.
Schrader, S.A., 2019. Activity, Diet and Social Practice: Addressing Everyday Life in Human Skeletal Remains. Springer, Cham, Switzerland.
Schrader, S.A., Buzon, M.R., 2017. Everyday life after collapse: a bioarchaeological examination of entheseal change and accidental injury in Postcolonial Nubia. Bioarch. Int. 1, 19–34. https://doi.org/10.5744/bi.2017.1000.
Sládek, V., Berner, M., Sailer, R., 2006. Mobility in central european late eneolithic and early bronze age: femoral cross-sectional geometry. Am. J. Phys. Anthropol. 130, 320–332. https://doi.org/10.1002/ajpa.20372.
Spahn, G., Lipfert, J.U., Maurer, C., Hartmann, B., Schiele, R., Klemm, H.-T., Grifka, J., Hofmann, G.O., 2017. Risk factors for cartilage damage and osteoarthritis of the elbow joint: case-control study and systematic literature review. Arch. Orthoped. Trauma Surgery 137, 557–566. https://link.springer.com/article/10.1007/s00402-017-2654-6.
Stirland, A., 1998. Musculoskeletal evidence for activity: problems of evaluation. Int. J. Osteoarchaeol. 8, 354–362. https://doi.org/10.1002/(SICI)1099-1212(1998090)8:5 < 354::AID-OA432 > 3.0.CO;2-3.
Stock, J.T., Shaw, C.N., 2007. Which measures of diaphyseal robusticity are robust? A comparison of external methods of quantifying the strength of long bone diaphyses to cross-sectional geometric properties. Am. J. Phys. Anth. 134, 412–423. https://doi.org/10.1002/ajpa.20686.
Titelbaum, A.R., 2012. Habitual Activity and Changing Adaptations at the El Brujo Archaeological Complex: a Diachronic Investigation of Musculoskeletal Stress and Degenerative Joint Disease in the Lower Chicama Valley of Northern Coastal Peru. PhD Dissertation. Department of Anthropology, Tulane University, New Orleans.
Torres-Rouff, C., Knudson, K.J., 2007. Examining the life history of an individual from Solcor 3, San Pedro de Atacama: combining bioarchaeology and archaeological chemistry. Chungara 39, 235–257. https://www.jstor.org/stable/27802486.
Toyne, J.M., 2002. Tales Woven in Their Bones: the Osteological Examination of the Human Skeletal Remains From the Stone Temple at Túcume, Peru. MA Thesis. Department of Anthropology, University of Western Ontario, London, Ontario.
Toyne, J.M., 2004. A Fisherman's Signature? An Observation of Activity Marker Patterns in a Pre-columbian Coastal Sample From Punta Lobos, Huarmey River Valley, Northern Coastal Peru. Paleopathol. Newsl. 9–20 September.
Toyne, J.M., 2008. Offering Their Hearts and Heads: a Bioarchaeological Analysis of Ancient Human Sacrifice on the Northern Coast of Peru. PhD Dissertation. Department of Anthropology, Tulane University, New Orleans.
Trinkaus, E., Churchill, S., 1999. Diaphyseal cross-sectional geometry of near eastern middle paleolithic humans: the humerus. J. Archaeol. Sci. 26, 173–184. https://doi.org/10.1006/jasc.1998.0314.
Verano, J.W., 1986. A mass burial of mutilated individuals at pacatnamu. In: Donnan, C.B., Cock, G.A. (Eds.), The Pacatnamu Papers. Museum of Cultural History, Los Angeles, pp. 117–138.
Verano, J.W., 1995. Where do they rest? The treatment of human offerings and trophies in ancient Peru. In: Dillehay, T.D. (Ed.), Tombs for the Living: Andean Mortuary Practices. Dumbarton Oaks, Washington, DC, pp. 189–227.
Verano, J.W., 1997. Advances in the paleopathology of Andean South America. J. World Prehist. 11, 237–268. https://link.springer.com/article/10.1007/BF02221205.
