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The Osteological Paradox 20 Years Later: Past Perspectives, Future Directions

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Abstract More than 20 years ago, Wood et al. (Curr Anthropol 33:343–370, 1992) published "The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples," in which they challenged bioarchaeologists to consider the effects of heterogeneous frailty and selective mortality on health inferences in past populations. Here, we review the paper's impact on bioarchaeology and paleopathology, focusing on recent advancements in studies of ancient health. We find the paper is often cited but infrequently engaged in a meaningful way. Despite an initial decade of limited progress, numerous researchers are now addressing components of the Paradox in more informed ways. We identify four areas of fruitful research: (1) intrasite, contextual perspectives, (2) subadults, (3) associating stress markers with demographic phenomena, and (4) skeletal lesion-formation processes. Although often seen as a problematic assumption, understanding the sources of heterogeneous frailty within human populations is a worthy research question in and of itself, and one that clearly links past and present health research within a global framework.

Keywords Paleopathology · Bioarchaeology · Ancient health · Demography · Sample bias · Mortality · Morbidity

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Introduction

Bioarchaeology is the study of skeletal remains from archaeological contexts to reconstruct the lifeways of past peoples (Buikstra 1977; Buikstra and Beck 2006; Larsen 1997). The field emerged as a distinct area of practice during the 1970s, borrowing elements from both the New Physical Anthropology and the New Archaeology through its emphasis on setting past human lives within broader social contexts. The goals of bioarchaeology differ slightly among practitioners (e.g., Buikstra 2006; Buikstra et al. 2012; Knüsel 2010; Larsen 2006; O'Donnabhain and Lozada 2014; Rakita 2014; Stojanowski and Duncan 2015), with some emphasizing social context and others placing the human skeleton within an evolutionary, adaptationist framework. Bioarchaeological data typically comprise information on burial taphonomy, paleodiet inferred through light stable isotopes, mobility inferred through heavy stable isotopes and long-bone morphology, evolutionary relationships as indicated by cranial and dental morphology, cultural body modifications, trauma and injury, dental health, skeletal stress, and disease experience (Grauer 2012; Katzenberg and Saunders 2008). Scholars often refer to the last two of these (skeletal stress and disease experience) as the study of "ancient health" despite the difficulties faced with defining health even in living populations (Brüssow 2013; Huber et al. 2011). Nonetheless, the study of skeletal stress indicators and disease experience has been a prominent aspect of bioarchaeological inquiry for the last three decades and continues to anchor many research foci. Indeed, paleopathology (the study of diseases in the past) and paleoepidemiology (the study of population-level disease dynamics in the past) are robust fields, as evidenced by recent synthetic book-length treatments (see Buikstra and Roberts 2012; Cohen and Crane-Kramer 2007a; Grauer 2012; Pinhasi and Stock 2011; Steckel and Rose 2002), the visibility of paleopathological research in flagship journals (e.g., *American Journal of Physical Anthropology*, *International Journal of Osteoarchaeology*), and the recent emergence of a distinct journal dedicated specifically to the topic (*International Journal of Paleopathology*).

The study of health and disease in the human past has experienced a number of changes in focus and challenges since the emergence of bioarchaeology from its descriptive phase in the 1970s (Buikstra and Roberts 2012; Cook and Powell 2006; Powell and Cook 2012). These challenges include small sample sizes, poor preservation and sample representativeness, selection biases that arise from mortuary practices, and time averaging of skeletal assemblages (for overviews see Jackes 2011; Ortner 2002, 2009; Pinhasi and Bourbou 2008; Waldron 1994, 2007). These are well-known and widely recognized limitations of archaeological research in general. Studies of ancient health, however, have an additional and unique set of challenges. For example, only a subset of diseases that affect humans also affect the skeleton, which constrains the depth of inference we can generate about health experience in past populations. This problem is exacerbated by inconsistencies in diagnostic criteria among researchers and the typically minimal information available from incomplete skeletal remains (Appleby et al. 2015; Brickley and Buckberry 2015).

Furthermore, health is notoriously difficult to define among living peoples (Brüssow 2013; Gage and DeWitte 2009), so much so that Jadad and O'Grady (2008) suggest that attempts to define health might be "futile." The current World Health Organization's definition of health, introduced in 1948, is "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO 2003). Researchers criticize the WHO's definition on the grounds that it is difficult to operationalize and measure "complete" well-being (Jadad and O'Grady 2008). Huber et al. (2011, p. 3) propose a formulation of health "as the ability to adapt and to self manage"; this includes the maintenance of physiological homeostasis, the ability to participate in social activities, and a sense of mental coherence. Researchers struggle to apply these concepts in meaningful and reproducible ways in studies of living populations. Difficult as it is to define health in living populations, it is even more difficult to do so for past populations. Health is a concept fundamentally linked to the conditions of the living, yet our data consist of those who have already died and for whom we cannot assess such phenomena as mental states or participation in social activities. Furthermore, WHO surveys designed to assess health states include eight "core domains of health": mobility, self-care, pain and discomfort, cognition, interpersonal activities, vision, sleep and energy, and affect (Prüss-Üstün et al. 2003, p. 30). Responses to the survey yield a metric that ranges from 0 (death) to 1 (perfect health) (Brüssow 2013). Given that so few of these domains can be observed in skeletal samples, perhaps the only unambiguous assessment of health that we can make for skeletons is that they are all, at the time of observation, in very poor health, as death is the ultimate state of poor health. A recent special issue of *American Journal of Physical Anthropology* includes several articles that grapple with the problems of defining health in the past (e.g., Reitsema and McIlvaine 2014; Temple and Goodman 2014; Wilson 2014), highlighting the persistence of these issues and potential avenues for incorporating findings and perspectives from other fields (e.g., DeWitte 2014; Kinnally 2014; Piperata et al. 2014; Tanner and Team 2014; Vercellotti et al. 2014). The fundamental fact that we use samples of the dead to reconstruct characteristics of once-living people is both obvious and perplexing and anchors what is known as the Osteological Paradox.

In their seminal paper, "The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples," Wood et al. (1992) described several fundamental problems inherent to paleodemographic and paleopathological analyses of past populations using data from human skeletons excavated from archaeological sites. These problems include (1) hidden heterogeneity in frailty, that is, individuals are unequal with respect to their susceptibility to different diseases and stressors and their risks of death; (2) selective mortality, that is, our data come from samples of the dead that are biased representatives of the once-living populations; and (3) demographic nonstationarity reflecting the fact that cemetery assemblages might be derived from populations that experienced migration or temporal changes in fertility and mortality. Wood et al.'s paper was published more than 20 years after substantial changes in the field were pioneered by researchers interested in changing health patterns across major human subsistence transitions (Armelagos 1969; Buikstra and Cook 1980; Goodman et al. 1988; Larsen 1987;

Weiss 1973). Research shifted away from the narrowly focused descriptive analysis of lesions and relatively simple tabulations of age and sex data toward more hypothesis-driven comparative research on population-level health, population demography, and evolutionary processes (Armelagos 2003; Buikstra and Roberts 2012; Cook and Powell 2006; Goodman and Martin 2002; Powell and Cook 2012; Wood et al. 1992). The problems of nonstationarity, selective mortality, and heterogeneous frailty complicate the study of demographic patterns and disease in past populations. In particular, these issues prevent us from making inferences about health and mortality *directly* from such measures as the mean age at death, estimation of life expectancy, or frequencies of skeletal lesions estimated from skeletal samples—what Milner (2013) calls the "conventional wisdom" approach—as had become the standard practice in the preceding decades.

The Osteological Paradox built on the work of other authors who had previously noted similar challenges. For example, Cook (1981), Cook and Buikstra (1979), and Guagliardo (1982) broached the issue of subadult mortality bias; Cadien et al. (1974) and Waldron (1994, 1996) discussed the complex relationship between the living population and the dead that form cemetery assemblages; and Angel (1975), Ortner (1991, 1992, 1998), and Harpending (1990)—a co-author of the Wood et al. paper—discussed the issue of survivorship and lesion-manifestation timing. Why Wood et al. made such an impact is unclear, but the paper was exceptionally well timed, published on the heels of the Bocquet-Appel and Masset (1982) (eschatological) critique of paleodemography's methods from which bioarchaeology was still reacting. The publication of the Osteological Paradox also coincided with the Columbian quincentennial, an event that initiated concerted exploration of the health and demographic consequences of European colonialism (Baker and Kealhofer 1996; Larsen et al. 2001; Thomas 1990a, b, c; Verano and Ubelaker 1992). Regardless, the paper initiated considerable debate and reflection that shows no signs of abating (see exchanges in Boldsen and Milner 2012; Cohen and Crane-Kramer 2007b; Milner 2013). It is a seminal paper in the field and one that is routinely incorporated into the pedagogy of bioarchaeology at the graduate and undergraduate levels. Our reading of the broader literature, however, suggests that although people often mention the tenets of the Osteological Paradox, they less frequently consider them seriously and rarely implement them directly in paleopathological research design.

Here we review Wood et al.'s (1992) paper and discuss the initial reactions to it. We focus on the key components of the critique with respect to ancient health research (hidden heterogeneity and selective mortality) and trace the paper's impact on the practice of paleopathology and paleoepidemiology. In a previous review of the topic, Wright and Yoder (2003) noted that, at the time of their writing, there had been few bioarchaeological studies that had explicitly addressed the Osteological Paradox. Our goal is to assess how this situation has changed and to summarize the recent work that speaks directly to advances in our understanding of ancient health. Because Wood et al. have polarized the field to some extent, we focus on the Osteological Paradox as an important and seminal document in the history of the field, attempt to dispel misperceptions about what their paper says and does not say, and establish a baseline from which future work can be situated. Our reading of the

broader literature identifies four topics for which the Osteological Paradox has been productively engaged: (1) research leveraging archaeological context, (2) research on individuals who died as subadults, (3) estimation of the associations between stress markers and demographic phenomena, and (4) research on the etiology and physiology of skeletal lesion formation.

The conventional approach to paleopathology and paleoepidemiology in bioarchaeology

Before discussing the Osteological Paradox in detail, we provide a brief overview of the practices of paleopathology and paleoepidemiology. Paleopathology is the study of ancient disease, including the origins and spatial–temporal distributions of diseases. The field has an origin independent of bioarchaeology but is now often practiced as a research specialization within the field as reflected in the pedagogy of the discipline and article keyword tagging. Paleopathology, broadly defined, includes both human and nonhuman cases, can be primarily medically oriented, and is focused on the manifestations or history of a disease itself and not necessarily on health-related inferences at the population level (Harper et al. 2011; Marden and Ortner 2011; Telldahl 2012; Thomas and Johannsen 2011). More recently, the field has expanded in focus, with greater emphasis on disability identity, wellness, care and compassion, and sickness ideology (Hawkey 1998; Hubert 2000; Marsteller et al. 2011; Oxenham et al. 2009; Roberts 2000; Tilley and Cameron 2014; Tilley and Oxenham 2011). Osteobiography—focusing on individual prehistoric lives through bioarchaeological analysis—continues to exert a strong presence (Stodder and Palkovich 2012; Zvelebil and Weber 2013), reflecting the diversity of topics, including more humanistic ones, that paleopathologists explore. For many of these

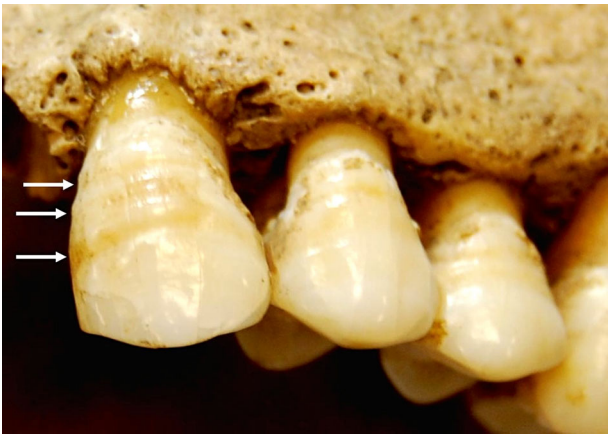

Fig. 1 Adult left maxillary canine and premolars with linear enamel hypoplasias, indicated by arrows. Enamel hypoplasias are visible and palpable grooves that run horizontally across the surface of the crown of the tooth (photo: Sharon DeWitte)

topics, the Osteological Paradox may be irrelevant. For example, methodological papers, those that focus on specific diseases and their histories, and pathological case studies that are primarily descriptive are not subject to the potential pitfalls of comparative analysis (see Armelagos and Van Gerven 2003; Mays 2012; Powell and Cook 2012; Stojanowski and Buikstra 2005).

Paleoepidemiology is the study of disease dynamics in past human populations and is one component of a broader paleopathological research program. Paleoepidemiology focuses on sites or cemeteries as the primary unit of analysis based on the assumption that the aggregate patterns of disease reflect health in the living population. Research design is comparative across space (e.g., within a regional exchange network), through time (e.g., across a subsistence transition), or across dimensions of social, cultural, or ethnic significance (core–periphery comparisons, urban–rural, elite–commoner, etc.). Although researchers often highlight specific diseases (scurvy, rickets, tuberculosis) when encountered, the vast majority of paleoepidemiological research focuses on more general, nonspecific, and macroscopic indicators of stress and presumed poor health. These indicators include enamel hypoplasias as markers of early childhood stress (Fig. 1; Goodman and Rose 1990; Roberts and Manchester 2005); oral health disorders, such as dental caries, periodontal disease, and abscesses (Fig. 2; Larsen 1997); periosteal reactions as signatures of bone infections or trauma (Figs. 3, 4); osteomyelitis as an indicator of infection with pyogenic bacteria (Fig. 5; Klaus 2014; Larsen 1997); and cribra orbitalia (Fig. 6) and porotic hyperostosis (Fig. 7) reflecting bodily response to anemia (Huss-Ashmore et al. 1982; Walker et al. 2009). The basic approach is to collect comparable data from a series of sites or samples that crosscut parameters of interest (space, time, culture); generate frequencies of each health indicator; and compare these frequencies across sites, time periods, or cultural groups. Although this brief description does not characterize the totality of paleoepidemiological research, it does represent a highly accessible approach that a majority of

Fig. 2 Right hemi-mandible observed from the lingual aspect (tongue side). The large hole in the lingual side of the mandible, indicated by an arrow, represents an abscess that was active at the time of death. The abscess penetrated through the mandibular body and also affected the buccal aspect (cheek side). The corresponding second molar is absent and likely lost due to the disease process (courtesy of Glen Doran)

Fig. 3 Adult tibia with healed periosteal new bone formation. The entire visible surface of the bone is affected by the abnormal proliferation of bone. The uneven surface is perforated by small holes with rounded margins, characteristic of healed lesions (photo: Sharon DeWitte)

Fig. 4 Shaft of a long bone from an infant showing severe and active persiosteal reaction. The dark, brown surface represents healthy unaffected bone, while the elevated gray bone is the result of new bone formation in response to some insult. The periosteal reaction consists of woven bone and was active and not healing at the time of death (photo: Chris Stojanowski) (Color figure online)

Fig. 5 Shaft of a human tibia showing osteomyelitis, represented by the uneven appearance of the external shaft of the bone, the presence of microporosity and macroporosity, and the large cloacae (holes) for drainage of pus from the internal surface of the shaft. The entire external surface of the bone is affected in this individual (photo: Chris Stojanowski)

Fig. 6 Left orbit of an adult with cribra orbitalia. Most of the orbital surface is normal cortical bone, which is smooth and dense. The cribra orbitalia appears as a scatter of micro- and macroporosity along the anterior and lateral margins. The arrow indicates just one of several of the abnormal holes characteristic of cribra orbitalia (photo: Sharon DeWitte)

Fig. 7 Posterior view of an adult skull with healed porotic hyperostosis. Most of the visible surface of the skull is covered by healed periosteal lesions, which are characterized by clusters of small holes with rounded margins (photo: Sharon DeWitte)

paleoepidemiological scholars have used successfully for several decades. Using this approach, bioarchaeologists have contributed significantly to the examination of the health consequences of the transition to agriculture (Bocquet-Appel et al. 2008;

Bocquet-Appel and Bar-Yosef 2008; Cohen and Armelagos 1984; Cohen and Crane-Kramer 2007a; Harper and Armelagos 2013; Oxenham and Tayles 2006; Pinhasi and Stock 2011; Steckel and Rose 2002); changes in aggregate health experience in Native American populations during the European colonial period (Baker and Kealhofer 1996; Larsen et al. 2001; Thomas 1990a, b, c; Verano and Ubelaker 1992); and the health consequences of urbanization (Lewis and Gowland 2007) and the industrial revolution (Lewis 2002; Zuckerman 2014).

The Osteological Paradox complicates studies that examine population-level trends or those that produce inferences that are relative in nature (better health, more stress). The frequency-based approach is particularly susceptible to hidden heterogeneity and selective mortality. The osteobiographic and the comparative populational frameworks, however, are two ends of a spectrum, both of which can be subject to the Paradox's constraints. For example, osteobiography that includes health comparisons that are framed in a relative manner should heed the warnings of Wood et al. In the absence of context, one cannot know if a 40–50-year-old male, who was 5.5 feet tall and with no visible signs of pathology or nonspecific stress, was healthy or not, was exposed to various pathological stressors or not, or suffered reduced longevity or not. Health is a relative, if poorly characterized, concept. This implies that pathological analyses of unique specimens, those of extreme age (e.g., Jantz and Owsley 1997; Shang and Trinkaus 2008; Trinkaus et al. 2008) or from poorly documented spatial–temporal contexts, may provide only limited health data beyond description for the purpose of documenting the history of a disease.

The Osteological Paradox

Wood et al.'s paper identified and developed three key conceptual challenges to the interpretation of health in past populations: demographic nonstationarity, selective mortality, and heterogeneous frailty. We discuss each of these in greater detail below.

A population that is not stationary is one that experiences population growth or decline because of changes in fertility, mortality, or migration. Many traditional bioarchaeological analyses, particularly within the realm of paleodemography, are based on the assumption that the population under consideration was stationary (Coale 1957). This assumption allows the construction of a life table based directly on the observed distribution of ages at death in a skeletal sample (which, if a population is in fact stationary, is equivalent to the column in a standard life table that represents the numbers of individuals dying within each age interval) (Wood et al. 2002). From a life table, one can assess phenomena such as life expectancies at each age and the force of mortality during each age interval. Unfortunately, if a population is not stationary, demographic estimates based on observed skeletal age-at-death distributions might not be accurate. For example, if a population experienced growth or decline, estimates of life expectancy will be underestimated or overestimated, respectively, even if mortality remained constant (Sattenspiel and Harpending 1983). These estimation problems occur because, even if mortality does not change over time, the proportion of infants and young children in a cemetery

associated with a growing population will increase. Conversely, in a cemetery associated with a declining population, the proportion of young individuals will drop over time. Sattenspiel and Harpending (1983) and Paine (1989), among others, have described the problem of demographic nonstationarity from a bioarchaeological perspective. Several researchers have proposed methods that address the probable violation of the stationarity assumption in past populations, such as using models that allow for the estimation of population growth rates or using proxies for birth rates based on the proportions of subadults in skeletal samples (Bocquet-Appel et al. 2008; Buikstra et al. 1986; Kohler and Reese 2014; White 2014; Wood et al. 2002). Archaeological research is also addressing migration and population growth (or decline) through isotope analysis (e.g., Beaumont et al. 2013; Keenleyside et al. 2011; Knudson et al. 2012), ancient DNA studies (e.g., Li et al. 2011; O'Fallon and Fehren-Schmitz 2011; Raff et al. 2011), biodistance analysis (e.g., McIlvaine et al. 2014; Torres-Rouff et al. 2013), and GIS-based analyses of settlement patterns and trends in population size (Jones 2010, 2014). Although demographic nonstationarity remains an important issue for bioarchaeologists, our primary focus here, following Wood et al. (1992), is on heterogeneous frailty and selective mortality, both of which affect ancient health research more directly.

The fundamental paradox in bioarchaeology is that we are attempting to reconstruct the lives and health conditions of people in past populations by using inherently biased samples of dead individuals. One reason why skeletal samples are unlikely to be representative of living populations is that every individual alive at a particular age is not at the same risk of dying at that age. It is much more likely that individuals in a population vary in terms of their relative risk of death compared with others in their birth cohort, and thus we should expect populations to be heterogeneous for frailty (the age-standardized relative risk of death) (Vaupel et al. 1979). This variation exists because of inherent biological differences (such as genetically determined immune responses or the generally immune-suppressive effects of testosterone), differences in exposure to disease vectors resulting from behavioral and cultural factors, differences in nutritional status, variation in environmental conditions, and other factors. In bioarchaeology, what we observe are aggregate patterns that can mask the underlying heterogeneity in the population. If not controlled for statistically, heterogeneous frailty can make it difficult to infer an individual's or subgroup's level of health or risk of dying or to compare general levels of health among different populations (Wood et al. 1992). If we can identify and control for potential sources of heterogeneity, such as sex or social status, it is possible to some extent to overcome the limitations of using aggregate skeletal data to examine individual and subgroup experiences in past populations. Complicating matters further, however, is what Wood et al. (1992) describe as "hidden" heterogeneity, wherein we cannot directly observe the variation in frailty. Although often treated as an assumption, documenting the causes and effects of heterogeneity in frailty is an interesting research question in and of itself, a point critical to discussions of the Osteological Paradox that is often overlooked.

Selective mortality acts upon heterogeneous frailty (Vaupel and Yashin 1985; Wood et al. 1992). Selective mortality refers to the fact that individuals who die at a given age are unlikely to be representative of the entire *living* population at risk of

death at that age. Instead, individuals with the highest frailty at a particular age are most likely to die at that age and thus be selected out of the population and enter skeletal samples. Because of selective mortality, one cannot use frequencies of stress markers in a skeletal sample to directly estimate the prevalence of the associated disorders in the once-living population. If stress markers are caused by conditions that increased risks of death, using the frequencies of skeletal stress markers to estimate the prevalence of the associated conditions would tend to produce overestimates of those conditions. Boldsen and Milner (2012) liken estimating disease prevalence from skeletal lesions to estimating the prevalence of various diseases in a living population by only observing people who are admitted to a hospital. In both cases, there is a strong possibility that one would have little to no information regarding the true population at risk and thus overestimate population prevalence. Even skeletal samples of individuals who died under catastrophic conditions or in episodes of warfare cannot be assumed to provide unbiased samples of all people who were once alive in a particular community (see Cox 1993; DeWitte and Wood 2008; Milner et al. 1991, 2008). For example, Milner et al. (1991) found that many adults in a skeletal sample from late prehistoric Illinois were killed by enemies and showed signs of debilitating conditions that would have hampered their ability to protect themselves or flee from danger.

According to Wood et al., the potential for heterogeneous frailty (and particularly hidden heterogeneity in frailty) and selective mortality means that we must be cautious when interpreting skeletal lesions or skeletal indicators of physiological stress (stress markers). Researchers often view skeletal stress markers as direct measures of health and interpret those individuals exhibiting stress markers as having been in poorer health than individuals without them. However, Wood et al., following Ortner (1991), suggest that some skeletal stress markers might *under some circumstances* actually indicate a relatively healthy individual. This is based on the fact that many of the visible stress markers that we typically analyze (such as periosteal new bone formation or cribra orbitalia) take time to form. They do not form immediately in response to trauma, disease, or other physiological disruptions but rather take weeks or months to become detectable. Individuals with stress markers might therefore have been healthier than their peers without them, given that they were able to survive malnutrition, trauma, or disease long enough for the stress marker to form. The absence of a certain stress marker might indicate relatively poor health, if individuals without them succumbed to illness, trauma, or malnutrition and died before stress markers formed. Wood et al. (1992) do not argue that stress markers are necessarily or even typically associated with better health; rather, bioarchaeologists cannot ignore that possibility in the absence of other supporting evidence.

Wood et al. identify four tasks to help address the challenges of heterogeneous frailty and selective mortality, three of which they deem to be beyond the purview of bioarchaeologists' expertise. First, they note that frailty is a poorly understood concept even in modern populations. Therefore, one goal should be to identify the sources of frailty in living people and to characterize the distribution of frailty among individuals in real world situations. Second, they note that we must have a better understanding of how a specific frailty distribution relates to variation in the

risks of death among individuals. This, in combination with the first goal, would allow for the construction of models to estimate the hidden heterogeneity in frailty within a population (Manton et al. 1986). The third point noted was that we need to better understand osteological indicators of sickness in terms of the dynamics of their formation and expression as affected by underlying biological/pathological processes and the health characteristics of the individual experiencing the insult. That is, we must better outline the process of lesion formation, and we must map variations in lesion-formation severity and onset to inter-individual variation in immune function. Wood et al. argue that contributions to these issues will most likely come from outside bioarchaeology rather than from osteologists themselves. Their fourth task, however, calls for bioarchaeologists to improve understanding of the role of cultural context for minimizing the effects of selective mortality and heterogeneous frailty on comparative patterns of health. Later in this paper, we assess the progress that has been made in addressing these four tasks.

Immediate reactions to the Osteological Paradox

The Osteological Paradox was published with comments from experts in the field and the authors' reply to those comments. The tenor of most comments is generally positive, with several researchers agreeing that heterogeneous frailty and selective mortality pose a problem for those interested in reconstructing life in the past and, indeed, for those whose focus is living populations, as pointed out by Lukacs (1992) and McGrath (1992). For example, Jankauskas and Česnys (1992) commend Wood et al. for attempting to respond to the need for theoretically sound approaches to evaluating skeletal data and emphasize the importance of collaborative projects for contextual analysis. Eisenberg (1992) focuses on the importance of distinguishing active and healed lesions. Hutchinson (1992) and Ubelaker (1992) reiterate longstanding issues of sample bias and its effects on patterns of pathological expression. Lukacs (1992) suggests that consideration of the relationships among the demographic characteristics of living populations, taphonomic processes, and the resulting skeletal assemblages, as presented by Wood et al., was long overdue. Comments by Cohen (1992) and Wilkinson (1992) were the most critical. Cohen emphasizes the use of multiple indicators and data types to tease apart signatures of poor and good health. His implication is that Wood et al. oversimplify research design greatly in their critique. Wilkinson agrees with the paper in theory but finds its applicability limited. In an often-overlooked commentary, Wilkinson also emphasizes the search for population subdivision within bioarchaeological samples and a refocusing of our attention on sites with less complex use histories, a point we return to later.

Several commentators characterize the Osteological Paradox as a new interpretation of skeletal lesions as indicators of good health (thus reversing the traditional view of lesions as indicators of poor health), and this is how the paper's message seems to have been interpreted by many over the last 20 years. McGrath and Wilkinson emphasize Wood et al.'s (1992, p. 356) statement that "better health makes for worse skeletons." McGrath indicates that Wood et al. are pointing out

that "individuals with skeletal lesions are *likely* to have been rather healthy" (1992, p. 362, emphasis added). Wood et al. write that statement, however, at the end of a description of a demographic model created to illustrate just one of several equally plausible interpretations of a particular set of data, and they make no judgments regarding the likelihood of any of the competing interpretations. Similarly, according to Eisenberg (1992, p. 359), Wood et al. "believe" that skeletal lesions and relatively young age at death typically characterize people from advantaged groups. Again, Wood et al. (1992, p. 355) express this as a *hypothesis* that is just as consistent with the data at hand as several other hypotheses, not as an idea that they "believe" to be true. Scholars have repeatedly attributed this new binary view—that skeletal lesions indicate relatively good health and an absence thereof indicates poor health—to Wood et al. over the last 20 years (e.g., Clark et al. 2014; Welinder 2001; Wright and Chew 1998), despite their attempt at clarification in their reply to the comments. Wood et al. encourage thinking that goes beyond simple binary distinctions. Although the presence of skeletal lesions is fairly clear evidence of exposure to some disease, the absence of lesions is, in their view, much more difficult to interpret. Wood et al. (1992, p. 365) emphasize that they do not suggest that the traditional interpretation of skeletal lesions (i.e., the presence of lesions indicates poor health) "must always be wrong"; rather they urge researchers to consider the possibility that skeletal lesions might, under some circumstances, indicate relatively good health and that we should not automatically assume otherwise. Despite their attempt at clarification, many people continue to characterize the Osteological Paradox in terms of skeletal lesions indicating good health; this might, unfortunately, have led some researchers to be prematurely dismissive of the suggestions offered by Wood et al. At the very least, undue emphasis on this specific aspect of the paper may have stalled the efforts of the other authors deemed more productive toward addressing the larger goals of research on ancient health.

Shortly after its publication, a number of papers directly responded to the Osteological Paradox, mostly in a reactive manner (Byers 1994; Cohen 1994; Goodman 1993; Jackes 1993); the paper by Saunders and Hoppa (1993) is the least reactive in tone. Jackes (1993) agrees with the overall tone of Wood et al.'s paper and the healthy skepticism it represents but feels the authors were giving a pass to some of the more fundamental and pressing issues of sample bias and the ineffectiveness of sex- and (especially) age-assessment techniques in bioarchaeology. In other words, Wood et al. do not go far enough in stating the direness of the bias problem. Concerns with archaeological biases continue to elicit considerable discussion in the field (see Jackes 2011) and are a perennially identified problem in paleopathology (Lukacs 1994; Mendonça de Souza et al. 2003; Ortner 2002, 2009; Pinhasi and Bourbou 2008; Waldron 1994).

Goodman (1993) reiterates his opinion that Wood et al. greatly overstate the importance of the Paradox and narrowly interpret the goals of paleoepidemiology. In particular, Goodman emphasizes the use of multiple stress indicators to overcome the concerns of the Osteological Paradox; he argues that different indicators reflect distinct aspects of the health experience of an individual. In addition, Goodman suggests that using multiple sources of information (the archaeological or historical

context) beyond just osteological indicators of pathology provides a more holistic reconstruction of health transitions through time. The repeatability of patterns across studies, sites, and time periods, and the use of modern analogs, all help contribute to proper interpretation of any particular pathology dataset. In a second response, Cohen (1994) acknowledges the reality of differential frailty and selective mortality but feels their effect on skeletal assemblages was greatly overstated. In particular, Cohen notes that Wood et al.'s reinterpretation of the agricultural transition was at odds with basic epidemiological theory and modern observations among living populations experiencing the transition to "20th-century conditions" (Cohen 1994, p. 630). In other words, differential frailty and selective mortality are theoretically and mathematically possible but at odds with reality, induce minimal effects on patterns of disease experience (because many deaths are due to random events), and are mitigated by multitrait analyses that emphasize consistent trends and analogs with modern datasets.

Byers' (1994) work was unique in suggesting a solution for identifying selective mortality based on distributional properties of metric variables that might be related to morbidity and mortality. Specifically, Byers proposes looking at skewness and kurtosis statistics for adult individuals, where positive skewness reflects selection against small stature in individuals who died as subadults. Because sample sizes need to be very large to detect significant departures from normality, Byers recommends looking at the patterning of positive and negative skewness among multiple metric indicators as a first approximation for determining whether bias may be affecting the observed sample. Despite a generally positive response by Wood and Milner (1994) and an expansion of the method, researchers have not widely adopted Byers' approach.

Lukacs (1994) also takes a second look at the Osteological Paradox in a follow-up paper in which he explores the relationship between paleopathological data and selectivity and heterogeneity of frailty. The details of the paper are worthy of serious consideration by those interested in paleoepidemiological research, and it is somewhat surprising that the paper has been cited only six times. Nonetheless, there are a number of important suggestions, including de-emphasizing prevalence data in favor of severity data, differentiating diseases that contribute to mortality from those that do not, distinguishing cases of pathological conditions that may have contributed to the death of a specific individual, carefully considering sources of sample bias, and looking closely at disease patterns at the intra-individual level within the context of age-structured pathology assessments.

Finally, Wood and Milner (1994) clarified some of the misconceptions with the original paper. Many of the points are quite specific and semantic and are not summarized here. Wood and Milner (1994) primarily take issue with Cohen's (1994) assertion that mortality is largely random and with Goodman's (1993) perceived misreading of several of the points they attempted to make. Wood and Milner stress that the argument is not about correct or incorrect interpretations of any particular dataset (such as those relevant to understanding the Neolithic transition), but about the existence of *equally plausible interpretations* for a given set of observations and our current inability to differentiate factors that produce a specific pattern. Wood and Milner's (1994) major point was that statistical models

need to be incorporated into research designs in order to better understand and account for the multitude of factors that contribute to the formation of archaeological cemetery samples.

Gauging the impact of the Osteological Paradox in bioarchaeology

In a previous review, Wright and Yoder (2003) summarized the decade of bioarchaeological research following publication of Wood et al. (1992), focusing on general methodological developments in bioarchaeology that *could* speak to the Osteological Paradox (not that these developments necessarily did so). By considering broader developments within the field, Wright and Yoder emphasized those aspects of paleopathology that Wood et al. (1992, p. 357) consider "widely recognized problems" with skeletal samples; they gave less attention to the core elements of the Osteological Paradox, those that require a "complete rethinking" of our approach to ancient health research. This emphasis on broader developments reflects the fact that little methodological progress had actually been made with regard to the challenges of the Osteological Paradox. Writing at about the same time, Ortner (2002) shared this opinion, commenting that the problems posed by Wood et al. were unresolved and in need of further debate and assessment regarding their severity and how best to deal with them. Goodman and Martin (2002, p. 13) offered a similar opinion; however, these authors reiterated the importance of using multiple stress or disease indicators in addressing Wood et al.'s concerns. These comments indicate just how nascent consideration of the Paradox was for the decade following its publication. Perhaps 10 years is too little time for the research and publication process to have unfolded.

Google Scholar data from 1992 to 2003 confirm that publications often cite Wood et al. (1992), but relatively few address the topics of selectivity and heterogeneity of frailty directly beyond the initial flurry of papers (discussed above) by Jackes (1993), Goodman (1993), Saunders and Hoppa (1993), Cohen (1994), and Byers (1994). Several papers within this time frame address related concerns, such as changes in long-term frailty with epidemic cycling (Paine and Boldsen 2002), sex-specific patterns of frailty and stress response (Ortner 1998; Sheridan and Van Gerven 1997), the ever-present issue of sampling bias (Mendonça de Souza et al. 2003; Saunders et al. 1995; Waldron 1994; see also Jackes 2011), and the continued defense of the specific interpretation of the Neolithic skeletal record (Cohen 1997, 2002). Wright and Yoder (2003) highlight papers by Storey (1997) and Wright and Chew (1998) as the only ones that directly assessed the impact of the Osteological Paradox using bioarchaeological data. To this we can add a paper by Lukacs (1994), Usher's (2000) dissertation, research by Boldsen (1997, 1998), and several chapters in the landmark volume by Steckel and Rose (2002) that address a critical aspect of the entire debate: Is the Osteological Paradox real and, if so, can it be identified in the archaeological record? Contributions in that volume are generally reactive in tone but are important, nonetheless, as they reflect the development of entrenched positions (see Armelagos and Brown 2002; Goodman and Martin 2002; Steckel and Rose 2002; Steckel et al. 2002).

To gauge the overall impact of the Osteological Paradox on bioarchaeological research, we downloaded all citations of Wood et al.'s paper from Google Scholar (data accessed 04/01/14). Wood et al.'s (1992) paper has been cited 558 times as of April 1, 2014. Publication venues are predominantly from bioarchaeology and biological anthropology, with site reports appearing in archaeology journals. The database includes relatively few papers whose goal is to directly address the Osteological Paradox and its implications (frailty and selectivity) as a subject worthy of inquiry in and of itself. These data confirm our subjective experience of the field's reaction. Excluding the original paper and the immediate responses published in 1993 and 1994 (as well as Wright and Yoder 2003), we identified only four papers that use the phrase "Osteological Paradox" in the title (Bombak 2012; Cohen 1997; Lukacs 1994; Siek 2013) and three papers that use the word "frailty" (Cucina 2011; DeWitte 2010; DeWitte and Bekvalac 2010). This disconnect between the sheer number of citations and the lack of papers that seem to specifically address the Paradox and its tenets begs the question exactly how the paper is being cited. To assess this, we sampled a subset of the complete dataset, focusing on papers published in 2012 and 2013 (roughly 10% of all citations are sampled, $n = 101$ papers). Four citation patterns emerged. The most common pattern is incidental reference to the Osteological Paradox as an important theoretical contribution ($n = 60$). Other papers cite the Osteological Paradox as a potential study limitation but do not directly account for frailty and selectivity ($n = 16$); papers in this category often reference Goodman's (1993) multitrait approach for overcoming the challenges of heterogeneity in frailty. An equal number of papers cite the Osteological Paradox in a post hoc manner as a possible explanation for contradictory results ($n = 16$); that is, when the data show conflicting signatures of comparative health, the Osteological Paradox is invoked as a possible explanation for the inconsistency. The fourth citation pattern directly addresses the Osteological Paradox's implications through consideration of frailty and selectivity in the bioarchaeological record ($n = 9$). It is within the pages of the last category of papers where true advances are occurring. We discuss these papers, and others, below.

Addressing the concerns of the Osteological Paradox

A number of studies published during the last 10 years have either directly addressed the Osteological Paradox or have advanced our understanding of lesion-formation processes, the dynamics of human frailty, and selective mortality in ways that improve our interpretations of paleopathological data. We identify four areas of emphasis that are apparent in recent bioarchaeological research, some of which have paralleled or incorporated advances made in other fields. In addition, these four topics align well with those defined by Wood et al. (1992) and reaffirmed by Wright and Yoder (2003). These include leveraging archaeological context to better inform ancient health inferences, focusing on subadults as non-survivors and age-structured comparisons of health data, estimation of the associations between lesions or other

potential markers of frailty and demographic phenomena, and examination of the etiology and physiology of skeletal lesion-formation.

Leveraging archaeological context

Of the four "tasks" identified by Wood et al., leveraging archaeological contextual information is the only one that fell entirely within the purview of bioarchaeology and paleopathology. It is also the task for which so little has been accomplished, at least as those authors define it. This does not mean the field has embraced a completely decontextualized approach to ancient health; in fact, this is completely opposite of the case, as strongly noted by early rebuttals to the Wood et al.'s critique (see Cohen 1992, 1994; Goodman 1993). Couching ancient health research within a historical or archaeological context, broadly defined, is not what Wood et al. suggested. Rather, they specifically call for a refocusing of paleopathological research on "simple societies" (noncomplex, egalitarian) and "simple sites" (those with short use histories and strong chronologies) as a means of minimizing the impact of heterogeneous frailty on inferences of ancient health. Discussions of the Osteological Paradox in which the axiom "better health makes for worse skeletons" is emphasized often overlook this aspect of the paper. This is ironic because it is the one area that falls entirely within our purview, is controllable to some extent, and offers real opportunities to produce novel contributions and perspectives on fundamental matters of ancient health research. "Simple" in this case means both culturally *and* biologically homogenous, drawn from one social group, and egalitarian—a framework that assumes the rise of inequality was correlated with variation in health experience and heterogeneous frailty. While intuitive, this relationship remains to be demonstrated and is a testable hypothesis central to the basis of the Paradox itself. Wilkinson's reply (1992, pp. 364–365) reiterated the importance of focusing on culturally and biologically homogeneous societies as a precursor to health inferences in more complex societies; however, publication data clearly show this has not occurred. We examined papers published between 2004 and 2014 in the *American Journal of Physical Anthropology*, the *International Journal of Osteoarchaeology*, and the *International Journal of Paleopathology*. These indicate no trend toward paleopathological research on hunter–gatherer–forager or egalitarian societies. Of the 283 papers published for which the scale of social complexity could be estimated, 207 (73%) analyzed data from state-level societies, 53 (19%) considered middle-range societies, and only 23 (8%) analyzed data from hunter–gatherer–forager populations. There also is no consistent trend for an increase in visibility of hunter–gatherer research within paleopathology through time. Broader research trends are clearly superseding concerns with the Osteological Paradox. Complex societies are better represented in the archaeological record and have traditionally been a strong focus of archaeological interest, and there is a clear articulation of paleoepidemiological research with archaeologically oriented problems.

Wood et al. (1992) also suggest that anthropologists can use archaeological context to minimize the effects of heterogeneous frailty by focusing on short-term

use cemeteries for which concerns with demographic nonstationarity are minimized. The rationale here is that short-term cemeteries more closely represent cohorts, generations, or populations and not time-averaged lineages (see Cadien et al. 1974). Using the same bibliometric survey data as above, we confirm that there has *not* been a shift toward short-term use cemeteries in paleoepidemiological research. The average site duration used was 552 years ($n = 252$, sd = 805) with a range from 1 to 7,000 years. There also is no trend evident in these data. Therefore, despite the fact that site selection and research design are the two things over which bioarchaeologists have some control, the call for an exploratory period focusing on simple societies and simple sites has simply not occurred.

There are, however, some exceptions to this overall trend. We identified several articles that use a sample of short duration (less than 30 years or about one generation). The majority of these papers analyze historical collections (Assis et al. 2011; Capasso 2007; Crist and Sorg 2014; Palubeckaitė et al. 2006) or collections associated with historically significant events (Geber and Murphy 2012; Mitchell 2006), which define the short duration of use. Several adopt a forensics perspective on trauma analysis using modern or near-modern collections (Nagaoka 2012; Steyn et al. 2010; van der Merwe et al. 2010). These papers are not relevant to the Osteological Paradox. Three papers use short-duration sites and consider patterns of health in a comparative sense (Geber and Murphy 2012; Hutchinson and Norr 2006; Nystrom 2013); however, they do not leverage the fine temporal control in ways that inform understanding of selective mortality and heterogeneous frailty.

Although we certainly cannot expect sites with complex, extended chronologies to be ignored, we do feel it is useful to outline the types of inferences possible using sites with tight chronologies. For example, DeWitte and colleagues present data from the East Smithfield cemetery, which consists of Black Death victims who died between 1348 and 1350 (DeWitte 2009; DeWitte and Hughes-Morey 2012; DeWitte and Wood 2008). In addition to providing a relatively large sample size ($n = 491$) from a short period of use (less than 18 months), the individuals interred here all died from a single, known cause of death. In this case, temporal control mitigates concerns with demographic nonstationarity, and it thus provides a clearer picture of the association between factors—such as age, sex, and health status, and risk of death—not confounded by temporal changes in diet, disease environment, or housing conditions. Further, in addition to allowing for the examination of patterns of Black Death mortality, the use of a sample of individuals who died from a single cause allows for a relatively straightforward interpretation of the results, uncomplicated by the possibility that different causes of death might vary in their selectivity with respect to pre-existing health conditions or other factors. By using a cemetery with such a short use period, DeWitte's research reveals that, contrary to longstanding assumptions, the Black Death disproportionately killed the elderly and individuals who had previously suffered physiological stress. Neither of these results was apparent in existing documentary data. Nevertheless, samples such as East Smithfield are the exception. When they are encountered, however, we should use short-duration cemeteries to pursue basic middle-range research on lesion-formation processes and the sensitivity of osteological data to health conditions in the past.

A third aspect of the Paradox that relates to archaeological context is the consideration of intrasite and interindividual patterns of variation. Wood et al. (1992), Wilkinson (1992), and Wright and Yoder (2003) all suggest that scholars should use archaeological data to identify socially meaningful subgroups (families, social classes, ethnic groups) within larger skeletal samples, which can then serve as the basis for comparison in a more nuanced and contextual analysis of individual- and group-level variations in health experience. Such approaches are extremely powerful when also paired with short-term use cemeteries because temporal changes in health are not conflated with synchronic social parameters. Identifying meaningful subgroups is especially crucial for health research in complex societies for which inequality among ethnic groups, social classes, or even among individual families may impact subgroup-level health experience and serve as an important source of heterogeneous frailty within that population (see Wilkinson 1992, p. 364).

If we can identify meaningful parameters of comparison, it is possible to compare pathology data among these sample subdivisions. For example, sites with internal spatial organization—for which burial subgroups represent status groups, neighborhoods, or different social groups—have been used to examine variations in health experience among these different subclasses of individuals (Stojanowski 2013; Stojanowski et al. 2007; Storey et al. 2012; Winkler 2011). For sites without internal spatial structure, we can use a host of other techniques to identify a priori groups of interest, also often inferred status groups. In this approach, researchers infer status using grave goods, grave styles, or interment positions as a means of comparing intrasite patterns of pathology experience (Griffin et al. 2011; Pechenkina and Delgado 2006; Peck 2013; Reisinger 2013; Robb et al. 2001; Sullivan 2004; Woo and Sciulli 2013). In other cases, for example, in large complex sites often of long duration, spatial statistics and GIS (Casgrain and Legendre 2001; Rosenberg and Anderson 2011; Šmejda 2004; Sosna et al. 2012) allow for the identification of status groups based on the clustering of artifact attributes within an otherwise homogeneously distributed grave field. Use of similar analyses for pathology data, or in combination with other mortuary or phenotypic variables, could provide new insights on heterogeneous frailty; however, this is rarely done in practice. GIS has simply not become part of the paleopathologist's toolkit, for whatever reason (for recent examples of the use of GIS in bioarchaeology, see ElSalam 2003; Herrmann 2002; Herrmann et al. 2014). As such, studies that compare pathology and status data within a spatial analytic framework have provided unique insights into ancient health dynamics in the past, but they have rarely addressed the Osteological Paradox directly. The research is often about status and inequality primarily and is not designed to test for selective mortality and heterogeneous frailty, which limits their utility in this discussion.