Verano, J.W., 2001. The physical evidence of human sacrifice in ancient Peru. In: Benson, E.P., Cook, A.G. (Eds.), Ritual Sacrifice in Ancient Peru. University of Texas Press, Austin, pp. 165–184.
Verano, J.W., 2008. Trophy head-taking and human sacrifice in Andean South America. In: Silverman, H., Isbell, W.H. (Eds.), Handbook of South American Archaeology. Springer, New York, pp. 1047–1060.
Verano, J.W., 2013. Excavation and analysis of human skeletal remains from a new dedicatory offering at Tiwanaku. In: Vranich, A., Levine, A.R. (Eds.), Advances in Titicaca Basin Archaeology-2. Cotsen Institute of Archaeology, Los Angeles, pp.

167–182.
Verano, J.W., 2014. Warfare and captive sacrifice in the moche culture: the battle continues. In: Scherer, A.W., Verano, J.W. (Eds.), Embattled Bodies, Embattled Places: War in pre-Columbian Mesoamerica and the Andes. Dumbarton Oaks, Washington, D.C, pp. 283–310.
Villotte, S., Castex, D., Couallier, V., Dutour, O., Knüsel, C.J., Henry-Gambier, D., 2010. Enthesopathies as occupational stress markers: evidence from the upper limb. Am. J. Phys. Anth. 142, 224–234. https://doi.org/10.1002/ajpa.21217.
Villotte, S., Knüsel, C.J., 2013. Understanding entheseal changes: definition and life course changes. Int. J. Osteoarchaeol. 23, 135–146. https://doi.org/10.1002/oa.2289.
Wallace, I.J., Winchester, J.M., Su, A., Boyer, D.M., Konow, N., 2017. Physical activity alters limb bone structure but not entheseal morphology. J. Hum. Evol. 107, 14–18. https://doi.org/10.1016/j.jhevol.2017.02.001.
Warner, S.C., Valdes, A.M., 2016. The genetics of osteoarthritis: a review. J. Funct. Morpho. Kinesiol. 1, 140.
Weiss, E., 2005. Humeral cross-sectional morphology from 18th century Quebec prisoners of war: limits to activity reconstruction. Am. J. Phys. Anth. 126, 311–317. https://doi.org/10.1002/ajpa.20069.
Weiss, E., 2007. Muscle markers revisited: activity pattern reconstruction with controls in a Central California amerind population. Am. J. Phys. Anth. 133, 931–940. https://doi.org/10.1002/ajpa.20607.
Weiss, E., 2015. Examining activity patterns and biological confounding factors: differences between fibrocartilaginous and fibrous musculoskeletal stress markers. Int. J. Osteoarchaeol. 25, 281–288. https://doi.org/10.1002/oa.2290.
Weiss, E., Jurmain, R., 2007. Osteoarthritis revisited: a contemporary review of aetiology. Int. J. Osteoarchaeol. 17, 437–450. https://doi.org/10.1002/oa.889.
Wescott, D., Cunningham, D., 2006. Temporal changes in Arikara humeral and femoral cross-sectional geometry associated with horticultural intensification. J. Archaeol. Sci. 33, 1022–1036. https://doi.org/10.1016/j.jas.2005.11.007.
Wise, K., Clark, N.R., Williams, S.R., 1994. A late Archaic period burial from the South-central Andean coast. Latin Am. Antiq. 5, 212–227. https://doi.org/10.2307/971881.
Yonemoto, S., 2016. Differences in the effects of age on the development of entheseal changes among historical Japanese populations. Am. J. Phys. Anth. 159, 267–283. https://doi.org/10.1002/ajpa.22870.
Yucesoy, B., Charles, L.E., Baker, B., Burchfiel, C.M., 2015. Occupational and genetic risk factors for osteoarthritis: a review. Work 50, 261–273. https://content.iospress.com/articles/work/wor01739.