One common feature of the above approaches is the primary emphasis placed on cultural parameters of variation. Heterogeneous frailty, however, is also a direct result of underlying genetic variation among individuals within a population, and as such it may have a detectable biological basis reflected in subpopulation level variation. If such cryptic subpopulations have a genetic or phenotypic basis, they may be identifiable using ancient DNA (Corruccini et al. 2002; Gamba et al. 2011; Haak et al. 2008; Schultes et al. 2000) or intra-cemetery biodistance approaches (Alt

and Vach 1995, 1998; Ĉesnys and Tutkuviené 2007; Jacobi 2000; Meyer et al. 2012; Paul et al. 2013; Pilloud and Larsen 2011; Ricaut et al. 2010; Stojanowski and Schillaci 2006) combined with spatial analysis that implements the search for hidden biological patterning within archaeological sites (Sokal et al. 1987; Stojanowski 2003; Usher and Allen 2005; Vach and Alt 1993). As with material culture, researchers can analyze biological data using spatial statistics and GIS to document clustering tendencies of morphological trait complexes that may reflect family-structured burial practices.

This is a largely untapped approach, but it aligns perfectly with Wood et al.'s call for a better understanding of the sources of heterogeneous frailty within human populations. There is no good explanation for why ancient health data have infrequently been paired with intrasite biodistance or ancient DNA analysis. We suspect this is an artifact of bioarchaeological training where analytic subspecialization is encouraged, although this seems to be rapidly changing. In addition, the lack of fundamental research on phenotypic variation, and its ties to racial craniometry, leads some to question the value of biodistance analysis. This is unfortunate. Stojanowski's (2005, 2013) work with the Spanish mission period site of San Pedro and San Pable de Patale provides one example of the power of combining spatial analysis with biodistance and pathology data at the site level. By identifying likely family groups within the church, Stojanowski demonstrates that some families were more susceptible to specific types of stress conditions than others and that families with higher mortality rates also exhibited higher rates of early childhood stress as reflected in elevated frequencies of linear enamel hypoplasias (Fig. 1). Although identifying family units may be difficult at many archaeological sites, we argue that family-centered research offers a powerful glimpse into social dynamics in past societies and the possible health repercussions of small-scale variations in genetics and lifestyle with clear analogs to modern peoples.

Subadults as non-survivors

Both Wood et al. (1992) and Wright and Yoder (2003) emphasize the importance of using age-structured data for comparing the frequencies of skeletal lesions as an important tool for weighing a traditional or "paradoxical" interpretation of data. While most researchers are aware of the age-progressive nature of many types of health indicators (osteoarthritic joint modifications, caries rates), others have focused specifically on subadults as a means for comparing the frailty of survivors and non-survivors—individuals who survive to later childhood, adolescence, or adulthood *versus* those who succumbed at earlier ages. The distinction between subadult, young adult, and older adult pathology that was developed by Storey in a series of publications on Maya health (Storey 1998, 1999; Storey et al. 2002) suggests that, at least in some contexts, the Osteological Paradox might be more of a concern for health comparisons among subadults than it is for adults. By comparing those who die early in childhood, during what are presumed to be risky periods (like weaning ages), to those who survived to later ages, the goal is to determine whether there are more lesions in the most highly vulnerable individuals (which would

conform to the expectations of "conventional wisdom") or if lesions are more common in older age groups and thus suggestive of higher robusticity or lower frailty (lending support to "Paradoxical" predictions). Some studies also focus explicitly on how stress early in life affects frailty at, or survival to, older ages (e.g., Cucina et al. 2011). One clear advantage of focusing on subadults is that age at death is more accurately and precisely determined. Thus, it is possible to examine with greater precision the age-structure of skeletal lesions in children as a means of exploring heterogeneous frailty (Bennike et al. 2005; Littleton 2011).

Some bioarchaeological studies of subadults have found evidence suggestive of paradoxical relationships between skeletal stress markers and survival and mortality. This includes positive relationships between stress markers and age, such as an increased number of lesions with age among children (Bennike et al. 2005; Storey 1997), and more lesions in those who survived to adulthood compared to those who died in childhood (Holland 2013). Wright and Chew (1998) interpret high frequencies of lesions that form in childhood as evidence of enhanced survivorship from childhood episodes of stress, possibly reflecting favorable weaning practices and lack of exposure to fatal infectious disease during childhood. Some studies have found evidence consistent with expectations based on "conventional wisdom." This includes relatively high frequencies of skeletal lesions at the youngest subadult ages (Perry 2014), or higher frequencies of skeletal signs of acute stress at younger ages but more evidence of *recovery* from growth restriction at older ages (Littleton 2011; Robbins Schug 2011). Similarly, several studies of tooth crown size have found smaller permanent teeth in subadults compared to adults in the same assemblages (Guagliardo 1982; Stojanowski et al. 2007). Small crown size can reflect exposure to developmental stressors that thwart achievement of maximum genetic potential, and the smaller size of permanent teeth in subadults compared to adults suggests higher risks of mortality for those exposed to such stressors (Stojanowski et al. 2007).

Other studies of subadults, however, have failed to find significant relationships between stress markers and age or longevity (e.g., Cucina et al. 2011). Saunders and Hoppa (1993) compare height-for-age distributions of survivors and non-survivors and conclude that there are negligible differences in growth between those who die at younger versus older ages. Finally, results within a single sample might be consistent with both a paradoxical and a conventional interpretation. Holland (2013), for example, finds that the relationship between lesions and survival is sex dependent. In a skeletal collection for which it was possible to assign sex to subadults, female survivors exhibit higher degrees of stress than non-survivors. However, the opposite is true for males, suggesting lower frailty and enhanced ability to survive stressors in general among females than their male peers.

Although many bioarchaeological studies of subadults focus on skeletal lesions, the survivor versus non-survivor approach also can be used in conjunction with isotope analysis to examine the long-term effects of diet and dietary practices (including weaning) at young ages (Tsutaya and Yoneda 2015). Sandberg et al. (2014), for example, combine enamel hypoplasia, stable isotope analysis, and longevity data to examine the effects of age at weaning and weaning foods on morbidity and mortality. Results suggest that systemic stress was experienced

during weaning for all individuals in their study, but children who were weaned at earlier ages were more likely to survive as their weaning diets were of higher nutritional quality than breast milk.

The variety of findings from these and other studies based on subadults highlights both the importance of considering context and the possibility of finding a variety of associations (even within a single setting) between stress markers and demographic phenomena that may or may not be consistent with paradoxical predictions. Thus, our reading of this literature suggests we really do need to heed the warnings of Wood et al. when it comes to interpreting subadult health patterns in the past.

Examination of frailty and demography

As predicted by Wood et al., advances in other fields such as demography, genetics, epidemiology, and human biology have improved our understanding of the sources and effects of variation in frailty and the interaction of heterogeneous frailty and selective mortality on aggregate patterns of morbidity and mortality. This work will ultimately prove crucial for improving bioarchaeological interpretations and research designs.

In the last two decades, there has been an explosion of research on the genetic determinants of disease and immune function, epigenetics, and the developmental origins of health. Recent research has revealed genes associated with differential susceptibility to, severity of, or mortality from numerous infectious and chronic/degenerative diseases (e.g., Hill 2012; Weiss and Buchanan 2003). The difficulties associated with predicting disease phenotype from genotype, small effect sizes, and rare genetic variants could limit the utility of many candidate genes for ancient DNA studies of health. Nonetheless, the identification of genetic susceptibilities to diseases that are of interest to paleopathologists might hold promise for investigations of these diseases in skeletal assemblages. For example, several studies (Hummel et al. 2005; Kremeyer et al. 2005; Zawicki and Witas 2008) have screened skeletal samples for the presence of an allele (CCR5Δ32) that confers resistance to HIV in living populations and also might have been beneficial during medieval plague outbreaks. Other studies have explored the genetic basis of specific skeletal pathologies, including rheumatoid arthritis (Korczowska 2014), ankylosing spondylitis (Sparks and Costenbader 2014), periodontal disease (Genco and Borgnakke 2013; Kang et al. 2014), osteochondritis dissecans (Bates et al. 2014), bone cancers (Kuehl and Bergsagel 2002; Mundy 2002; Prideaux et al. 2014), and hundreds of inherited skeletal disorders (Warman et al. 2011).

Research on epigenetics and the developmental origins of health has improved our understanding of the individual and intergenerational effects of environmental, physiological, and psychosocial stressors on health. Evidence of associations between early growth patterns and chronic diseases in adulthood have fueled research addressing the long-term effects of stress experienced during fetal or childhood development, expressed variably as the fetal origins, Barker, fetal programming, or Developmental Origins of Health and Disease (DOHaD) hypotheses (Almond and Currie 2011; Barker 1990, 1994; Kuzawa and Sweet 2009; Worthman and Kuzara 2005). The mechanisms linking fetal and early-life

exposure to stress, such as nutritional deprivation and maternal psychosocial stress, and adult health outcomes include modification of tissues or organ growth, neuroendocrine alterations, and epigenetic mechanisms (Bell and Beck 2010; Feinberg 2007; Gluckman and Hanson 2004; Kuzawa and Sweet 2009; Robertson 2005; Thayer and Kuzawa 2014; Worthman and Kuzara 2005). The last of these, epigenetics, has received considerable attention in the last decade.

Epigenetic mechanisms include a suite of processes such as DNA methylation, micro RNA regulation, and histone modification that modify the way genes are switched on and off but do not change the genetic code itself (Jones and Takai 2001; Martens et al. 2011; Suzuki and Bird 2008; Tammen et al. 2013). These changes can be heritable, so a stressor can affect the health not just of the individuals who experienced it but also that of their children, thus establishing a mechanism of transgenerational health outcomes that are not purely biological or social (Bjornsson et al. 2008; Heijmans et al. 2008; Hochberg et al. 2011; Lam et al. 2012; Rodney and Mulligan 2014; Tobi et al. 2009). To date, much of this work has focused on health conditions not observable in the past—obesity, diabetes, heart disease, various soft tissue cancers, and psychological disorders, for example (Barres and Zierath 2011; Bell and Beck 2010; Esteller 2008; Feinberg 2007). Research on aging and longevity (Calvanese et al. 2009; Huidobro et al. 2013; Slagboom et al. 2011) and bone homeostatic disruptions (Gordon et al. 2014; Vrtačnik et al. 2014) are more relevant to bioarchaeology and discussions of the Osteological Paradox. For example, epigenetic research on osteoporosis and osteoarthritis (Barter and Young 2013; Delgado-Calle et al. 2013; Iliopoulos et al. 2008; Soto-Hermida et al. 2014), rheumatoid arthritis (Liu et al. 2013; Zufferey et al. 2014), and malignant bone cancers such as multiple myeloma (Chim et al. 2004; Chim et al. 2007), chondrosarcoma (Fitzgerald et al. 2011; Mak et al. 2015), and Ewing's sarcoma (Alholle et al. 2013; Patel et al. 2012; see also Mundy 2002; Wise et al. 2015) may help explain some aspects of health and stress conditions in the past. Research demonstrating a relationship between diet and different mechanisms of the epigenome (Burdge and Lillycrop 2010; Zhang et al. 2011) also help contextualize the well-documented synergy between dietary foci and health experiences in past populations. Each of these topics is worthy of concerted review itself; the pace of research in epigenetics over the last decade is staggering.

Despite the expansion of research on epigenetics, or perhaps because of this, few bioarchaeological studies have incorporated epigenetic and developmental influences into interpretations of ancient health patterns. Klaus (2014) notes the promise of epigenetics but also remains more muted in his outlook for the relevance of epigenetic research in bioarchaeology. One problem is a murky path between primary research and operationalized models that can be used on archaeological samples. That is, the types of skeletal markers we observe in ancient skeletons generally do not also receive attention in the epigenetic literature because the former are not the leading causes of poor health observed in living peoples. Klaus (2014) further notes that we cannot directly observe epigenetic mechanisms in the cross-sectional samples we typically observe. Therefore, invoking epigenetic mechanisms to explain a data pattern may, for the foreseeable future, amount to an interpretive black box that is easy to suggest but difficult to substantiate. Echoing the emphasis

of the previous section, Klaus (2014) suggests that sites with strong chronological control may allow us to implement epigenetic analyses in archaeological samples. There is little doubt that the genetic origins of disease susceptibility as well as the epigenetic basis of transgenerational heritability of heterogeneous frailty will become an increasingly important area of research in paleopathology and bioarchaeology.

Although the full potential of epigenetics research is unrealized, several researchers have addressed the DOHaD hypothesis using bioarchaeological data (Amoroso et al. 2014; Armelagos et al. 2009; Miszkiewicz 2012; Steckel 2005; Temple 2014; Weisensee 2013). Many researchers had previously noted a relationship between the presence, severity, or periodicity of enamel hypoplasias (Fig. 1) and adult health, including reduced longevity (Cook and Buikstra 1979; Duray 1996; Goodman 1996; Steckel 2005), yet Armelagos et al. (2009) were the first to link these data specifically to Barker's work. As Armelagos et al. are careful to note, the DOHaD hypothesis is not fully accepted by the medical community; results in modern populations are mixed (e.g., Kannisto et al. 1997). Therefore, bioarchaeologists are encouraged to not only consider fetal programming in their interpretations, but also to use bioarchaeological data to add new avenues of research that test the validity of the DOHaD hypothesis. For example, Temple (2014) uses enamel hypoplasias to test predictive adaptive response versus plasticity/constraint hypotheses about early-life stress in a Jomon period hunter–gatherer sample. His work finds support for the plasticity/constraint hypothesis based on associations between various measures of enamel hypoplasia timing and age at death. On the other hand, Amoroso et al. (2014) find conflicting support for the DOHaD hypothesis; significant associations between enamel hypoplasias and longevity are not robust to variation in socioeconomic circumstances, indicating that life-long health issues may be more responsible for early mortality than fetal programming alone. Given the unique visibility of hypoplastic defects, recordable in both ancient and living peoples, there is a tremendous opportunity to generate synthetic research examining a host of health and stress conditions at various points in an individual's life.

Paralleling research in epigenetics and human biology, many demographers have examined the effects of early-life exposure to physiological stress on individual health and mortality later in life, and the relationship between early-age and late-age risks of mortality at the population level. Evidence linking infections early in life with disease later in life and evidence that cohorts with lower mortality at early ages also have lower mortality at older ages suggests that decreases in inflammation early in life lead to decreased morbidity and mortality from chronic diseases at older ages (Finch and Crimmins 2004). That is, the "epidemiological environment" at early ages can have long-lasting effects on mortality. Some studies have indicated that physiological stress at young ages in the absence of strong selective mortality can result in long-term negative effects via the survival of frail individuals, what Zheng (2014) refers to as "scarring." Costa (2012) found that the processes of both selective mortality (producing robust survivors) and physiological scarring (producing frail survivors) can occur; the outcome depends on the age at which the stressor occurred. Zheng (2014) similarly revealed that the two processes are not

mutually exclusive. Young- and old-age mortality rates can be positively associated (i.e., indicative of scarring), while young-age mortality rates are simultaneously negatively associated with mortality acceleration (the rate of increase in the mortality rate) late in life (indicative of selective mortality).

Numerous studies have revealed that improvements in mortality early in life and longevity are often associated with declines in health at older adult ages (Crimmins 2004; Crimmins et al. 1994; Molla et al. 2003) or increased variation in mortality risk at older ages. With respect to the latter, as survival improves overall within a population, the cohorts that are capable of surviving to each age may become more heterogeneous, and thus health disparities may become apparent at increasingly older ages (Engelman et al. 2010). These findings suggest that evidence of declines in health or increased heterogeneity at older ages might indicate improvements in health or mortality at younger ages. Some studies have found, however, that survival is positively associated with health at older adult ages (Ailshire et al. 2011), so the association might be context dependent. Robine et al. (2010) identify three levels of selective mortality (mild, intermediate, and strong) among five countries included in their study; the chances of surviving from age 80 to 100 were 2.5 and 1.5 times higher in the mild and intermediate levels of selective mortality, respectively, compared to the strongest level. The identification of these levels may allow for an examination of the potential trade-off between the level of selective mortality and the functional health status of survivors.

Recent demographic research also has improved our understanding of the role of selective mortality in producing differentials in health and mortality based on sex, race, or socioeconomic status. Demographers have examined selective mortality in the context of the US Black–White mortality crossover, whereby age-specific mortality rates for Blacks drop below those of Whites at advanced ages (Johnson 2000; Manton et al. 1979; Sautter et al. 2012). This pattern might result from stronger selective mortality among the Blacks at younger ages and thus a relatively robust cohort at older ages. Another topic that has received attention is the way in which socioeconomic or educational health disparities change with age (Beckett 2000; Dupre 2007; McMunn et al. 2009; Zajacova et al. 2009). Most studies have found that such inequities in health diminish in later adulthood (supporting the "age-as-leveler" hypothesis), and the predominant explanation for this is selective mortality disproportionately selecting out the frail individuals of the disadvantaged group(s) (Dupre 2007; Zajacova et al. 2009). Another major area of research is the male–female health and mortality paradox: females in most populations live longer than males but often suffer from poorer health later in life in terms of disease, disability, and functional limitations (Crimmins et al. 2002; Doblhammer and Hoffmann 2010; Oksuzyan et al. 2008). This paradox might be explained, at least in part, by higher male mortality, which results in males facing higher selective pressure such that those who survive to later ages are healthier in general than females of the same ages (Crimmins et al. 2002; Doblhammer and Hoffmann 2010).

Several demographers have proposed tools for examining heterogeneous frailty and selective mortality, such as focusing on mortality deceleration (slowing of the rate of increase in mortality with age). This is considered by some to be an indicator of heterogeneity and previous selective mortality, as survivors at each age are

increasingly drawn from relatively robust subcohorts (Lynch et al. 2003). Wrigley-Field (2014), however, argues that deceleration patterns may reveal little about heterogeneous frailty, even with the use of very simple models. Researchers have suggested ways to model frailty distributions, which might allow us to make better sense of observed aggregate mortality hazards (e.g., Aalen 1994; Steinsaltz and Wachter 2006; Vaupel and Carey 1993; Vaupel and Yashin 1985; Zahl 1997). Noymer (2009) suggests examining the interaction of different diseases as one way of studying the association between observed death rates and frailty distributions, as exposure to one disease can enhance mortality risk to another.

Bioarchaeologists, in general, have not applied many of the relevant models generated in other fields, in part, because their application requires large sample sizes. For example, comparison of patterns of mortality deceleration requires high-quality data at old ages (Wrigley-Field 2014), which might not be possible in bioarchaeological research, even with the application of newer age-estimation methods that produce better estimates for the oldest individuals (Boldsen et al. 2002; Milner and Boldsen 2012; Wittwer-Backofen et al. 2004). There has, however, been an increase in bioarchaeological research that is explicitly designed to detect heterogeneity in frailty and selective mortality using observable skeletal stress markers and other factors (such as sex or socioeconomic status) that might reflect underlying frailty and measuring the association between these factors and mortality or survival (Boldsen 2005a, b, 2007; DeWitte and Wood 2008; Hughes-Morey 2012; Kreger 2010; Redfern and DeWitte 2011a; Usher 2000; Wilson 2010).

To explicitly examine heterogeneous frailty and selective mortality, Usher (2000) developed a multistate model that allows for an examination of the relationship between skeletal stress markers and risks of mortality by modeling stress markers as a covariate affecting a baseline hazard of mortality, such as the Siler or Gompertz models. Demographers have demonstrated that these hazard models fit most human mortality patterns and, importantly, are applicable to small bioarchaeological samples, allowing for the estimation of mortality patterns without imposing any particular pattern on the data (Gage 1988). Usher's model includes a covariate that reveals whether, in a particular context, the presence of a stress marker is indicative of an elevated or reduced risk of mortality and thus entry into the skeletal assemblage. Usher's tests of this model revealed significant positive associations between several stress markers typically used in paleopathology and risks of mortality. This model has been informative in examinations of selective mortality during the medieval Black Death (DeWitte and Wood 2008) and frailty in the context of urbanism and migration in Postclassic Cholula (Kreger 2010).

Other researchers have applied hazard analysis using more generalized models than Usher's model. Wilson (2010) applies hazard analysis to examine the health and demographic effects of the intensification of maize agriculture, the adoption of Mississippian lifeways, and increased interpersonal violence and warfare in prehistoric Illinois. He finds different associations between the presence of skeletal lesions and mortality between the sexes for some lesions, demonstrating the presence of heterogeneity in frailty between males and females. Other scholars have used similar hazards approaches to investigate the interrelationships among stature, body mass, skeletal stress markers, mortality, and socioeconomic status in

18–19th-century London (Hughes-Morey 2012); frailty in the context of the Romanization of Britain (Redfern and DeWitte 2011a, b); demographic patterns in the aftermath of the Black Death in London (DeWitte 2014); and mortality in medieval monastic communities (DeWitte et al. 2013).

Advances in our understanding of lesion-formation processes

Over the last 20 years, researchers in anthropology and other fields have examined the pathophysiology of skeletal lesions that are of interest to bioarchaeologists and improved our understanding of the underlying health characteristics of individuals who develop some of those lesions. This addresses Wood et al.'s call for more research on the sources of frailty in living people and Wright and Yoder's (2003) request for a stronger connection between modern health research and paleopathology as a means for better informing interpretations of health data in past societies. Not surprisingly, however, research in fields outside of anthropology has focused on those skeletal lesions that are of concern to living people. Some lesions that are commonly examined in bioarchaeological studies (such as cribra orbitalia and porotic hyperostosis) remain less well understood. We focus here on those lesions that bioarchaeologists most often include in studies on past health in general: enamel hypoplasia, dental caries, periodontal disease, cribra orbitalia, porotic hyperostosis, and periosteal new bone formation.

Research on enamel hypoplasia (Fig. 1) and hypomineralization has examined the genetic, environmental (drugs, chemicals, and trauma), and systemic (metabolic conditions and infections) factors that affect their formation (Brook and Smith 1998; Seow 2014; Souza et al. 2012; Taji et al. 2000). Studies have investigated how various health characteristics affect the development and severity of enamel hypoplasias. For example, Skinner et al. (2014) revealed that localized enamel defects occur more frequently in pigs that are sick at the time of death and that they co-occur with both infection and poor growth. Numerous studies have found that low birth weight and preterm birth are associated with increased risk of enamel hypoplasia and that maternal health plays a role in enamel hypoplasia formation in children (Gravina et al. 2013; Jacobsen et al. 2014; Masumo et al. 2013; Silva-Sousa et al. 2003; Souza et al. 2012). Research among living people indicates that children with enamel hypoplasia are of significantly shorter stature than those without them (Lukacs et al. 2001). Other risk factors for enamel defects include low prenatal vitamin D (Schroth et al. 2014), infections or high fever during childhood (Ford et al. 2009; Ghanim et al. 2013; Souza et al. 2012), celiac disease (Munoz et al. 2012), and immunodeficiency diseases (Meighani et al. 2011). The established associations between enamel hypoplasia and poor health and the fact that enamel does not remodel after formation makes these lesions particularly useful for paleopathological analyses, some of which have begun to explore the developmental origins of poor adult health (see above). We provide additional recent references on methods for identification and measurement of enamel hypoplasia, estimating their age at formation, and determining how they reflect the severity of stress in the bibliography of recent literature.

Investigations also have focused on dental caries and periodontal disease, both very common chronic diseases in living populations. Numerous studies have found both dental pathologies to be associated with poor health. Periodontal disease is associated with a highly elevated risk of all-cause mortality (DeStefano et al. 1993), and it is a risk factor for cardiovascular diseases, respiratory infections, cancer, diabetes mellitus, renal disease, and numerous other poor health outcomes (Li et al. 2000; Williams et al. 2008; Ylostalo et al. 2006). Dental caries is associated with such adverse health conditions as cardiovascular disease, asthma, liver disease, and poor growth (Acs et al. 1999; Glodny et al. 2013; Johnston and Vieira 2014). Periodontal disease and dental caries may be causally related to diseases such as cardiovascular disease, cancer, and respiratory infections by affecting systemic inflammatory cytokine levels and via the spread of infectious pathogens from the oral cavity to other parts of the body (Beck and Offenbacher 2005; Joshipura et al. 2006; Lombardo Bedran et al. 2013; Loos 2005; Meyer et al. 2008; Paju and Scannapieco 2007; Watts et al. 2008). The two conditions and their association with other health problems also might reflect other underlying risk factors, such as compromised immune responses (Acs et al. 1999; Michaud et al. 2008). We provide references on new methods for identifying and quantifying dental caries and periodontal disease in the bibliography of recent literature.

Bioarchaeologists typically view periosteal new bone formation (i.e., periosteal lesions; Figs. 3, 4) as a marker of nonspecific infection, although continuing research is improving our understanding of the numerous etiologies of the lesions, including those that are noninfectious. The causes of periosteal lesions include stimuli that traumatize the periosteum, local or systemic infection or inflammation, and nutritional imbalances, such as vitamin deficiencies that increase the risk of hemorrhages and hematoma formation and which trigger inflammatory responses that can lead to the formation of new bone (Bastian et al. 2011; Geber and Murphy 2012; Huss-Ashmore et al. 1982; Larsen 1997; Ortner 2003; Paine and Brenton 2006; Roberts and Manchester 2005; Weston 2008). Periosteal lesions also are associated with neoplastic, metabolic, congenital, and genetic diseases (Chen et al. 2012). New bone formation ultimately occurs because of the activity of osteoblasts, and factors that result in an increase in vascular permeability and edema can create conditions that promote osteoblast activity (Ragsdale and Lehmer 2012). Recent work has revealed specific inflammatory factors, hormones, and other signaling molecules that affect the formation of periosteal lesions (Dimitriou et al. 2005; Klaus 2014; Weston 2012). Although inflammation can interfere with bone formation by down-regulating osteoblast activity and promoting bone resorption by increasing osteoclast activity, some pro-inflammatory mediators do promote new bone formation. This occurs via stimulation of osteoblast proliferation and production of bone matrix and increasing blood flow, which can lead to periosteal hyperplasia (DeFranco et al. 2007; Frost et al. 1997; Lange et al. 2010; Thomas and Puleo 2011).

Because a wide variety of factors can cause periosteal lesions, as with other skeletal lesions, we are limited in our ability to diagnose specific conditions from them and thus often cannot examine the effect of specific diseases on morbidity and mortality. To address this limitation, Weston (2008) uses radiographs to examine

periosteal lesions from individuals with known metabolic and infectious conditions, but she fails to find any characteristics of the lesions that were specific to those disease states. Weston cautions against assigning a diagnosis of "nonspecific infection" from periosteal lesions, given that they can be caused by numerous noninfectious conditions. Weston (2012) also argues that the body's physiological response to stress is not likely to promote the formation of periosteal new bone, and thus the typical interpretation of these lesions as stress indicators is flawed. Work by others (DeWitte and Wood 2008; Kreger 2010), however, indicates that periosteal lesions are associated with elevated risks of mortality and are therefore informative about frailty.

Cribra orbitalia (Fig. 6) and porotic hyperostosis (Fig. 7) are common in bioarchaeological samples. Clinicians, however, rarely report them in living individuals (Exner et al. 2004; Rothschild 2012), which limits investigation into the etiologies of the lesions and their association with underlying health and physiological conditions. Paleopathologists commonly attribute both of these lesions to anemia and particularly iron-deficiency anemia. Histological studies of cribra orbitalia, however, have shown evidence, in at least some cases, of causes other than anemia, such as inflammation, osteoporosis, and rickets (Wapler et al. 2004). Walker et al. (2009) summarize recent findings from hematological studies and, based on evidence that iron deficiency inhibits marrow hypertrophy rather than causing the marrow expansion that produces porotic hyperostosis and cribra orbitalia, conclude that iron-deficiency anemia is not likely a cause of the lesions. The proximate causes of porotic hyperostosis are more likely hemolytic and megaloblastic anemias, which result in high levels of erythropoiesis; the etiology of cribra orbitalia is likely more complex and includes inflammation and vitamin deficiencies such as scurvy. Oxenham and Cavill (2010) object to Walker et al.'s rejection of the iron-deficiency hypothesis to explain high frequencies of porotic hyperostosis and cribra orbitalia in skeletal samples, citing evidence that iron-deficiency anemia can lead to marrow hyperplasia. Oxenham and Cavill (2010) and McIlvaine (2013) encourage bioarchaeologists to consider various possible causes of porotic hyperostosis and cribra orbitalia, including, but not limited to iron-deficiency anemia. McIlvaine emphasizes that multiple, interacting etiologies might mask the expression of these lesions, creating hidden heterogeneity in skeletal samples in previously unrecognized ways. Recent applications of computed tomography and microscopy to study the morphological characteristics of cribra orbitalia might stimulate further study of the lesion in living people that would improve our understanding of its etiology and association with other health characteristics (Exner et al. 2004; Naveed et al. 2012; Schultz 2011). Furthermore, Piperata et al. (2014) push for examinations of not just the proximate causes of anemia and resulting skeletal lesions, but also of its ultimate causes and its effects on self-assessments of health. Understanding both of these might allow for better inferences about health in the past, particularly when included in an analytic framework that incorporates individual frailty (Piperata et al. 2014).

The availability of morbidity, physiological stress, and cause of death data from identified skeletal collections and living populations can provide insights into the associations and interactions among various disease and stress processes (some of

which might produce skeletal lesions) (Tanner and Team 2014; van Schaik et al. 2014). Van Schaik et al. (2014) compare evidence of disease from autopsy reports and skeletal data from an identified collection to produce a method for estimating general disease burdens from skeletal data. They assessed the co-occurrences of "living diseases" and "osteological diseases," and the results confirm that it is difficult to predict disease burden based on skeletal data alone, as there is considerable variability in comorbidities. They conclude that future work might yield a more refined model for predicting soft tissue pathology based on skeletal pathology.

In addition to these recent advances in understanding specific skeletal lesions, the field also has benefitted from improved approaches to extracting the maximum amount of information from distributions of lesions in skeletal samples in general. Boldsen and Milner (2012) reiterate that simple tabulations of lesion frequencies can mask important patterns and might prove misleading; dividing skeletal samples into broad age groups (such as young, middle, and old adults) is not an adequate solution, as it still leads to a loss of information. They emphasize that moving forward, analyses of lesions should be probabilitistic in nature and that bioarchaeologists must be aware of the problems associated with sensitivity and specificity. In the context of paleopathology, sensitivity refers to the proportion of individuals who have a disease and exhibit a skeletal indicator of that disease; specificity refers to the proportion of individuals who do not have the disease and do not exhibit the associated skeletal indicator. Boldsen and Milner describe a way to estimate the prevalence of a disease in a once-living population based on skeletal data and reasonable assumptions about sensitivity and specificity (which might be based on clinical or historical evidence). The approach allows for the possibility of estimating disease prevalence even when it is not possible to identify, skeletally, those individuals who had a particular disease (Boldsen and Milner 2012).

Finally, increasing paleopathological applications of imaging technology (such as computed tomography scanning), ancient DNA analysis, histology, and parasitology are improving our diagnostic capabilities. This allows for precise assessments of pathogen and parasite loads and helps clarify the etiology, sensitivity, and specificity of skeletal lesions including, but not limited to those described above. We provide references highlighting the application and promise of these approaches in the bibliography of recent literature.

Conclusions and future directions

In 2003, Wright and Yoder felt that bioarchaeology had yet to engage the challenges set forth by Wood et al. but that the field had made some progress, in particular with respect to general research methods in bioarchaeology. Tellingly, Wright and Yoder (2003, p. 56) had noted that "[r]ather than dismissing the issue as unlikely to be significant or simply ignoring it, as many have done, explicit consideration of *multiple alternate interpretations* of bioarchaeological data is critical to arriving at an appropriate inference" (emphasis added, note "multiple" not "one correct"). Nearly a decade later, Agarwal and Glencross (2011, p. 2) noted that the corollaries

of the Paradox are "now expected and routine considerations in all bioarchaeological investigations of health in the past," an opinion consistent with the increasing frequency of citation documented over the last 10 years. Our assessment of the literature, however, is a bit more muted than the optimism of Agarwal and Glencross. We agree generally with Wright and Yoder (2003) that the Paradox is cited often, implemented infrequently (and conveniently), and directly addressed rarely. Our reading of the burgeoning literature suggests that three distinct handlings of the Paradox have emerged. The first is represented by papers that cite Wood et al. but are generally dismissive of the Paradox's significance with respect to interpreting health patterns in the past. Invoking the "conventional wisdom" approach (sensu Milner 2013), these papers tend to be broadly comparative in aim and scope. The second approach represents the work of more recent scholars that incorporates consideration of the Paradox's warnings into research design in a relatively unforced manner but continues to do so within a generally comparative, frequency-based perspective. As such, despite being better informed by broader theoretical perspectives, the research design remains strongly aligned with more traditional, population-based analyses. Finally, the third approach directly addresses specific aspects of the Paradox through epidemiological analyses that attempt to statistically model selectivity and frailty. Papers defined by the second and third approaches did not exist prior to the Wright and Yoder (2003) review, and hence we can confidently state that progress is being made.

Advances in genomics, phenomics, and epigenetics are just now beginning to permeate into ancient health research, suggesting a bright future for paleopathology. In the future, closer collaboration between scientists across disciplines will no doubt lead to better informed inferences about the meaning of skeletal indicators of stress and disease and what changes in those indicators (either in terms of frequency or severity) mean for health dynamics in the past. Methods for detecting potential sources of heterogeneity in frailty show the most promise. Technological advances in ancient biomolecule analysis now make it possible to screen for the presence of specific pathogens (e.g., Drancourt et al. 2007; Harbeck et al. 2013; Müller et al. 2014) or to identify and quantify all microbes (pathogenic or otherwise) present in skeletal samples (e.g., Bos et al. 2015; Devault et al. 2014; Warinner et al. 2014). There also have been advances in the identification of parasites from archaeological sites and human remains (Mitchell 2013). These allow bioarchaeologists to confirm disease diagnoses based on skeletal lesions or burial context. These advances also allow for an examination of the diversity and distribution of parasites and pathogens on a larger scale within skeletal samples, which can improve our ability to identify victims of certain diseases and our understanding of disease ecology. There also is an ever increasing number of candidate genes for disease susceptibility that we might use to provide temporal depth to understanding variation in risks for infectious and chronic diseases (e.g., Hummel et al. 2005). Stable isotope analysis can identify migrants (e.g., Kendall et al. 2013), variation in diet in skeletal assemblages (e.g., Reitsema and Vercellotti 2012; Yoder 2012), and cortisol production in response to stress (Webb et al. 2014), all of which might affect heterogeneity in frailty. Similarly, advances in our understanding and measurement of human phenotypic variation (Boyer et al. 2011; Sherwood and Duren 2013) may

improve the ability of biological distance analyses to identify migrants and to estimate levels of genetic variability within skeletal assemblages. Once identified, any of these potential markers of frailty can be included in analyses explicitly designed to test patterns of selective mortality, such as the hazards approaches currently used by DeWitte, Kreger, Wilson, and others.

One of the most telling results of this review is how bioarchaeologists and paleopathologists treat the Osteological Paradox as an assumption, limitation, post hoc explanation, or framework for research and study design and *not* as a topic worthy of study in and of itself. Frailty—and its causes and consequences—is actually one of the more intriguing topics in the health sciences today, one to which researchers across a number of domains contribute. Furthermore, understanding the nature of human frailty and how it relates to social inequality and social complexity is a highly relevant topic that crosscuts disciplinary boundaries (Flannery and Marcus 2012; Kintigh et al. 2014a, b; Price and Feinman 1995). Yet bioarchaeologists have largely, though not entirely, avoided explorations of the topic of heterogeneous frailty. Emphasis on comparative health within a biocultural, adaptationist framework anchors much of the published literature. While this work continues to produce novel and interesting insights into health patterns in the past, a more direct exploration of the causes of heterogeneous frailty aligns well with biocultural approaches that explore the effects of social and political structures on health disparities. Instead of assuming that heterogeneous frailty exacts a minimal effect on disease patterns, we can instead focus on how these disparities arise and what their consequences are. Bioarchaeology is well suited to provide temporal depth to these discussions, but this will require a rethinking of research questions and concerted collaborative partnerships. We stress that examinations of health disparities with regard to status differences and frequencies of lesions, though useful, do not fully address the heterogeneous frailty that can result from variations in genetics, epigenetics, and micro-adversities at much finer scales. It is the ability of bioarchaeology to move between analytical scales—from the individual to the family to the community—that is so powerful. But as Milner (2013) notes, these kinds of analyses require a more contextualized, particularistic consideration of health at the site and community level, a change in emphasis that may move against current headwinds in academia rewarding broad-scale conclusions with greater initial impact outside the immediate field of study. These sociological considerations are difficult to overcome at the individual level, and researchers cannot be blamed for engaging research that is most likely to be published and thus have an impact within and beyond the field. Better integration of paleopathology and intracemetery spatial analyses may heed Milner's (2013) call for a community-based perspective in paleopathology that considers the individual with respect to the local community where time is parsed on the order of years not decades.

In conclusion, over the last decade (and particularly in the last 5 years), paleopathology and bioarchaeology have developed a number of new techniques and perspectives that are finally beginning to address the Osteological Paradox in direct and meaningful ways. As others have done before us, we conclude with three suggestions for future research:

First, we reiterate Wright and Yoder's (2003) call for a multidisciplinary bioarchaeology that emphasizes cultural context and allows for research designs that leverage heterogeneity of frailty as an interesting research question in and of itself. Far from being a problem to be ignored or solved, heterogeneous frailty is a worthwhile topic of exploration in past societies. We cannot stress this element of our review enough.

Second, we highlight calls from multiple authors (Klaus 2014; Wilkinson 1992; Wood et al. 1992; Wright and Yoder 2003) to focus on ideal sites with straightforward chronologies, emphasizing cultural context and intrasite patterns of biological variation. Between the individual (osteobiography) and the population (frequency-based perspectives) lies the community, and disentangling familial and community scale variation in health experience has much to offer.

Finally, it is crucial for researchers interested in directly assessing heterogeneous frailty and selective mortality to consider these phenomena at the research design stage. We should make decisions about which data to collect and which analytical approaches to take based on the questions at hand before our field or lab work begins, rather than engaging in post hoc decision making about how to analyze data that might not be maximally informative about frailty. Along these lines, we question whether existing standards, at least by themselves, will continue to serve the needs of a more analytically sophisticated paleoepidemiological approach to ancient health research. While paleopathological description is part of standard data recording practices within bioarchaeology (e.g., Brickley and McKinley 2004; Buikstra and Ubelaker 1994; Smithsonian Institution 2011), the use of standards means that data can be, and often are, collected without a specific research design. Doing so may result in data that are divorced from the needs of current standards of analysis. Once data are collected, researchers are understandably tempted to use them, even if the samples are biased and the data are potentially flawed. While we are aware of the need for standardized data-collection methods to facilitate sharing of data and comparison of results among researchers, the use of standards should be balanced with the need to collect those data best suited to addressing a wider range of perspectives including heterogeneous frailty.

References

Aalen, O. O. (1994). Effects of frailty in survival analysis. *Statistical Methods in Medical Research* **3:** 227–243.

Acs, G., Shulman, R., Ng, M. W., and Chussid, S. (1999). The effect of dental rehabilitation on the body weight of children with early childhood caries. *Pediatric Dentistry* **21:** 109–113.

Agarwal, S. C., and Glencross, B. A. (2011). Building a social bioarchaeology. In Agarwal, S. C., and Glencross, B. A. (eds.), *Social Bioarchaeology*, Wiley-Blackwell, Malden, MA, pp. 1–11.

Ailshire, J. A., Beltrán-Sánchez, H., and Crimmins, E. M. (2011). Social characteristics and health status of exceptionally long-lived Americans in the health and retirement study. *Journal of the American Geriatrics Society* **59:** 2241–2248.

Alholle, A., Brini, A. T., Gharanei, S., Vaiyapuri, S., Arrigoni, E., Dallol, A., Gentle, D., Kishida, T., Hiruma, T., Avigad, S., Grimer, R., Maher, E. R., and Latif, F. (2013). Functional epigenetic approach identifies frequently methylated genes in Ewing sarcoma. *Epigenetics* **8:** 1198–1204.

Almond, D., and Currie, J. (2011). Killing me softly: The fetal origins hypothesis. *The Journal of Economic Perspectives* **25:** 153–172.

Alt, K. W., and Vach, W. (1995). Odontologic kinship analysis in skeletal remains: Concepts, methods, and results. *Forensic Science International* **74:** 99–113.

Alt, K. W., and Vach, W. (1998). Kinship studies in skeletal remains: Concepts and examples. In Alt, K. W., Rosing, F. W., and Techler-Nicola, M. (eds.), *Dental Anthropology Fundamentals, Limits, and Prospects*, Springer, Vienna, pp. 537–554.

Amoroso, A., Garcia, S. J., and Cardoso, H. F. V. (2014). Age at death and linear enamel hypoplasias: Testing the effects of childhood stress and adult socioeconomic circumstances in premature mortality. *American Journal of Human Biology* **26:** 461–468.

Angel, J. (1975). Paleoecology, paleodemography and health. In Polgar, S. (ed.), *Population, Ecology and Social Evolution*, Mouton, The Hague, pp. 167–190.

Appleby, J., Thomas, R., and Buikstra, J. (2015). Increasing confidence in paleopathological diagnosis: Application of the istanbul terminological framework. *International Journal of Paleopathology* **8:** 19–21.

Armelagos, G. J. (2003). Bioarchaeology as anthropology. In Gillespie, S. D., and Nichols, D. L. (eds.), *Archaeology is Anthropology,* Archeological Papers No. 13, American Anthropological Association, Washington, DC, pp. 27–40.

Armelagos, G., and Brown, P. J. (2002). The body as evidence: The body of evidence. In Steckel, R. H., and Rose, J. C. (eds.), *The Backbone of History: Health and Nutrition in the Western Hemisphere*, Cambridge University Press, Cambridge, pp. 593–602.

Armelagos, G. J. (1969). Disease in ancient Nubia. *Science* **163:** 255–259.

Armelagos, G. J., Goodman, A. H., Harper, K. N., and Blakey, M. L. (2009). Enamel hypoplasia and early mortality: Bioarcheological support for the Barker hypothesis. *Evolutionary Anthropology* **18:** 261–271.

Armelagos, G. J., and Van Gerven, D. P. (2003). A century of skeletal biology and paleopathology: Contrasts, contradictions, and conflicts. *American Anthropologist* **105:** 53–64.

Assis, S., Santos, A. L., and Roberts, C. A. (2011). Evidence of hypertrophic osteoarthropathy in individuals from the Coimbra skeletal identified collection (Portugal). *International Journal of Paleopathology* **1:** 155–163.

Baker, B. J., and Kealhofer, L. (1996). *Bioarchaeology of Native American Adaptation in the Spanish Borderlands*, University Press of Florida, Gainesville.

Barker, D. J. P. (1994). *Mothers, Babies, and Disease Later in Life*, BMJ Publishing, London.

Barker, D. J. P. (1990). The fetal and infant origins of adult disease. *British Medical Journal* **301:** 1111.

Barres, R., and Zierath, J. R. (2011). DNA methylation in metabolic disorders. *The American Journal of Clinical Nutrition* **93:** 897S–900S.

Barter, M. J., and Young, D. A. (2013). Epigenetic mechanisms and non-coding RNAs in osteoarthritis. *Current Rheumatology Reports* **15:** 353.

Bastian, O., Pillay, J., Alblas, J., Leenen, L., Koenderman, L., and Blokhuis, T. (2011). Systemic inflammation and fracture healing. *Journal of Leukocyte Biology* **89:** 669–673.

Bates, J. T., Jacobs, J. C., Shea, K. G., and Oxford, J. T. (2014). Emerging genetic basis of osteochondritis dissecans. *Clinics in Sports Medicine* **33:** 199–220.

Beaumont, J., Geber, J., Powers, N., Wilson, A., Lee-Thorp, J., and Montgomery, J. (2013). Victims and survivors: Stable isotopes used to identify migrants from the Great Irish Famine to 19th century London. *American Journal of Physical Anthropology* **150:** 87–98.

Beck, J. D., and Offenbacher, S. (2005). Systemic effects of periodontitis: Epidemiology of periodontal disease and cardiovascular disease. *Journal of Periodontology* **76:** 2089–2100.

Beckett, M. (2000). Converging health inequalities in later life: An artifact of mortality selection. *Journal of Health and Social Behavior* **41:** 106–119.

Bell, C. G., and Beck, S. (2010). The epigenomic interface between genome and environment in common complex diseases. *Briefings in Functional Genomics* **9:** 477–485.

Bennike, P., Lewis, M. E., Schutkowski, H., and Valentin, F. (2005). Comparison of child morbidity in two contrasting medieval cemeteries from Denmark. *American Journal of Physical Anthropology* **128:** 734–746.

Bjornsson, H. T., Sigurdsson, M. I., Fallin, M. D., Irizarry, R. A., Aspelund, T., Cui, H., Yu, W., Rongione, M. A., Ekström, T. J., Harris, T. B., Launer, L. J., Eiriksdottir, G., Leppert, M. F., Sapienza, C., Gudnason, V., and Feinberg, A. P. (2008). Intra-individual change over time in DNA methylation with familial clustering. *Journal of the American Medical Association* **299:** 2877–2883.

Bocquet-Appel, J.-P., Naji, S., and Bandy, M. (2008). Demographic and health changes during the transition to agriculture in North America. In Bocquet-Appel, J. P. (ed.), *Recent Advances in Palaeodemography*, Springer, Dordrecht, The Netherlands, pp. 277–292.

Bocquet-Appel, J. P., and Bar-Yosef, O. (eds.) (2008). *The Neolithic Demographic Transition and Its Consequences*, Springer, New York.

Bocquet-Appel, J. P., and Masset, C. (1982). Farewell to paleodemography. *Journal of Human Evolution* **11:** 321–333.

Boldsen, J. L. (1997). Estimating patterns of disease and mortality in a medieval Danish village. In Paine, R. R. (ed.), *Integrating Archaeological Demography: Multidisciplinary Approaches to Prehistoric Population,* Occasional Paper No. 24, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 229–241.

Boldsen, J. L. (1998). Pathogenesis of dental abscesses in a medieval village community. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* **10:** 345–356.

Boldsen, J. L. (2005a). Analysis of dental attrition and mortality in the medieval village of Tirup, Denmark. *American Journal of Physical Anthropology* **126:** 169–176.

Boldsen, J. L. (2005b). Leprosy and mortality in the medieval Danish village of Tirup. *American Journal of Physical Anthropology* **126:** 159–168.

Boldsen, J. L. (2007). Early childhood stress and adult age mortality: A study of dental enamel hypoplasia in the medieval Danish village of Tirup. *American Journal of Physical Anthropology* **132:** 59–66.

Boldsen, J. L., and Milner, G. R. (2012). An epidemiological approach to paleopathology. In Grauer, A. L. (ed.), *A Companion to Paleopathology*, Wiley-Blackwell, Malden, MA, pp. 114–132.

Boldsen, J. L., Milner, G. R., Konigsberg, L. W., and Wood, J. W. (2002). Transition analysis: A new method for estimating age from skeletons. In Hoppa, R. D., and Vaupel, J. W. (eds.), *Paleodemography: Age Distributions from Skeletal samples*, Cambridge University Press, Cambridge, pp. 73–106.

Bombak, A. E. (2012). Diffuse idiopathic skeletal hyperostosis and the Osteological Paradox. *Totem: The University of Western Ontario Journal of Anthropology* **20:** Article 7.

Bos, K. I., Jäger, G., Schuenemann, V. J., Vågene, Å. J., Spyrou, M. A., Herbig, A., Nieselt, K., and Krause, J. (2015). Parallel detection of ancient pathogens via array-based DNA capture. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* **370:** 1660, DOI:10.1098/rstb.2013.0375.

Boyer, D. M., Lipman, Y., Clair, E. S., Puente, J., Patel, B. A., Funkhouser, T., Jernvall, J., and Daubechies, I. (2011). Algorithms to automatically quantify the geometric similarity of anatomical surfaces. *Proceedings of the National Academy of Sciences USA* **108:** 18221–18226.

Brickley, M., and McKinley, J. I. (2004). *Guidelines to the Standards for Recording Human Remains*, IFA Technical Paper No. 7, BABAO, Department of Archaeology, University of Southampton, UK.

Brickley, M. B., and Buckberry, J. (2015). Picking up the pieces: Utilizing the diagnostic potential of poorly preserved remains. *International Journal of Paleopathology* **8:** 51–54.

Brook, A. H., and Smith, J. M. (1998). The aetiology of developmental defects of enamel: A prevalence and family study in East London, UK. *Connective Tissue Research* **39:** 151–156; discussion 187–194.

Brüssow, H. (2013). What is health? *Microbial Biotechnology* **6:** 341–348.

Buikstra, J. E. (1977). Biocultural dimensions of archaeological study: A regional perspective. In Blakely, R. L. (ed.), *Biocultural Adaptation in Prehistoric America*, University of Georgia Press, Athens, pp. 67–84.

Buikstra, J. E. (2006). On to the 21st century. In Buikstra, J. E., and Beck, L. A. (eds.), *Bioarchaeology: The Contextual Analysis of Human Remains*, Academic Press, Burlington, MA, pp. 347–357.

Buikstra, J. E., Baadsgaard, A., and Boutin, A. T. (2012). Introduction. In Baadsgaard, A., Boutin, A. T., and Buikstra, J. E. (eds.), *Breathing New Life into the Evidence of Death Contemporary Approaches to Bioarchaeology*, School for Advanced Research Press, Santa Fe, NM, pp. 3–26.

Buikstra, J. E., and Beck, L. A. (2006). *Bioarchaeology: The Contextual Analysis of Human Remains*, Academic Press, Burlington, MA.

Buikstra, J. E., and Cook, D. C. (1980). Paleopathology: An American account. *Annual Review of Anthropology* **9:** 433–470.

Buikstra, J. E., Konigsberg, L. W., and Bullington, J. (1986). Fertility and the development of agriculture in the prehistoric Midwest. *American Antiquity* **51:** 528–546.

Buikstra, J. E., and Roberts, C. A. (2012). *The Global History of Paleopathology: Pioneers and Prospects*, Oxford University Press, Oxford.

Buikstra, J. E., and Ubelaker, D. H. (eds.) (1994). *Standards for Data Collection from Human Skeletal Remains: Proceedings of a Seminar at the Field Museum of Natural History,* Arkansas Archaeology Research Series No. 44, Arkansas Archeological Survey Press, Fayetteville.

Burdge, G. C., and Lillycrop, K. A. (2010). Nutrition, epigenetics, and developmental plasticity: Implications for understanding human disease. *Annual Review of Nutrition* **30:** 315–339.

Byers, S. N. (1994). On stress and stature in the "Osteological Paradox." *Current Anthropology* **35:** 282–284.

Cadien, J. D., Harris, E. F., Jones, W. P., and Mandarino, L. J. (1974). Biological lineages, skeletal populations, and microevolution. *Yearbook of Physical Anthropology* **18:** 194–201.

Calvanese, V., Lara, E., Kahn, A., and Fraga, M. F. (2009). The role of epigenetics in aging and age-related diseases. *Ageing Research Reviews* **8:** 268–276.

Capasso, L. (2007). Infectious diseases and eating habits at Herculaneum (1st century AD, southern Italy). *International Journal of Osteoarchaeology* **17:** 350–357.

Casgrain, P., and Legendre, P. (2001). *The R Package for Multivariate and Spatial Analysis, Version 4.0 d6, User's Manual*, Departament de Sciences Biologiques, Université de Montreal, Montreal.

Ĉesnys, G., and Tutkuviené, J. (2007). Topographical approach to kinship assessment within population according to discrete cranial traits: The 5th-6th cc. Plikkaigalis cemetery. *Acta Medica Lituanica* **14:** 7–16.

Chen, E. M., Masih, S., Chow, K., Matcuk, G., and Patel, D. (2012). Periosteal reaction: Review of various patterns associated with specific pathology. *Contemporary Diagnostic Radiology* **35:** 1–5.

Chim, C. S., Fung, T. K., Cheung, W. C., Liang, R., and Kwong, Y. L. (2004). *SOCS1* and *SHP1* hypermethylation in multiple myeloma: Implications for epigenetic activation of the Jak/STAT pathway. *Blood* **103:** 4630–4635.

Chim, C. S., Pang, R., Fung, T. K., Choi, C. L., and Liang, R. (2007). Epigenetic dysregulation of Wnt signaling pathway in multiple myeloma. *Leukemia* **21:** 2527–2536.

Clark, A. L., Tayles, N., and Halcrow, S. E. (2014). Aspects of health in prehistoric mainland Southeast Asia: Indicators of stress in response to the intensification of rice agriculture. *American Journal of Physical Anthropology* **153:** 484–495.

Coale, A. J. (1957). How the age distribution of a human population is determined. *Cold Spring Harbor Symposia on Quantitative Biology* **22:** 83–89.

Cohen, M. N. (1992). Comment on "The Osteological Paradox," by J. W. Wood et al. *Current Anthropology* **33:** 358–359.

Cohen, M. N. (1994). The Osteological Paradox reconsidered. *Current Anthropology* **35:** 629–631.

Cohen, M. N. (1997). Does paleopathology measure community health? A rebuttal of 'the Osteological Paradox' and its implication for world history. In Paine, R. R. (ed.), *Integrating Archaeological Demography: Multidisciplinary Approaches to Prehistoric Population,* Occasional Paper No. 24, Center for Archaeological Investigations, Southern Illinois University, Carbondale, pp. 242–260.

Cohen, M. N. (2002). The economies of late pre-farming and farming communities and their relation to the problem of dispersals. In Bellwood, P., and Renfrew, A. C. (eds.), *Examining the Farming/ Language Dispersal Hypothesis*, McDonald Institute for Archaeological Research, Cambridge, pp. 181–207.

Cohen, M. N., and Armelagos, G. J. (eds.) (1984). *Paleopathology at the Origins of Agriculture*, Academic Press, New York.

Cohen, M. N., and Crane-Kramer, G. M. M. (2007a). *Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification*, Gainesville, FL: University Press of Florida.

Cohen, M. N., and Crane-Kramer, G. M. (2007b). Appendix. In Cohen, M. N., and Crane-Kramer, G. M. (eds.), *Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification*, University Press of Florida, Gainesville, pp. 345–347.

Cook, D. C. (1981). Mortality, age structure, and status in the interpretation of stress indicators in prehistoric skeletons: A dental example from the lower Illinois Valley. In Chapman, R., Kinnes, I., and Randsborg, K. (eds.), *The Archaeology of Death*, Cambridge University Press, Cambridge, pp. 133–144.

Cook, D. C., and Buikstra, J. E. (1979). Health and differential survival in prehistoric populations: Prenatal dental defects. *American Journal of Physical Anthropology* **51:** 649–664.

Cook, D. C., and Powell, M. L. (2006). The evolution of american paleopathology. In Buikstra, J. E., and Beck,L. A. (eds.), *Bioarchaeology: The Contextual Analysis of Human Remains*, Academic Press, New York, pp. 281–322.

Corruccini, R. S., Shimada, I., and Shinoda, K. (2002). Dental and mtDNA relatedness among thousand-year-old remains from Huaca Loro, Peru. *Dental Anthropology* **16:** 9–14.

Costa, D. L. (2012). Scarring and mortality selection among civil war POWs: A long-term mortality, morbidity, and socioeconomic follow-up. *Demography* **49:** 1185–1206.

Cox, M. (1993). Epidemics and skeletal populations: Problems and limitations. In Champion, J. (ed.), *Epidemic Disease in London,* Working Paper Series No. 1, Centre for Metropolitan History, London, pp. 71–79.

Crimmins, E. M. (2004). Trends in the health of the elderly. *Annual Review of Public Health* **25:** 79–98.

Crimmins, E. M., Hayward, M. D., and Saito, Y. (1994). Changing mortality and morbidity rates and the health status and life expectancy of the older population. *Demography* **31:** 159–175.

Crimmins, E. M., Kim, J. K., and Hagedorn, A. (2002). Life with and without disease: Women experience more of both. *Journal of Women & Aging* **14:** 47–59.

Crist, T. A., and Sorg, M. H. (2014). Adult scurvy in New France: Samuel de Champlain's "mal de la terre" at Saint Croix Island, 1604–1605. *International Journal of Paleopathology* **5:** 95–105.

Cucina, A. (2011). Maya sub adult mortality and individual physiological frailty: An analysis of infant stress by means of linear enamel hypoplasia. *Childhood in the Past* **4:** 105–116.

Cucina, A., Cantillo, C. P., Sosa, T. S., and Tiesler, V. (2011). Carious lesions and maize consumption among the Prehispanic Maya: An analysis of a coastal community in northern Yucatan. *American Journal of Physical Anthropology* **145:** 560–567.

DeFranco, A. L., Locksley, R. M., and Robertson, M. (2007). *Immunity: The Immune Response in Infectious and Inflammatory Disease*, New Science Press, London.

Delgado-Calle, J., Fernández, A. F., Sainz, J., Zarrabeitia, M. T., Sañudo, C., García-Renedo, R., Pérez-Núñez, M. I., García-Ibarbia, C., Fraga, M. F., and Riancho, J. A. (2013). Genome-wide profiling of bone reveals differentially methylated regions in osteoporosis and osteoarthritis. *Arthritis and Rheumatism* **65:** 197–205.

DeStefano, F., Anda, R. F., Kahn, H. S., Williamson, D. F., and Russell, C. M. (1993). Dental disease and risk of coronary heart disease and mortality. *British Medical Journal* **306:** 688–691.

Devault, A. M., McLoughlin, K., Jaing, C., Gardner, S., Porter, T. M., Enk, J. M., Thissen, J., Allen, J., Borucki, M., DeWitte, S. N., Dhody, A. N., and Poinar, H. N. (2014). Ancient pathogen DNA in archaeological samples detected with a microbial detection array. *Scientific Reports* **4:** 4245.

DeWitte, S. N., and Hughes-Morey, G. (2012). Stature and frailty during the Black Death: The effect of stature on risks of epidemic mortality in London, AD 1348–1350. *Journal of Archaeological Science* **39:** 1412–1419.

DeWitte, S. N. (2009). The effect of sex on risk of mortality during the Black Death in London, AD 1349–1350. *American Journal of Physical Anthropology* **139:** 222–234.

DeWitte, S. N. (2010). Sex differentials in frailty in medieval England. *American Journal of Physical Anthropology* **143:** 285–297.

DeWitte, S. N. (2014). Health in post-Black Death London (1350–1538): Age patterns of periosteal new bone formation in a post-epidemic population. *American Journal of Physical Anthropology* **155:** 260–267.

DeWitte, S. N., and Bekvalac, J. (2010). Oral health and frailty in the medieval English cemetery of St. Mary Graces. *American Journal of Physical Anthropology* **142:** 341–354.

DeWitte, S. N., Boulware, J. C., and Redfern, R. C. (2013). Medieval monastic mortality: Hazard analysis of mortality differences between monastic and nonmonastic cemeteries in England. *American Journal of Physical Anthropology* **152:** 322–332.

DeWitte, S. N., and Wood, J. W. (2008). Selectivity of Black Death mortality with respect to preexisting health. *Proceedings of the National Academy of Sciences USA* **105:** 1436–1441.

Dimitriou, R., Tsiridis, E., and Giannoudis, P. V. (2005). Current concepts of molecular aspects of bone healing. *Injury* **36:** 1392–1404.

Doblhammer, G., and Hoffmann, R. (2010). Gender differences in trajectories of health limitations and subsequent mortality: A study based on the German Socioeconomic Panel 1995-2001 with a mortality follow-up 2002-2005. *The Journals of Gerontology Series B, Psychological Sciences and Social Sciences* **65:** 482–491.

Drancourt, M., Signoli, M., Dang, L. V., Bizot, B., Roux, V., Tzortzis, S., and Raoult, D. (2007). *Yersinia pestis orientalis* in remains of ancient plague patients. *Emerging Infectious Diseases* **13**: 332–333.

Dupre, M. E. (2007). Educational differences in age-related patterns of disease: Reconsidering the cumulative disadvantage and age-as-leveler hypotheses. *Journal of Health and Social Behavior* **48:** 1–15.

Duray, S. M. (1996). Dental indicators of stress and reduced age at death in prehistoric Native Americans. *American Journal of Physical Anthropology* **99:** 275–286.

Eisenberg, L. E. (1992). Comment on "The Osteological Paradox," by J. W. Wood et al. *Current Anthropology* **33:** 359–360.

ElSalam, H. A. (2003). *Using Geographic Information Systems (GIS) in Spatial Analysis of Mortuary Practices in the Kellis 2 Cemetery, Dakhle Oasis, Egypt*, PhD thesis, Department of Anthropology, Cairo University, Cairo.

Engelman, M., Canudas-Romo, V., and Agree, E. M. (2010). The implications of increased survivorship for mortality variation in aging populations. *Population and Development Review* **36:** 511–539.

Esteller, M. (2008). Epigenetics in cancer. *The New England Journal of Medicine* **358:** 1148–1159.

Exner, S., Bogusch, G., and Sokiranski, R. (2004). Cribra orbitalia visualized in computed tomography. *Annals of Anatomy—Anatomischer Anzeiger* **186:** 169–172.

Feinberg, A. P. (2007). Phenotypic plasticity and the epigenetics of human disease. *Nature* **447:** 433–440.

Finch, C. E., and Crimmins, E. M. (2004). Inflammatory exposure and historical changes in human lifespans. *Science* **305:** 1736–1739.

Fitzgerald, M. P., Gourronc, F., Teoh, M. L. T., Provenzano, M. J., Case, A. J., Martin, J. A., and Domann, F. E. (2011). Human chondrosarcoma cells acquire an epithelial-like gene expression pattern via an epigenetic switch: Evidence for mesenchymal-epithelial transition during sarcomagenesis. *Sarcoma* **2011:** 598218, DOI:10.1155/2011/598218.

Flannery, K. V., and Marcus, J. (2012). *The Creation of Inequality: How Our Prehistoric Ancestors Set the Stage for Monarchy, Slavery, and Empire*, Harvard University Press, Cambridge, MA.

Ford, D., Seow, W. K., Kazoullis, S., Holcombe, T., and Newman, B. (2009). A controlled study of risk factors for enamel hypoplasia in the permanent dentition. *Pediatric Dentistry* **31:** 382–388.

Frost, A., Jonsson, K. B., Nilsson, O., and Ljunggren, Ö. (1997). Inflammatory cytokines regulate proliferation of cultured human osteoblasts. *Acta Orthopaedica Scandinavica* **68:** 91–96.

Gage, T. B. (1988). Mathematical hazard models of mortality: An alternative to model life tables. *American Journal of Physical Anthropology* **76:** 429–441.

Gage, T. B., and DeWitte, S. (2009). What do we know about the agricultural demographic transition? *Current Anthropology* **50:** 649–655.

Gamba, C., Fernández, E., Tirado, M., Pastor, F., and Arroyo-Pardo, E. (2011). Brief communication: Ancient nuclear DNA and kinship analysis: The case of a medieval burial in San Esteban church in Cuellar (Segovia, central Spain). *American Journal of Physical Anthropology* **144:** 485–491.

Geber, J., and Murphy, E. (2012). Scurvy in the great Irish famine: Evidence of vitamin C deficiency from a mid-19th century skeletal population. *American Journal of Physical Anthropology* **148:** 512–524.

Genco, R. J., and Borgnakke, W. S. (2013). Risk factors for periodontal disease. *Periodontology 2000* **62:** 59–94.

Ghanim, A., Manton, D., Bailey, D., Marino, R., and Morgan, M. (2013). Risk factors in the occurrence of molar-incisor hypomineralization amongst a group of Iraqi children. *International Journal of Paediatric Dentistry* **23:** 197–206.

Glodny, B., Nasseri, P., Crismani, A., Schoenherr, E., Luger, A. K., Bertl, K., and Petersen, J. (2013). The occurrence of dental caries is associated with atherosclerosis. *Clinics (São Paulo, Brazil)* **68:** 946–953.

Gluckman, P. D., and Hanson, M. A. (2004). Living with the past: Evolution, development, and patterns of disease. *Science* **305:** 1733–1736.

Goodman, A. H. (1993). On the interpretation of health from skeletal remains. *Current Anthropology* **34:** 281–288.

Goodman, A. H. (1996). Early life stresses and adult health: Insights from dental enamel development. In Henry, C. J., and Ulijaszek, S. J., (eds.), *Long-term Consequences of Early Environment: Growth, Development, and the Lifespan Developmental Perspective*, Cambridge University Press, New York, pp. 163–182.

Goodman, A. H., and Martin, D. L. (2002). Reconstructing health profiles from skeletal remains. In Steckel, R. H., and Rose, J. C. (eds.), *The Backbone of History: Health and Nutrition in the Western Hemisphere*, Cambridge University Press, Cambridge, pp. 11–60.

Goodman, A. H., and Rose, J. C. (1990). Assessment of systemic physiological perturbations from dental enamel hypoplasias and associated histological structures. *Yearbook of Physical Anthropology* **33:** 59–110.

Goodman, A. H., Thomas, B. R., Swedlund, A. C., and Armelagos, G. J. (1988). Biocultural perspectives on stress in prehistoric, historical, and contemporary population research. *Yearbook of Physical Anthropology* **31:** 169–202.

Gordon, J. A., Montecino, M. A., Aqeilan, R. I., Stein, J. L., Stein, G. S., and Lian, J. B. (2014). Epigenetic pathways regulating bone homeostasis: Potential targeting for intervention of skeletal disorders. *Current Osteoporosis Reports* **12:** 496–506.

Grauer, A. L. (2012). *A Companion to Paleopathology*, Wiley-Blackwell, Malden, MA.

Gravina, D. B. L., Cruvinel, V. R. N., Azevedo, T. D. P. L., Toledo, O. A., and Bezerra, A. C. B. (2013). Enamel defects in the primary dentition of preterm and full-term children. *The Journal of Clinical Pediatric Dentistry* **37:** 391–395.

Griffin, R., Pitts, M., Smith, R., and Brook, A. (2011). Inequality at Late Roman Baldock, UK: The impact of social factors on health and diet. *Journal of Anthropological Research* **67:** 533–556.

Guagliardo, M. F. (1982). Tooth crown size differences between age groups: A possible new indicator of stress in skeletal samples. *American Journal of Physical Anthropology* **58:** 383–389.

Haak, W., Brandt, G., de Jong, H. N., Meyer, C., Ganslmeier, R., Heyd, V., Hawkesworth, C., Pike, A. W. G., Meller, H., and Alt, K. W. (2008). Ancient DNA, strontium isotopes, and osteological analyses shed light on social and kinship organization of the later Stone Age. *Proceedings of the National Academy of Sciences USA* **105:** 18226–18231.

Harbeck, M., Seifert, L., Hänsch, S., Wagner, D. M., Birdsell, D., Parise, K. L., Wiechmann, I., Grupe, G., Thomas, A., Keim, P., Zöller, L., Bramanti, B., Riehm, J. M., and Scholz, H. C. (2013). *Yersinia pestis* DNA from skeletal remains from the 6th century AD reveals insights into Justinianic plague. *PLOS Pathogens* **9:** e1003349.

Harpending, H. (1990). Review of "Health and the Rise of Civilization" by M. N. Cohen. *American Ethnologist* **14:** 799–800.

Harper, K. N., and Armelagos, G. J. (2013). Genomics, the origins of agriculture, and our changing microbe-scape: Time to revisit some old tales and tell some new ones. *American Journal of Physical Anthropology* **152:** 135–152.

Harper, K. N., Zuckerman, M. K., Harper, M. L., Kingston, J. D., and Armelagos, G. J. (2011). The origin and antiquity of syphilis revisited: An appraisal of Old World pre-Columbian evidence for treponemal infection. *American Journal of Physical Anthropology* **146:** 99–133.

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.

Heijmans, B. T., Tobi, E. W., Stein, A. D., Putter, H., Blauw, G. J., Susser, E. S., Slagboom, P. E., and Lumey, L. H. (2008). Persistent epigenetic differences associated with prenatal exposure to famine in humans. *Proceedings of the National Academy of Sciences USA* **105:** 17046–17049.

Herrmann, N. (2002). GIS applied to bioarchaeology: An example from the Río Talgua caves in northeast Honduras. *Journal of Cave and Karst Studies* **64:** 17–22.

Herrmann, N. P., Devlin, J. L., and Stanton, J. C. (2014). Bioarchaeological spatial analysis of the Walker-Noe Crematory (15GD56). In Osterholtz, A. J., Baustian, K. M., and Martin, D. L. (eds.), *Commingled and Disarticulated Human Remains: Working Toward Improved Theory, Method, and Data*, Springer, New York, pp. 51–66.

Hill, A. V. (2012). Evolution, revolution and heresy in the genetics of infectious disease susceptibility. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences* **367:** 840–849.

Hochberg, Z., Feil, R., Constancia, M., Fraga, M., Junien, C., Carel, J. C., Boileau, P., Le Bouc, Y., Deal, C. L., Lillycrop, K., Scharfmann, R., Sheppard, A., Skinner, M., Szyf, M., Waterland, R. A., Waxman, D. J., Whitelaw, E., Ong, K., and Albertsson-Wikland, K. (2011). Child health, developmental plasticity, and epigenetic programming. *Endocrine Reviews* **32:** 159–224.

Holland, E. J. (2013). *Bringing Childhood Health into Focus: Incorporating Survivors Into Standard Methods of Investigation,* PhD dissertation, Department of Anthropology, University of Toronto, Toronto.

Huber, M., Knottnerus, J. A., Green, L., van der Horst, H., Jadad, A. R., Kromhout, D., Leonard, B., Lorig, K., Loureiro, M. I., van der Meer, J. W. M., Schnabel, P., Smith, R., van Weel, C., and Smid, H. (2011). How should we define health? *British Medical Journal* **343:** d4163.

Hubert, J. (2000). *Madness, Disability and Social Exclusion: The Archaeology and Anthropology of Difference*, Routledge, London.

Hughes-Morey, G. (2012). *Body Size and Mortality in Medieval England,* PhD dissertation, Department of Anthropology, University at Albany, SUNY, Albany.

Huidobro, C., Fernandez, A. F., and Fraga, M. F. (2013). Aging epigenetics: Causes and consequences. *Molecular Aspects of Medicine* **34:** 765–781.

Hummel, S., Schmidt, D., Kremeyer, B., Herrmann, B., and Oppermann, M. (2005). Detection of the CCR5Δ32 HIV resistance gene in Bronze Age skeletons. *Genes and Immunity* **6:** 371–374.

Huss-Ashmore, R., Goodman, A. H., and Armelagos, G. J. (1982). Nutritional inference from paleopathology. *Advances in Archaeological Method and Theory* **5:** 395–474.

Hutchinson, D. L. (1992). Comment on "The Osteological Paradox," by J. W. Wood et al. *Current Anthropology* **33:** 360.

Hutchinson, D. L., and Norr, L. (2006). Nutrition and health at contact in late prehistoric central Gulf Coast Florida. *American Journal of Physical Anthropology* **129:** 375–386.

Iliopoulos, D., Malizos, K. N., Oikonomou, P., and Tsezou, A. (2008). Integrative microrna and proteomic approaches identify novel osteoarthritis genes and their collaborative metabolic and inflammatory networks. *PLoS ONE* **3:** e3740.

Jackes, M. (1993). On paradox and osteology. *Current Anthropology* **34:** 434–439.

Jackes, M. (2011). Representativeness and bias in archaeological skeletal samples. In Agarwal, S. C., and Glencross, B. A. (eds.), *Social Bioarchaeology*, Wiley-Blackwell, Malden, MA, pp. 107–146.

Jacobi, K. (2000). *Last Rites for the Tipu Maya: Genetic Structuring in a Colonial Cemetery*, University of Alabama Press, Tuscaloosa.

Jacobsen, P. E., Haubek, D., Henriksen, T. B., Østergaard, J. R., and Poulsen, S. (2014). Developmental enamel defects in children born preterm: A systematic review. *European Journal of Oral Sciences* **122:** 7–14.

Jadad, A. R., and O'Grady, L. (2008). How should health be defined? *British Medical Journal* **337:** 1363–1364.

Jankauskas, R., and Česnys, G. (1992). Comment on "The Osteological Paradox," by J. W. Wood et al. *Current Anthropology* **33**. 360–361.

Jantz, R. L., and Owsley, D. W. (1997). Pathology, taphonomy, and cranial morphometrics of the spirit cave mummy. *Nevada Historical Society Quarterly* **40:** 62–82.

Johnson, N. E. (2000). The racial crossover in comorbidity, disability, and mortality. *Demography* **37:** 267–283.

Johnston, L., and Vieira, A. R. (2014). Caries experience and overall health status. *Oral Health & Preventive Dentistry* **12:** 163–170.

Jones, E. E. (2010). Population history of the Onondaga and Oneida Iroquois, AD 1500–1700. *American Antiquity* **75:** 387–407.

Jones, E. E. (2014). A spatiotemporal analysis of Old World diseases in North America, AD 1519–1807. *American Antiquity* **79:** 487–506.

Jones, P. A., and Takai, D. (2001). The role of DNA methylation in mammalian epigenetics. *Science* **293:** 1068–1070.

Joshipura, K. J., Pitiphat, W., Hung, H. C., Willett, W. C., Colditz, G. A., and Douglass, C. W. (2006). Pulpal inflammation and incidence of coronary heart disease. *Journal of Endodontics* **32:** 99–103.

Kang, S. W., Han, S. Y., Lim, S. B., Cho, K. B., and Ban, J. Y. (2014). ACE insertion/deletion polymorphism is associated with periodontal disease in Korean population. *Archives of Oral Biology* **60:** 496–500.

Kannisto, V., Christensen, K., and Vaupel, J. W. (1997). No increased mortality in later life for cohorts born during famine. *American Journal of Epidemiology* **145:** 987–994.

Katzenberg, M. A., and Saunders, S. R. (eds.) (2008). *Biological Anthropology of the Human Skeleton*, John Wiley and Sons, Hoboken, NJ.

Keenleyside, A., Schwarcz, H. P., and Panayotova, K. (2011). Oxygen isotopic evidence of residence and migration in a Greek colonial population on the Black Sea. *Journal of Archaeological Science* **38:** 2658–2666.

Kendall, E. J., Montgomery, J., Evans, J. A., Stantis, C., and Mueller, V. (2013). Mobility, mortality, and the middle ages: Identification of migrant individuals in a 14th century Black Death cemetery population. *American Journal of Physical Anthropology* **150:** 210–222.

Kinnally, E. L. (2014). Epigenetic plasticity following early stress predicts long-term health outcomes in rhesus macaques. *American Journal of Physical Anthropology* **155:** 192–199.

Kintigh, K. W., Altshcul, J. H., Beaudry, M. C., Drennan, R. D., Kinzig, A. P., Kohler, T. A., Limp, W. F., Maschner, H. D. G., Michener, W. K., Pauketat, T. R., Peregrine, P., Sabloff, J. A., Wilkinson, T.

J., Wright, H. T., and Zeder, M. A. (2014a). Grand challenges for archaeology. *American Antiquity* **79:** 5–24.

Kintigh, K. W., Altschul, J. H., Beaudry, M. C., Drennan, R. D., Kinzig, A. P., Kohler, T. A., Limp, W. F., Maschner, H. D. G., Michener, W. K., Pauketat, T. R., Peregrine, P., Sabloff, J. A., Wilkinson, T. J., Wright, H. T., and Zeder, M. A. (2014b). Grand challenges for archaeology. *Proceedings of the National Academy of Sciences USA* **111:** 879–880.

Klaus, H. D. (2014). Frontiers in the bioarchaeology of stress and disease: Cross-disciplinary perspectives from pathophysiology, human biology, and epidemiology. *American Journal of Physical Anthropology* **155:** 294–308.

Knudson, K. J., O'Donnabhain, B., Carver, C., Cleland, R., and Price, T. D. (2012). Migration and Viking Dublin: Paleomobility and paleodiet through isotopic analyses. *Journal of Archaeological Science* **39:** 308–320.

Knüsel, C. J. (2010). Bioarchaeology: A synthetic approach. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* **22:** 62–73.

Kohler, T. A., and Reese, K. M. (2014). Long and spatially variable Neolithic demographic transition in the North American Southwest. *Proceedings of the National Academy of Sciences USA* **111:** 10101–10106.

Korczowska, I. (2014). Rheumatoid arthritis susceptibility genes: An overview. *World Journal of Orthopedics* **5:** 544–549.

Kreger, M. B. (2010). *Urban Population Dynamics in a Preindustrial New World City: Morbidity, Mortality, and Immigration in Postclassic Cholula*, PhD dissertation, Department of Anthropology, Pennsylvania State University, University Park.

Kremeyer, B., Hummel, S., and Herrmann, B. (2005). Frequency analysis of the Δ32ccr5 HIV resistance allele in a medieval Plague mass grave. *Anthropologischer Anzeiger* **63:** 13–22.

Kuehl, W. M., and Bergsagel, P. L. (2002). Multiple myeloma: Evolving genetic events and host interactions. *Nature Reviews Cancer* **2:** 175–187.

Kuzawa, C. W., and Sweet, E. (2009). Epigenetics and the embodiment of race: Developmental origins of US racial disparities in cardiovascular health. *American Journal of Human Biology* **21:** 2–15.

Lam, L. L., Emberly, E., Fraser, H. B., Neumann, S. M., Chen, E., Miller, G. E., and Kobor, M. S. (2012). Factors underlying variable DNA methylation in a human community cohort. *Proceedings of the National Academy of Sciences USA* **109:** 17253–17260.

Lange, J., Sapozhnikova, A., Lu, C., Hu, D., Li, X., Miclau, T., and Marcucio, R. S. (2010). Action of IL-1β during fracture healing. *Journal of Orthopaedic Research* **28:** 778–784.

Larsen, C. S. (1987). Bioarchaeological interpretations of subsistence economy and behavior from human skeletal remains. In Schiffer, M. B. (ed.), *Advances in Archaeological Method and Theory*, Academic Press, San Diego, CA, pp. 339–445.

Larsen, C. S. (1997). *Bioarchaeology: Interpreting Behavior from the Human Skeleton*, Cambridge University Press, New York.

Larsen, C. S. (2006). The changing face of bioarchaeology: An interdisciplinary science. In Buikstra, J. E., and Beck, L. A. (eds.), *Bioarchaeology the Contextual Analysis of Human Remains*, Academic Press, New York, pp. 359–374.

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., and Schultz, M. (2001). Frontiers of contact: Bioarchaeology of Spanish Florida. *Journal of World Prehistory* **15:** 69–123.

Lewis, M. E. (2002). Impact of industrialization: Comparative study of child health in four sites from medieval and postmedieval England (AD 850-1859). *American Journal of Physical Anthropology* **119:** 211–223.

Lewis, M. E., and Gowland, R. (2007). Brief and precarious lives: Infant mortality in contrasting sites from medieval and post-medieval England (AD 850-1859). *American Journal of Physical Anthropology* **134:** 117–129.

Li, H., Zhao, X., Zhao, Y., Li, C., Si, D., Zhou, H., and Cui, Y. (2011). Genetic characteristics and migration history of a Bronze culture population in the west Liao-River valley revealed by ancient DNA. *Journal of Human Genetics* **56:** 815–822.

Li, X., Kolltveit, K. M., Tronstad, L., and Olsen, I. (2000). Systemic diseases caused by oral infection. *Clinical Microbiology Reviews* **13:** 547–558.

Littleton, J. (2011). Moving from the canary in the coalmine: Modeling childhood in Britain. In Agarwal, S. C., and Glencross, B. A. (eds.), *Social Bioarchaeology*, Wiley-Blackwell, Malden, MA, pp. 361–389.

Liu, Y., Aryee, M. J., Padyukov, L., Fallin, M. D., Hesselberg, E., Runarsson, A., Reinius, L., Acevedo, N., Taub, M., Ronninger, M., Shchetynsky, K., Scheynius, A., Kere, J., Alfredsson, L., Klareskog, L., Ekström, T. J., and Feinberg, A. P. (2013). Epigenome-wide association data implicate DNA methylation as an intermediary of genetic risk in rheumatoid arthritis. *Nature Biotechnology* **31:** 142–147.

Lombardo Bedran, T. B., Azelmat, J., Palomari Spolidorio, D., and Grenier, D. (2013). Fibrinogen-induced streptococcus mutans biofilm formation and adherence to endothelial cells. *BioMed Research International* **2013:** 431465, DOI:10.1155/2013/431465.

Loos, B. G. (2005). Systemic markers of inflammation in periodontitis. *Journal of Periodontology* **76:** 2106–2115.

Lukacs, J. R. (1992). Comment on "The Osteological Paradox," by J. W. Wood et al. *Current Anthropology* **33:** 361–362.

Lukacs, J. R. (1994). The osteological paradox and the Indus civilization: Problems inferring health from human skeletons at Harappa. In Kenoyer, J. (ed.), *From Sumer to Meluhha: Contributions to the Archaeology of South and West Asia in Memory of George F. Dales Jr.,* Wisconsin Archaeological Reports Vol. 3, Department of Anthropology, University of Wisconsin, Madison, pp. 143–155.

Lukacs, J. R., Walimbe, S. R., and Floyd, B. (2001). Epidemiology of enamel hypoplasia in deciduous teeth: Explaining variation in prevalence in western India. *American Journal of Human Biology* **13:** 788–807.

Lynch, S. M., Brown, J. S., and Harmsen, K. G. (2003). Black-White differences in mortality compression and deceleration and the mortality crossover reconsidered. *Research on Aging* **25:** 456–483.

Mak, I. W. Y., Singh, S., Turcotte, R., and Ghert, M. (2015). The epigenetic regulation of SOX9 by miR-145 in human chondrosarcoma. *Journal of Cellular Biochemistry* **116:** 37–44.

Manton, K. G., Poss, S. S., and Wing, S. (1979). The Black/White mortality crossover: Investigation from the perspective of the components of aging. *The Gerontologist* **19:** 291–300.

Manton, K. G., Stallard, E., and Vaupel, J. W. (1986). Alternative models for the heterogeneity of mortality risks among the aged. *Journal of the American Statistical Association* **81:** 635–644.

Marden, K., and Ortner, D. J. (2011). A case of treponematosis from pre-Columbian Chaco Canyon, New Mexico. *International Journal of Osteoarchaeology* **21:** 19–31.

Marsteller, S. J., Torres-Rouff, C., and Knudson, K. J. (2011). Pre-Columbian Andean sickness ideology and the social experience of leishmaniasis: A contextualized analysis of bioarchaeological and paleopathological data from San Pedro de Atacama, Chile. *International Journal of Paleopathology* **1:** 24–34.

Martens, J. H. A., Stunnenberg, H. G., and Logie, C. (2011). The decade of the epigenomes? *Genes & Cancer* **2:** 680–687.

Masumo, R., Bårdsen, A., and Åstrøm, A. N. (2013). Developmental defects of enamel in primary teeth and association with early life course events: A study of 6-36 month old children in Manyara, Tanzania. *BMC Oral Health* **13:** 21.

Mays, S. (2012). The impact of case reports relative to other types of publication in palaeopathology. *International Journal of Osteoarchaeology* **22:** 81–85.

McGrath, J. W. (1992). Comment on "The Osteological Paradox," by J. W. Wood et al. *Current Anthropology* **33:** 362–363.

McIlvaine, B. K. (2013). Implications of reappraising the iron-deficiency anemia hypothesis. *International Journal of Osteoarchaeology*, DOI:10.1002/oa.2383 (accessed 07/09/14).

McIlvaine, B. K., Schepartz, L. A., Larsen, C. S., and Sciulli, P. W. (2014). Evidence for long-term migration on the Balkan Peninsula using dental and cranial nonmetric data: Early interaction between Corinth (Greece) and its colony at Apollonia (Albania). *American Journal of Physical Anthropology* **153:** 236–248.

McMunn, A., Nazroo, J., and Breeze, E. (2009). Inequalities in health at older ages: A longitudinal investigation of the onset of illness and survival effects in England. *Age and Ageing* **38:** 181–187.

Meighani, G., Aghamohammadi, A., Javanbakht, H., Abolhassani, H., Nikayin, S., Jafari, S. M., Ghandehari Motlagh, M., Shamshiri, A. R., and Rezaei, N. (2011). Oral and dental health status in patients with primary antibody deficiencies. *Iranian Journal of Allergy, Asthma and Immunology* **10:** 289–293.

Mendonça de Souza, S. M. F., de Carvalho, D. M., and Lessa, A. (2003). Paleoepidemiology: Is there a case to answer? *Memórias do Instituto Oswaldo Cruz* **98:** 21–27.

Meyer, C., Ganslmeier, R., Dresely, V., and Alt, K. (2012). New approaches to the reconstruction of kinship and social structure based on bioarchaeological analysis of neolithic multiple and collective graves. In Kolář, J., and Trampota, F. (eds.), *Theoretical and Methodological Considerations in Central European Neolithic Archaeology,* BAR International Series 2325, Archaeopress, Oxford, pp. 11–23.

Meyer, M. S., Joshipura, K., Giovannucci, E., and Michaud, D. S. (2008). A review of the relationship between tooth loss, periodontal disease, and cancer. *Cancer Causes & Control* **19:** 895–907.

Michaud, D. S., Liu, Y., Meyer, M., Giovannucci, E., and Joshipura, K. (2008). Periodontal disease, tooth loss, and cancer risk in male health professionals: A prospective cohort study. *The Lancet Oncology* **9:** 550–558.

Milner, G. (2013). Trauma in the medieval to early modern Sortebrødre skeletons from Odense, Denmark. In Lozada, M. C., and O'Donnabhain, B. (eds.), *The Dead Tell Tales: Essays in Honor of Jane E Buikstra*, Cotsen Institute of Archaeology Press, Los Angeles, pp. 172–185.

Milner, G. R., Anderson, E., and Smith, V. G. (1991). Warfare in late prehistoric west-central Illinois. *American Antiquity* **56:** 581–603.

Milner, G. R., and Boldsen, J. L. (2012). Transition analysis: A validation study with known-age modern American skeletons. *American Journal of Physical Anthropology* **148:** 98–110.

Milner, G. R., Wood, J. W., and Boldsen, J. L. (2008). Paleodemography. In Katzenberg, M., and Saunders, S. (eds.), *Biological Anthropology of the Human Skeleton*, Wiley-Liss, New York, pp. 561–600.

Miszkiewicz, J. J. (2012). Linear enamel hypoplasia and age-at-death at medieval (11th-16th centuries) St. Gregory's Priory and Cemetery, Canterbury, UK. *International Journal of Osteoarchaeology* **25:** 79–87.

Mitchell, P. D. (2006). Trauma in the Crusader period city of Caesarea: A major port in the medieval eastern Mediterranean. *International Journal of Osteoarchaeology* **16:** 493–505.

Mitchell, P. D. (2013). The importance of research into ancient parasites. *International Journal of Paleopathology* **3:** 189–190.

Molla, M., Madans, J., Wagener, D. K., and Crimmins, E. (2003). *Summary Measures of Population Health: Report of Findings on Methodologic and Data Issues,* National Center for Health Statistics, Hyattsville, MD.

Müller, R., Roberts, C. A., and Brown, T. A. (2014). Biomolecular identification of ancient *Mycobacterium tuberculosis* complex DNA in human remains from Britain and continental Europe. *American Journal of Physical Anthropology* **153:** 178–189.

Mundy, G. R. (2002). Metastasis to bone: Causes, consequences and therapeutic opportunities. *Nature Reviews Cancer* **2:** 584–593.

Munoz, F., Del Rio, N., Sóñora, C., Tiscornia, I., Marco, A., and Hernández, A. (2012). Enamel defects associated with coeliac disease: Putative role of antibodies against gliadin in pathogenesis. *European Journal of Oral Sciences* **120:** 104–112.

Nagaoka, T. (2012). Cranial traumatic injuries caused by weapons in Tokugawa Japan. *International Journal of Osteoarchaeology* **22:** 138–144.

Naveed, H., Abed, S. F., Davagnanam, I., Uddin, J. M., and Adds, P. J. (2012). Lessons from the past: Cribra orbitalia, an orbital roof pathology. *Orbit* **31:** 394–399.

Noymer, A. (2009). Testing the influenza-tuberculosis selective mortality hypothesis with Union Army data. *Social Science & Medicine* **68:** 1599–1608.

Nystrom, K. C. (2013). Dental health of free Blacks in New York State during the mid-19th century. *International Journal of Osteoarchaeology* **23:** 505–528.

O'Donnabhain, B., and Lozada, M. C. (2014). *Archaeological Human Remains: Global Perspectives*, Springer, New York.

O'Fallon, B. D., and Fehren-Schmitz, L. (2011). Native Americans experienced a strong population bottleneck coincident with European contact. *Proceedings of the National Academy of Sciences USA* **108:** 20444–20448.

Oksuzyan, A., Juel, K., Vaupel, J. W., and Christensen, K. (2008). Men: Good health and high mortality: Sex differences in health and aging. *Aging Clinical and Experimental Research* **20:** 91–102.

Ortner, D. J. (1991). Theoretical and methodological issues in paleopathology. In Ortner, D. J., and Aufderheide, A. C. (eds.), *Human Paleopathology: Current Syntheses and Future Options*, Smithsonian Institution Press, Washington, DC, pp. 5–11.

Ortner, D. J. (1992). Skeletal paleopathology: Probabilities, possibilities, and impossibilities. In Verano, J. W., and Ubelaker, D. H. (eds.), *Disease and Demography in the Americas*, Smithsonian Institution Press, Washington, DC, pp. 5–13.

Ortner, D. J. (1998). Male-female immune reactivity and its implications for interpreting evidence in human skeletal paleopathology. In Grauer, A. L., and Stuart-Macadam, P. (eds.), *Sex and Gender in Paleopathological Perspective*, Cambridge University Press, Cambridg, pp. 79–92.

Ortner, D. J. (2002). Palaeopathology in the twenty-first century. In Dobney, K., and O'Connor, T. (eds.), *Bones and the Man: Studies in Honour of Don Brothwell*, Oxbow Books, Oxford, pp. 5–13.

Ortner, D. J. (2003). *Identification of Pathological Conditions in Human Skeletal Remains*, Academic Press, San Diego, CA.

Ortner, D. J. (2009). Issues in paleopathology and possible strategies for dealing with them. *Anthropologischer Anzeiger* **67:** 323–340.

Oxenham, M. F., Tilley, L., Matsumura, H., Nguyen, L. C., Nguyen, K. T., Nguyen, K. D., Domett, K., and Huffer, D. (2009). Paralysis and severe disability requiring intensive care in Neolithic Asia. *Anthropological Science* **117:** 107–112.

Oxenham, M. F., and Cavill, I. (2010). Porotic hyperostosis and cribra orbitalia: The erythropoietic response to iron-deficiency anaemia. *Anthropological Science* **118:** 199–200.

Oxenham, M. F., and Tayles, N. (eds.) (2006). *Bioarchaeology of Southeast Asia*, Cambridge University Press, Cambridge.

Paine, R. R. (1989). Model life table fitting by maximum likelihood estimation: A procedure to reconstruct paleodemographic characteristics from skeletal age distributions. *American Journal of Physical Anthropology* **79:** 51–61.

Paine, R. R., and Boldsen, J. L. (2002). Linking age-at-death distributions and ancient population dynamics: A case study. In Hoppa, R., and Vaupel, J. W. (eds.), *Paleodemography: Age Distributions from Skeletal Samples*, Cambridge University Press, Cambridge, pp. 169–180.

Paine, R. R., and Brenton, B. P. (2006). The paleopathology of pellagra: Investigating the impact of prehistoric and historical dietary transitions to maize. *Journal of Anthropological Sciences* **84:** 125–135.

Paju, S., and Scannapieco, F. A. (2007). Oral biofilms, periodontitis, and pulmonary infections. *Oral Diseases* **13:** 508–512.

Palubeckaitė, Ž., Jankauskas, R., Ardagna, Y., Macia, Y., Rigeade, C., Signoli, M., and Dutour, O. (2006). Dental status of Napoleon's Great Army's (1812) mass burial of soldiers in Vilnius: Childhood peculiarities and adult dietary habits. *International Journal of Osteoarchaeology* **16:** 355–365.

Patel, N., Black, J., Chen, X., Marcondes, A. M., Grady, W. M., Lawlor, E. R., and Borinstein, S. C. (2012). DNA methylation and gene expression profiling of Ewing sarcoma primary tumors reveal genes that are potential targets of epigenetic inactivation. *Sarcoma* **2012:** 498472, DOI:10.1155/2012/498472.

Paul, K. S., Stojanowski, C. M., and Butler, M. M. (2013). Biological and spatial structure of an Early Classic period cemetery at Charco Redondo, Oaxaca. *American Journal of Physical Anthropology* **152:** 217–229.

Pechenkina, E. A., and Delgado, M. (2006). Dimensions of health and social structure in the Early Intermediate period cemetery at Villa El Salvador, Peru. *American Journal of Physical Anthropology* **131:** 218–235.

Peck, J. J. (2013). Status, health, and lifestyle in Middle Iron Age Britain: A bioarcheological study of elites and non-elites from East Yorkshire, northern England. *International Journal of Paleopathology* **3:** 83–94.

Perry, M. A. (2014). Tracking the second epidemiological transition using bioarchaeological data on infant morbidity and mortality. In Zuckerman, M. K. (ed.), *Modern Environments and Human Health: Revisiting the Second Epidemiological Transition*, Wiley Blackwell, Hoboken, NJ, pp. 225–241.

Pilloud, M. A., and Larsen, C. S. (2011). "Official" and "practical" kin: Inferring social and community structure from dental phenotype at Neolithic Çatalhöyük, Turkey. *American Journal of Physical Anthropology* **145:** 519–530.

Pinhasi, R., and Bourbou, C. (2008). How representative are human skeletal assemblages for population analysis? In Pinhasi, R., and Mays, S. (eds.), *Advances in Human Palaeopathology*, Wiley, Chichester, UK, pp. 31–44.

Pinhasi, R., and Stock, J. (eds.) (2011). *Human Bioarchaeology at the Transition to Agriculture*, Wiley-Blackwell, Chichester, UK.

Piperata, B. A., Hubbe, M., and Schmeer, K. K. (2014). Intra-population variation in anemia status and its relationship to economic status and self-perceived health in the Mexican family life survey: Implications for bioarchaeology. *American Journal of Physical Anthropology* **155:** 210–220.

Powell, M. L., and Cook, D. C. (2012). How does the history of paleopathology predict its future? In Grauer, A. L. (ed.), *A Companion to Paleopathology*, Wiley-Blackwell, Malden, MA, pp. 214–224.

Price, T. D., and Feinman, G. M. (eds.) (1995). *Foundations of Social Inequality*, Springer, New York.

Prideaux, S. M., Conway O'Brien, E., and Chevassut, T. J. (2014). The genetic architecture of multiple myeloma. *Advances in Hematology* **2014:** 864058, DOI:10.1155/2014/864058.

Prüss-Üstün, A., Mathers, C., Corvalán, C., and Woodward, A. (2003). *Introduction and Methods: Assessing the Environmental Burden of Disease at National and Local Levels,* WHO Environmental Burden of Disease Series No. 1, World Health Organization, Geneva.

Raff, J. A., Bolnick, D. A., Tackney, J., and O'Rourke, D. H. (2011). Ancient DNA perspectives on American colonization and population history. *American Journal of Physical Anthropology* **146:** 503–514.

Ragsdale, B. D., and Lehmer, L. M. (2012). A knowledge of bone at the cellular (histological) level is essential to paleopathology. In Grauer, A. L. (ed.), *A Companion to Paleopathology*, Wiley-Blackwell, Malden, MA, pp. 225–249.

Rakita, G. F. M. (2014). Bioarchaeology as a process: An examination of bioarchaeological tribes in the USA. In O'Donnabhain, B., and Lozada, M. C. (eds.), *Archaeological Human Remains Global Perspectives*, Springer, Dordrecht, The Netherlands, pp. 213–234.

Redfern, R. C., and DeWitte, S. N. (2011a). A new approach to the study of Romanization in Britain: A regional perspective of cultural change in Late Iron Age and Roman Dorset using the Siler and Gompertz-Makeham models of mortality. *American Journal of Physical Anthropology* **144:** 269–285.

Redfern, R. C., and DeWitte, S. N. (2011b). Status and health in Roman Dorset: The effect of status on risk of mortality in post-conquest populations. *American Journal of Physical Anthropology* **146:** 197–208.

Reisinger, M. R. (2013). Fluctuating asymmetry in the context of social stratification: A Bronze Age population, MS thesis, Department of Anthropology, Universität Wien, Vienna.

Reitsema, L. J., and McIlvaine, B. K. (2014). Reconciling "stress" and "health" in physical anthropology: What can bioarchaeologists learn from the other subdisciplines? *American Journal of Physical Anthropology* **155:** 181–185.

Reitsema, L. J., and Vercellotti, G. (2012). Stable isotope evidence for sex- and status-based variations in diet and life history at medieval Trino Vercellese, Italy. *American Journal of Physical Anthropology* **148:** 589–600.

Ricaut, F.-X., Auriol, V., von Cramon-Taubadel, N., Keyser, C., Murail, P., Ludes, B., and Crubézy, E. (2010). Comparison between morphological and genetic data to estimate biological relationship: The case of the Egyin Gol Necropolis (Mongolia). *American Journal of Physical Anthropology* **143:** 355–364.

Robb, J., Bigazzi, R., Lazzarini, L., Scarsini, C., and Sonego, F. (2001). Social "status" and biological "status": A comparison of grave goods and skeletal indicators from Pontecagnano. *American Journal of Physical Anthropology* **115:** 213–222.

Robbins Schug, G. (2011). *Bioarchaeology and Climate Change: A View from South Asian Prehistory*, University Press of Florida, Gainesville.

Roberts, C. A. (2000). Did they take sugar? The use of skeletal evidence in the study of disability in past populations. In Hubert, J. (ed.), *Madness, Disability and Social Exclusion: The Archaeology and Anthropology of Difference*, Routledge, London, pp. 46–59.

Roberts, C. A., and Manchester, K. (2005). *The Archaeology of Disease*, Cornell University Press, Ithaca, NY.

Robertson, K. D. (2005). DNA methylation and human disease. *Nature Reviews Genetics* **6:** 597–610.

Robine, J.-M., Cheung, S. L. K., Saito, Y., Jeune, B., Parker, M. G., and Herrmann, F. R. (2010). Centenarians today: New insights on selection from the 5-COOP study. *Current Gerontology and Geriatrics Research* **2010:** 120354, DOI:10.1155/2010/120354.

Rodney, N. C., and Mulligan, C. J. (2014). A biocultural study of the effects of maternal stress on mother and newborn health in the Democratic Republic of Congo. *American Journal of Physical Anthropology* **155:** 200–209.

Rosenberg, M. S., and Anderson, C. D. (2011). Passage: Pattern analysis, spatial statistics and geographic exegesis: Version 2. *Methods in Ecology and Evolution* **2:** 229–232.

Rothschild, B. (2012). Extirpolation of the mythology that porotic hyperostosis is caused by iron deficiency secondary to dietary shift to maize. *Advances in Anthropology* **2:** 157–160.

Sandberg, P. A., Sponheimer, M., Lee-Thorp, J., and Van Gerven, D. (2014). Intra-tooth stable isotope analysis of dentine: A step toward addressing selective mortality in the reconstruction of life history in the archaeological record. *American Journal of Physical Anthropology* **155:** 281–293.

Sattenspiel, L., and Harpending, H. (1983). Stable populations and skeletal age. *American Antiquity* **48:** 489–498.

Saunders, S. R., and Hoppa, R. D. (1993). Growth deficit in survivors and non-survivors: Biological mortality bias in subadult skeletal samples. *American Journal of Physical Anthropology* **36:** 127–151.

Saunders, S. R., Herring, D. A., and Boyce, G. (1995). Can skeletal samples accurately represent the living populations they come from? The St. Thomas' Cemetery site, Belleville, Ontario. In Grauer, A. L. (ed.), *Bodies of Evidence: Reconstructing History Through Skeletal Analysis*, Wiley-Liss, New York, pp. 69–89.

Sautter, J. M., Thomas, P. A., Dupre, M. E., and George, L. K. (2012). Socioeconomic status and the Black-White mortality crossover. *American Journal of Public Health* **102:** 1566–1571.

Schroth, R. J., Lavelle, C., Tate, R., Bruce, S., Billings, R. J., and Moffatt, M. E. (2014). Prenatal vitamin D and dental caries in infants. *Pediatrics* **133:** e1277–e1284, DOI:10.1542/peds.2013-2215.

Schultes, T., Hummel, S., and Herrmann, B. (2000). Ancient DNA-typing approaches for the determination of kinship in a disturbed collective burial site. *Anthropologischer Anzeiger* **58:** 37–44.

Schultz, M. (2011). Light microscopic analysis of macerated pathologically changed bone. In Crowder, C., and Stout, S. (eds.), *Bone Histology: An Anthropological Perspective*, Taylor and Francis, Hoboken, NJ, pp. 253–296.

Seow, W. K. (2014). Developmental defects of enamel and dentine: Challenges for basic science research and clinical management. *Australian Dental Journal* **59** (Suppl 1): 143–154.

Shang, H., and Trinkaus, E. (2008). An ectocranial lesion on the Middle Pleistocene human cranium from Hulu Cave, Nanjing, China. *American Journal of Physical Anthropology* **135:** 431–437.

Sheridan, S. G., and Van Gerven, D. P. (1997). Female biological resiliency: Differential stress response by sex in human remains from ancient Nubia. *Human evolution* **12:** 241–252.

Sherwood, R. J., and Duren, D. L. (2013). The genetics of morphology. In Begun, D. J. (ed.), *Companion to Paleoanthropology,* Wiley-Blackwell, Malden, MA, pp. 306–320.

Siek, T. (2013). The Osteological Paradox and issues of interpretation in paleopathology. *vis-à-vis: Explorations in Anthropology* **13:** 92–101.

Silva-Sousa, Y. T. C., Peres, L. C., and Foss, M. C. (2003). Enamel hypoplasia in a litter of rats with alloxan-induced diabetes mellitus. *Brazilian Dental Journal* **14:** 87–93.

Skinner, M. F., Rodrigues, A. T., and Byra, C. (2014). Developing a pig model for crypt fenestration-induced localized hypoplastic enamel defects in humans. *American Journal of Physical Anthropology* **154:** 239–250.

Slagboom, P. E., Beekman, M., Passtoors, W. M., Deelen, J., Vaarhorst, A. a. M., Boer, J. M., Akker, E. B. v. d., Heemst, D. v., Craen, A. J. d., Maier, A. B., Rozing, M., Mooijaart, S. P., Heijmans, B. T., and Westendorp, R. G. (2011). Genomics of human longevity. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* **366:** 35–42.

Šmejda, L. (2004). Potential of GIS for analysis of funerary areas: Prehistoric cemetery at Holešov, Distr. Kroměříž, Czech Republic. In Šmejda, L., and Turek, J. (eds.), *Spatial Analysis of Funerary Areas*, Department of Archaeology, Faculty of Humanities, University of West Bohemia, Plzeň, Czech Republic, pp. 57–68.

Smithsonian Institution. (2011). Osteoware: Standardized skeletal documentation software (http://osteoware.Si.Edu/) (accessed June 12, 2014).

Sokal, R. R., Lengyel, I. A., Derish, P. A., Wooten, M. C., and Oden, N. L. (1987). Spatial autocorrelation of ABO serotypes in medieval cemeteries as an indicator of ethnic and familial structure. *Journal of Archaeological Science* **14:** 615–633.

Sosna, D., Galeta, P., Šmejda, V., Sládek, V., and Bruzek, J. (2012). Burials and graphs: Relational approach to mortuary analysis. *Social Science Computer Review* **31:** 56–70.

Soto-Hermida, A., Fernández-Moreno, M., Oreiro, N., Fernández-López, C., Rego-Pérez, I., and Blanco, F. J. (2014). MtDNA haplogroups and osteoarthritis in different geographic populations. *Mitochondrion* **15**: 18–23.

Souza, J. F., Costa-Silva, C. M., Jeremias, F., Santos-Pinto, L., Zuanon, A. C., and Cordeiro, R. C. (2012). Molar incisor hypomineralisation: Possible aetiological factors in children from urban and rural areas. *European Archives of Paediatric Dentistry* **13:** 164–170.

Sparks, J. A., and Costenbader, K. H. (2014). Genetics, environment, and gene-environment interactions in the development of systemic rheumatic diseases. *Rheumatic Diseases Clinics of North America* **40:** 637–657.

Steckel, R. H. (2005). Young adult mortality following severe physiological stress in childhood: Skeletal evidence. *Economics & Human Biology* **3:** 314–328.

Steckel, R. H., and Rose, J. C. (eds.) (2002). *The Backbone of History: Health and Nutrition in the Western Hemisphere*, Cambridge University Press, Cambridge.

Steckel, R. H., Sciulli, P. W., and Rose, J. C. (2002). A health index from skeletal remains. In Steckel, R. H., and Rose, J. C. (eds.), *The Backbone of History: Health and Nutrition in the Western Hemisphere*, Cambridge University Press, Cambridge, pp. 61–93.

Steinsaltz, D. R., and Wachter, K. W. (2006). Understanding mortality rate deceleration and heterogeneity. *Mathematical Population Studies* **13:** 19–37.

Steyn, M., Işçan, M. Y., De Kock, M., Kranioti, E. F., Michalodimitrakis, M., and L'Abbe, E. N. (2010). Analysis of ante mortem trauma in three modern skeletal populations. *International Journal of Osteoarchaeology* **20:** 561–571.

Stodder, A. L., and Palkovich, A. M. (2012). *The Bioarchaeology of Individuals*, University Press of Florida, Gainesville.

Stojanowski, C. M. (2005). *Biocultural Histories in La Florida: A Bioarchaeological Perspective*, University of Alabama Press, Tuscaloosa.

Stojanowski, C. M. (2003). Matrix decomposition model for investigating prehistoric intracemetery biological variation. *American Journal of Physical Anthropology* **122:** 216–231.

Stojanowski, C. M. (2013). *Mission Cemeteries, Mission Peoples: Historical and Evolutionary Dimensions of Intracemetary Bioarchaeology in Spanish Florida*, University Press of Florida, Gainesville.

Stojanowski, C. M., and Buikstra, J. E. (2005). Research trends in human osteology: A content analysis of papers published in the American Journal of Physical Anthropology. *American Journal of Physical Anthropology* **128:** 98–109.

Stojanowski, C. M., and Duncan, W. N. (2015). Engaging bodies in the public imagination: Bioarchaeology as social science, science, and humanities. *American Journal of Human Biology* **27:** 51–60.

Stojanowski, C. M., Larsen, C. S., Tung, T. A., and McEwan, B. G. (2007). Biological structure and health implications from tooth size at Mission San Luis de Apalachee. *American Journal of Physical Anthropology* **132:** 207–222.

Stojanowski, C. M., and Schillaci, M. A. (2006). Phenotypic approaches for understanding patterns of intracemetery biological variation. *Yearbook of Physical Anthropology* **131:** 49–88.

Storey, R. (1997). Individual frailty, children of privilege, and stress in Late Classic Copán. In Whittington, S., and Reed, D. (eds.), *Bones of the Maya*, University of Alabama Press, Tuscaloosa, pp. 116–126.

Storey, R. (1998). The mothers and daughters of a patrilineal civilization: The health of females among Late Classic Maya of Copan, Honduras. In Grauer, A. L., and Stuart-Macadam, P. (eds.), *Sex and Gender in Paleopathological Perspective*, Cambridge University Press, Cambridge, pp. 133–148.

Storey, R. (1999). Late Classic nutrition and skeletal indicators at Copán, Honduras. In White, C. (ed.), *Reconstructing Ancient Maya Diet*, University of Utah Press, Salt Lake City, pp. 169–182.

Storey, R., Márquez Morfín, L., and Núñez, L. F. (2012). Teotihuacan neighborhoods and the health of residents: The risks of preindustrial urban living. In Arnauld, M. C., Manzanilla, L. R., and Smith, M. E. (eds.), *The Neighborhood as a Social and Spatial Unit in Mesoamerican Cities*, University of Arizona Press, Tuscon, pp. 117–131.

Storey, R., Márquez Morfín, L., and Smith, V. (2002). Social disruption and the Maya civilization of Mesoamerica: A study of health and economy of the last thousand years. In Steckel, R. H., and Rose, J. C. (eds.), *The Backbone of History: Health and Nutrition in the Western Hemisphere*, Cambridge University Press, New York, pp. 283–306.

Sullivan, A. (2004). Reconstructing relationships among mortality, status, and gender at the medieval Gilbertine Priory of St. Andrew, Fishergate, York. *American Journal of Physical Anthropology* **124:** 330–345.

Suzuki, M. M., and Bird, A. (2008). DNA methylation landscapes: Provocative insights from epigenomics. *Nature Reviews Genetics* **9:** 465–476.

Taji, S., Hughes, T., Rogers, J., and Townsend, G. (2000). Localised enamel hypoplasia of human deciduous canines: Genotype or environment? *Australian Dental Journal* **45:** 83–90.

Tammen, S. A., Friso, S., and Choi, S.-W. (2013). Epigenetics: The link between nature and nurture. *Molecular Aspects of Medicine* **34:** 753–764.

Tanner, S., and TAPS Bolivia Study Team. (2014). Health and disease: Exploring the relation between parasitic infections, child nutrition status, and markets. *American Journal of Physical Anthropology* **155:** 221–228.

Telldahl, Y. (2012). Skeletal changes in lower limb bones in domestic cattle from Eketorp ringfort on the Öland Island in Sweden. *International Journal of Paleopathology* **2:** 208–216.

Temple, D. H. (2014). Plasticity and constraint in response to early-life stressors among Late/Final Jomon period foragers from Japan: Evidence for life history trade-offs from incremental microstructures of enamel. *American Journal of Physical Anthropology* **155:** 537–545.

Temple, D. H., and Goodman, A. H. (2014). Bioarcheology has a "health" problem: Conceptualizing "stress" and "health" in bioarcheological research. *American Journal of Physical Anthropology* **155:** 186–191.

Thayer, Z. M., and Kuzawa, C. W. (2014). Early origins of health disparities: Material deprivation predicts maternal evening cortisol in pregnancy and offspring cortisol reactivity in the first few weeks of life. *American Journal of Human Biology* **26:** 723–730.

Thomas, D. H. (1990a). *Columbian Consequences, Volume 1: Archaeological and Historical Perspectives on the Spanish Borderlands West*, Smithsonian Institution Press, Washington, DC.

Thomas, D. H. (1990b). *Columbian Consequences, Volume 2: Archaeological and Historical Perspectives on the Spanish Borderlands East*, Smithsonian Institution Press, Washington, DC.

Thomas, D. H. (1990c). *Columbian Consequences, Volume 3: The Spanish Borderlands in Pan-American Perspective*, Smithsonian Institution Press, Washington, DC.

Thomas, M. V., and Puleo, D. A. (2011). Infection, inflammation, and bone regeneration: A paradoxical relationship. *Journal of Dental Research* **90:** 1052–1061.

Thomas, R., and Johannsen, N. (2011). Articular depressions in domestic cattle phalanges and their archaeological relevance. *International Journal of Paleopathology* **1:** 43–54.

Tilley, L., and Cameron, T. (2014). Introducing the index of care: A web-based application supporting archaeological research into health-related care. *International Journal of Paleopathology* **6:** 5–9.

Tilley, L., and Oxenham, M. F. (2011). Survival against the odds: Modeling the social implications of care provision to seriously disabled individuals. *International Journal of Paleopathology* **1:** 35–42.

Tobi, E. W., Lumey, L. H., Talens, R. P., Kremer, D., Putter, H., Stein, A. D., Slagboom, P. E., and Heijmans, B. T. (2009). DNA methylation differences after exposure to prenatal famine are common and timing- and sex-specific. *Human Molecular Genetics* **18:** 4046–4053.

Torres-Rouff, C., Knudson, K. J., and Hubbe, M. (2013). Issues of affinity: Exploring population structure in the middle and regional developments periods of San Pedro de Atacama, Chile. *American Journal of Physical Anthropology* **152:** 370–382.

Trinkaus, E., Maley, B., and Buzhilova, A. P. (2008). Brief communication: Paleopathology of the Kiik-Koba 1 Neandertal. *American Journal of Physical Anthropology* **137:** 106–112.

Tsutaya, T., and Yoneda, M. (2015). Reconstruction of breastfeeding and weaning practices using stable isotope and trace element analyses: A review. *American Journal of Physical Anthropology* **156** (Suppl 59): 2–21.

Ubelaker, D. H. (1992). Comment on "The Osteological Paradox," by J. W. Wood et al. *Current Anthropology* **33:** 363–364.

Usher, B. M. (2000). *A Multistate Model of Health and Mortality for Paleodemography: Tirup Cemetery,* PhD dissertaion, Department of Anthropology, Pennsylvania State University, University Park.

Usher, B. M., and Allen, K. L. (2005). Identifying kinship clusters: SatScan for genetic spatial analysis. *American Journal of Physical Anthropology* **S36:** 210.

Vach, W., and Alt, K. W. (1993). Detection of kinship structures in prehistoric burial sites based on odontological traits. In Andresen, J., Madsen, T., and Scollar, I. (eds.), *Computing the Past*, Alden Press, Oxford, pp. 287–292.

Van der Merwe, A. E., Steyn, M., and L'Abbe, E. N. (2010). Trauma and amputations in 19th century miners from Kimberley, South Africa. *International Journal of Osteoarchaeology* **20:** 291–306.

van Schaik, K., Vinichenko, D., and Rühli, F. (2014). Health is not always written in bone: Using a modern comorbidity index to assess disease load in paleopathology. *American Journal of Physical Anthropology* **154:** 215–221.

Vaupel, J. W., and Carey, J. R. (1993). Compositional interpretations of medfly mortality. *Science* **260:** 1666–1667.

Vaupel, J. W., Manton, K. G., and Stallard, E. (1979). The impact of heterogeneity in individual frailty on the dynamics of mortality. *Demography* **16:** 439–454.

Vaupel, J. W., and Yashin, A. I. (1985). Heterogeneity's ruses: Some surprising effects of selection on population dynamics. *American Statistician* **39:** 176–185.

Verano, J. W., and Ubelaker, D. H. (eds.) (1992). *Disease and Demography in the Americas*, Smithsonian Institution Press, Washington, DC.

Vercellotti, G., Piperata, B. A., Agnew, A. M., Wilson, W. M., Dufour, D. L., Reina, J. C., Boano, R., Justus, H. M., Larsen, C. S., Stout, S. D., and Sciulli, P. W. (2014). Exploring the multidimensionality of stature variation in the past through comparisons of archaeological and living populations. *American Journal of Physical Anthropology* **155:** 229–242.

Vrtačnik, P., Marc, J., and Ostanek, B. (2014). Epigenetic mechanisms in bone. *Clinical Chemistry and Laboratory Medicine* **52:** 589–608.

Waldron, T. (1994). *Counting the Dead: The Epidemiology of Skeletal Populations*, Wiley, Chichester, UK.

Waldron, T. (1996). What was the prevalence of malignant disease in the past? *International Journal of Osteoarchaeology* **6:** 463–470.

Waldron, T. (2007). *Paleoepidemiology: The Measure of Disease in the Human Past*, Left Coast Press, Walnut Creek, CA.

Walker, P. L., Bathurst, R. R., Richman, R., Gjerdrum, T., and Andrushko, V. A. (2009). The causes of porotic hyperostosis and cribra orbitalia: A reappraisal of the iron-deficiency-anemia hypothesis. *American Journal of Physical Anthropology* **139:** 109–125.

Wapler, U., Crubézy, E., and Schultz, M. (2004). Is cribra orbitalia synonymous with anemia? Analysis and interpretation of cranial pathology in Sudan. *American Journal of Physical Anthropology* **123:** 333–339.

Warinner, C., Rodrigues, J. F., Vyas, R., Trachsel, C., Shved, N., Grossmann, J., Radini, A., Hancock, Y., Tito, R. Y., Fiddyment, S., Speller, C., Hendy, J., Charlton, S., Luder, H. U., Salazar-García, D. C., Eppler, E., Seiler, R., Hansen, L. H., Castruita, J. A., Barkow-Oesterreicher, S., Teoh, K. Y., Kelstrup, C. D., Olsen, J. V., Nanni, P., Kawai, T., Willerslev, E., von Mering, C., Lewis, C. M., Collins, M. J., Gilbert, M. T., Rühli, F., and Cappellini, E. (2014). Pathogens and host immunity in the ancient human oral cavity. *Nature Genetics* **46:** 336–344.

Warman, M. L., Cormier-Daire, V., Hall, C., Krakow, D., Lachman, R., LeMerrer, M., Mortier, G., Mundlos, S., Nishimura, G., Rimoin, D. L., Robertson, S., Savarirayan, R., Sillence, D., Spranger, J., Unger, S., Zabel, B., and Superti-Furga, A. (2011). Nosology and classification of genetic skeletal disorders: 2010 revision. *American Journal of Medical Genetics Part A* **155:** 943–968.

Watts, A., Crimmins, E. M., and Gatz, M. (2008). Inflammation as a potential mediator for the association between periodontal disease and Alzheimer's disease. *Neuropsychiatric Disease and Treatment* **4:** 865–876.

Webb, E. C., White, C. D., Van Uum, S., and Longstaffe, F. J. (2014). Integrating cortisol and isotopic analyses of archeological hair: Reconstructing individual experiences of health and stress. *American Journal of Physical Anthropology*, DOI:10.1002/ajpa.22673 (accessed 12/31/14).

Weisensee, K. E. (2013). Assessing the relationship between fluctuating asymmetry and cause of death in skeletal remains: A test of the developmental origins of health and disease hypothesis. *American Journal of Human Biology* **25:** 411–417.

Weiss, K. M. (1973). *Demographic Models for Anthropology*, Society for American Archaeology, Washington, DC.

Weiss, K. M., and Buchanan, A. V. (2003). Evolution by phenotype: A biomedical perspective. *Perspectives in Biology and Medicine* **46:** 159–182.

Welinder, S. (2001). The archaeology of old age. *Current Swedish Archaeology* **9:** 163–178.

Weston, D. A. (2008). Investigating the specificity of periosteal reactions in pathology museum specimens. *American Journal of Physical Anthropology* **137:** 48–59.

Weston, D. A. (2012). Nonspecific infection in paleopathology: Interpreting periosteal reactions. In Grauer, A. L. (ed.), *A Companion to Paleopathology*, Wiley-Blackwell, Malden, MA, pp. 492–512.

White, A. A. (2014). Mortality, fertility, and the OY ratio in a model hunter-gatherer system. *American Journal of Physical Anthropology* **154:** 222–231.
Wilkinson, R. G. (1992). Comment on "The Osteological Paradox," by J. W. Wood et al. *Current Anthropology* **33:** 364–365.
Williams, R. C., Barnett, A. H., Claffey, N., Davis, M., Gadsby, R., Kellett, M., Lip, G. Y., and Thackray, S. (2008). The potential impact of periodontal disease on general health: A consensus view. *Current Medical Research & Opinion* **24:** 1635–1643.
Wilson, J. J. (2010). *Modeling Life Through Death in Late Prehistoric West-Central Illinois: An Assessment of Paleodemographic and Paleoepidemiological Variability,* PhD dissertation, Department of Anthropology, Binghamton University, SUNY, Binghamton.
Wilson, J. J. (2014). Paradox and promise: Research on the role of recent advances in paleodemography and paleoepidemiology to the study of "health" in Precolumbian societies. *American Journal of Physical Anthropology* **155:** 268–280.
Winkler, L. A. (2011). The social structuring of stress in contact-era Spanish Florida: A bioarchaeological case study from Santa Catalina de Guale, St. Catherines Island, Georgia, MA thesis, Department of Anthropology, Ohio State University, Columbus.
Wise, P. M., Challagundla, K., and Fabbri, M. (2015). Epigenetics and microRNAs in cancer. In Rezaei, N. (ed.), *Cancer Immunology: A Translational Medical Context*, Springer, New York, pp. 285–294.
Wittwer-Backofen, U., Gampe, J., and Vaupel, J. W. (2004). Tooth cementum annulation for age estimation: Results from a large known-age validation study. *American Journal of Physical Anthropology* **123:** 119–129.
Woo, E. J., and Sciulli, P. W. (2013). Degenerative joint disease and social status in the terminal Late Archaic period (1000–500 BC) of Ohio. *International Journal of Osteoarchaeology* **23:** 529–544.
Wood, J. W., Holman, D. J., O'Connor, K. A., and Ferrell, R. J. (2002). Mortality models for paleodemography. In Hoppa, R. D., and Vaupel, J. W. (eds.), *Paleodemography: Age Distributions from Skeletal Samples*, Cambridge University Press, Cambridge, pp. 129–168.
Wood, J. W., and Milner, G. R. (1994). Reply. *Current Anthropology* **35:** 631–637.
Wood, J. W., Milner, G. R., Harpending, H. C., and Weiss, K. M. (1992). The Osteological Paradox: Problems of inferring prehistoric health from skeletal samples. *Current Anthropology* **33:** 343–370.
World Health Organization. (2003). Who definition of health (http://www.who.int/about/definition/en/print.html) (accessed 11/28/14).
Worthman, C. M., and Kuzara, J. (2005). Life history and the early origins of health differentials. *American Journal of Human Biology* **17:** 95–112.
Wright, L. E., and Chew, F. (1998). Porotic hyperostosis and paleoepidemiology: A forensic perspective on anemia among the ancient Maya. *American Anthropologist* **100:** 924–939.
Wright, L. E., and Yoder, C. J. (2003). Recent progress in bioarchaeology: Approaches to the Osteological Paradox. *Journal of Archaeological Research* **11:** 43–70.
Wrigley-Field, E. (2014). Mortality deceleration and mortality selection: Three unexpected implications of a simple model. *Demography* **51:** 51–71.
Ylostalo, P. V., Jarvelin, M. R., Laitinen, J., and Knuuttila, M. L. (2006). Gingivitis, dental caries and tooth loss: Risk factors for cardiovascular diseases or indicators of elevated health risks. *Journal of Clinical Periodontology* **33:** 92–101.
Yoder, C. (2012). Let them eat cake? Status-based differences in diet in medieval Denmark. *Journal of Archaeological Science* **39:** 1183–1193.
Zahl, P. H. (1997). Frailty modelling for the excess hazard. *Statistics in Medicine* **16:** 1573–1585.
Zajacova, A., Goldman, N., and Rodriguez, G. (2009). Unobserved heterogeneity can confound the effect of education on mortality. *Mathematical Population Studies* **16:** 153–173.
Zawicki, P., and Witas, H. W. (2008). HIV-1 protecting *CCR5-delta32* allele in medieval Poland. *Infection, Genetics and Evolution* **8:** 146–151.
Zhang, F. F., Morabia, A., Carroll, J., Gonzalez, K., Fulda, K., Kaur, M., Vishwanatha, J. K., Santella, R. M., and Cardarelli, R. (2011). Dietary patterns are associated with levels of global genomic DNA methylation in a cancer-free population. *The Journal of Nutrition* **141:** 1165–1171.
Zheng, H. (2014). Aging in the context of cohort evolution and mortality selection. *Demography* **51:** 1295–1317.
Zuckerman, M. K. (2014). *Modern Environments and Human Health: Revisiting the Second Epidemiological Transition*, Wiley-Blackwell, Hoboken, NJ.
Zufferey, F., Williams, F. M. K., and Spector, T. D. (2014). Epigenetics and methylation in the rheumatic diseases. *Seminars in Arthritis & Rheumatism* **43:** 692–700.

Zvelebil, M., and Weber, A. W. (2013). Human bioarchaeology: Group identity and individual life histories: Introduction. *Journal of Anthropological Archaeology* **32**: 275–279.

Bibliography of recent literature (last 3–5 years)

Anastasiou, E., and Mitchell, P. D. (2013). Palaeopathology and genes: Investigating the genetics of infectious diseases in excavated human skeletal remains and mummies from past populations. *Gene* **528:** 33–40.

Bianucci, R., Giuffra, V., Bachmeier, B. E., Ball, M., Pusch, C. M., Fornaciari, G., and Nerlich, A. G. (2012). Eleonora of Toledo (1522–1562): Evidence for tuberculosis and leishmaniasis co-infection in renaissance Italy. *International Journal of Paleopathology* **2:** 231–235.

Brothwell, D. (2010). On problems of differential diagnosis in palaeopathology, as illustrated by a case from prehistoric Indiana. *International Journal of Osteoarchaeology* **20:** 621–622.

Buikstra, J. (2010). Paleopathology: A contemporary perspective. In Larsen, C. S. (ed.), *A Companion to Biological Anthropology*, Wiley-Blackwell, Chichester, UK, pp. 395–411.

Bullock, M., Márquez, L., Hernández, P., and Ruíz, F. (2013). Paleodemographic age-at-death distributions of two Mexican skeletal collections: A comparison of transition analysis and traditional aging methods. *American Journal of Physical Anthropology* **152:** 67–78.

Chhem, R. K., and Brothwell, D. R. (2008). *Paleoradiology: Imaging Mummies and Fossils*, Springer, Berlin.

Crandall, J. J., and Klaus, H. D. (2014). Advancements, challenges, and prospects in the paleopathology of scurvy: Current perspectives on vitamin C deficiency in human skeletal remains. *International Journal of Paleopathology* **5:** 1–8.

De Boer, H. H., Van der Merwe, A. E., and Maat, G. J. R. (2013). The diagnostic value of microscopy in dry bone palaeopathology: A review. *International Journal of Paleopathology* **3:** 113–121.

Degusta, D. (2010). Cribra orbitalia: A non-human primate perspective. *International Journal of Osteoarchaeology* **20:** 597–602.

DeWitte, S. N., and Bekvalac, J. (2011). The association between periodontal disease and periosteal lesions in the St. Mary Graces cemetery, London, England AD 1350–1538. *American Journal of Physical Anthropology* **146:** 609–618.

Dittmar, K. (2009). Old parasites for a new world: The future of paleoparasitological research. A review. *The Journal of Parasitology* **95:** 365–371.

Dutour, O. (2013). Paleoparasitology and paleopathology. Synergies for reconstructing the past of human infectious diseases and their pathocenosis. *International Journal of Paleopathology* **3:** 145–149.

Essex, M. J., Boyce, W. T., Hertzman, C., Lam, L. L., Armstrong, J. M., Neumann, S. M., and Kobor, M. S. (2013). Epigenetic vestiges of early developmental adversity: Childhood stress exposure and DNA methylation in adolescence. *Child Development* **84:** 58–75.

Gillett-Netting, R., and Murphy, K. (2010). New method for age estimation of developmental defects of enamel formation in living populations. *American Journal of Human Biology* **22:** 563–566.

Goldring, M. B., and Marcu, K. B. (2012). Epigenomic and microrna-mediated regulation in cartilage development, homeostasis, and osteoarthritis. *Trends in Molecular Medicine* **18:** 109–118.

Gowland, R., and Redfern, R. (2010). Childhood health in the Roman world: Perspectives from the centre and margin of the Empire. *Childhood in the Past* **3:** 15–42.

Gowland, R. L., and Western, A. G. (2012). Morbidity in the marshes: Using spatial epidemiology to investigate skeletal evidence for malaria in Anglo-Saxon England (AD 410–1050). *American Journal of Physical Anthropology* **147:** 301–311.

Hassett, B. R. (2012). Evaluating sources of variation in the identification of linear hypoplastic defects of enamel: A new quantified method. *Journal of Archaeological Science* **39:** 560–565.

Hassett, B. R. (2014). Missing defects? A comparison of microscopic and macroscopic approaches to identifying linear enamel hypoplasia. *American Journal of Physical Anthropology* **153:** 463–472.

Hillson, S. (2014). *Tooth Development in Human Evolution and Bioarchaeology*, Cambridge University Press, Cambridge.

Holt, S. A., Reid, D. J., and Guatelli-Steinberg, D. (2012). Brief communication: Premolar enamel formation: Completion of figures for aging leh defects in permanent dentition. *Dental Anthropology* **25:** 4–7.

Hubbard, A., Guatelli-Steinberg, D., and Sciulli, P. W. (2009). Under restrictive conditions, can the widths of linear enamel hypoplasias be used as relative indicators of stress episode duration? *American Journal of Physical Anthropology* **138:** 177–189.

Inwood, K., and Roberts, E. (2010). Longitudinal studies of human growth and health: A review of recent historical research. *Journal of Economic Surveys* **24:** 801–840.

Jirtle, R. L., and Skinner, M. K. (2007). Environmental epigenomics and disease susceptibility. *Nature Reviews Genetics* **8:** 253–262.

Klaus, H. D., and Tam, M. E. (2009). Contact in the Andes: Bioarchaeology of systemic stress in colonial Mórrope, Peru. *American Journal of Physical Anthropology* **138:** 356–368.

Lambert, P. M. (2009). Health versus fitness: Competing themes in the origins and spread of agriculture? *Current Anthropology* **50:** 603–608.

Larsen, C. S., and Walker, P. L. (2010). Bioarchaeology: Health, lifestyle, and society in recent human evolution. In Larsen, C. S. (ed.), *A Companion to Biological Anthropology*, Wiley Liss, New York, pp. 379–394.

Liebe-Harkort, C., Ástvaldsdóttir, Á., and Tranæus, S. (2010). Quantification of dental caries by osteologists and odontologists: A validity and reliability study. *International Journal of Osteoarchaeology* **20:** 525–539.

Liebe-Harkort, C., Ástvaldsdóttir, Á., and Tranæus, S. (2011). Visual and radiographic assessment of dental caries by osteologists: A validity and reliability study. *International Journal of Osteoarchaeology* **21:** 55–65.

Łukasik, S., and Krenz-Niedbała, M. (2014). Age of linear enamel hypoplasia formation based on massler and colleagues' and Reid and Dean's standards in a Polish sample dated to 13th–18th century CE. *Homo* **65:** 296–310.

McFarlane, G., Littleton, J., and Floyd, B. (2014). Estimating striae of Retzius periodicity nondestructively using partial counts of perikymata. *American Journal of Physical Anthropology* **154:** 251–258.

Mitchell, P. D. (2011). Retrospective diagnosis and the use of historical texts for investigating disease in the past. *International Journal of Paleopathology* **1:** 81–88.

Mummert, A., Esche, E., Robinson, J., and Armelagos, G. J. (2011). Stature and robusticity during the agricultural transition: Evidence from the bioarchaeological record. *Economics & Human Biology* **9:** 284–301.

O'Brien, J. J., Battista, J. J., Romagnoli, C., and Chhem, R. K. (2009). CT imaging of human mummies: A critical review of the literature (1979–2005). *International Journal of Osteoarchaeology* **19:** 90–98.

Oelze, V. M., Koch, J. K., Kupke, K., Nehlich, O., Zauner, S., Wahl, J., Weise, S. M., Rieckhoff, S., and Richards, M. P. (2012). Multi-isotopic analysis reveals individual mobility and diet at the early Iron Age monumental tumulus of Magdalenenberg, Germany. *American Journal of Physical Anthropology* **148:** 406–421.

Papageorgopoulou, C., Suter, S. K., Rühli, F. J., and Siegmund, F. (2011). Harris lines revisited: Prevalence, comorbidities, and possible etiologies. *American Journal of Human Biology* **23:** 381–391.

Park, V. M., Roberts, C. A., and Jakob, T. (2010). Palaeopathology in Britain: A critical analysis of publications with the aim of exploring recent trends (1997–2006). *International Journal of Osteoarchaeology* **20:** 497–507.

Pfeiffer, S., and Pinto, D. (2011). Histological analyses of human bone from archaeological contexts. In Crowder, C, and Stout, S. (eds.), *Bone Histology: An Anthropological Perspective*, Taylor and Francis, Hoboken, NJ, pp. 298–311.

Pinhasi, R., and Turner, K. (2008). Epidemiological approaches in paleopathology. In Pinhasi, R., and Mays, S. (eds.), *Advances in Human Palaeopathology*, Wiley, Chichester, UK, pp. 177–188.

Plomp, K. A., Roberts, C. A., and Vietharsdottir, U. S. (2012). Vertebral morphology influences the development of Schmorl's nodes in the lower thoracic vertebrae. *American Journal of Physical Anthropology* **149:** 572–582.

Ramos, Y. F. M., den Hollander, W., Bovée, J. V. M. G., Bomer, N., van der Breggen, R., Lakenberg, N., Keurentjes, J. C., Goeman, J. J., Slagboom, P. E., Nelissen, R. G., Bos, S. D., and Meulenbelt, I. (2014). Genes involved in the osteoarthritis process identified through genome wide expression analysis in articular cartilage: The RAAK study. *PLoS ONE* **9:** e103056.

Rando, C., and Waldron, T. (2012). TMJ osteoarthritis: A new approach to diagnosis. *American Journal of Physical Anthropology* **148:** 45–53.

Reinhard, K. J., and Araújo, A. (2012). Synthesizing parasitology with archaeology in paleopathology. In Buikstra, J., and Roberts, C. (eds.), *The Global History of Paleopathology: Pioneers and Prospects*, Oxford University Press, Oxford, pp. 751–764.

Reitsema, L. J. (2013). Beyond diet reconstruction: Stable isotope applications to human physiology, health, and nutrition. *American Journal of Human Biology* **25:** 445–456.

Richards, M., and Montgomery, J. (2012). Isotope analysis and paleopathology: A short review and future developments. In Buikstra, J., and Roberts, C. (eds.), *The Global History of Paleopathology: Pioneers and Prospects*, Oxford University Press, Oxford, pp. 718–731.

Ritzman, T. B., Baker, B. J., and Schwartz, G. T. (2008). A fine line: A comparison of methods for estimating ages of linear enamel hypoplasia formation. *American Journal of Physical Anthropology* **135:** 348–361.

Roberts, C., and Ingham, S. (2008). Using ancient DNA analysis in palaeopathology: A critical analysis of published papers, with recommendations for future work. *International Journal of Osteoarchaeology* **18:** 600–613.

Roberts, C. A., Millard, A. R., Nowell, G. M., Grocke, D. R., Macpherson, C. G., Pearson, D. G., and Evans, D. H. (2013). Isotopic tracing of the impact of mobility on infectious disease: The origin of people with treponematosis buried in Hull, England, in the late medieval period. *American Journal of Physical Anthropology* **150:** 273–285.

Rühli, F. (2012). Imaging: The history of radiography, current issues and future trends. In Buikstra, J., and Roberts, C. (eds.), *The Global History of Paleopathology: Pioneers and Prospects*, Oxford University Press, Oxford, pp. 732–737.

San Millán, M., Rissech, C., and Turbón, D. (2013). A test of Suchey-Brooks (pubic symphysis) and Buckberry-Chamberlain (auricular surface) methods on an identified Spanish sample: Paleodemographic implications. *Journal of Archaeological Science* **40:** 1743–1751.

Sattenspiel, L., and Stoops, M. (2010). Gleaning signals about the past from cemetery data. *American Journal of Physical Anthropology* **142:** 7–21.

Schug, G. R., and Goldman, H. M. (2014). Birth is but our death begun: A bioarchaeological assessment of skeletal emaciation in immature human skeletons in the context of environmental, social, and subsistence transition. *American Journal of Physical Anthropology* **155:** 243–259.

Schultz, M. C. (2012). A short history of paleohistology. In Buikstra, J., and Roberts, C. (eds.), *The Global History of Paleopathology: Pioneers and Prospects*, Oxford University Press, Oxford, pp. 738–750.

Sołtysiak, A. (2013). Technical note: False catastrophic age-at-death profiles in commingled bone deposits. *American Journal of Physical Anthropology* **152:** 554–557.

Spigelman, M., Shin, D. H., and Bar Gal, G. K. (2012). The promise, the problems, and the future of DNA analysis in paleopathology studies. In Grauer, A. L. (ed.), *A Companion to Paleopathology*, Wiley-Blackwell, Malden, MA, pp. 133–151.

Stark, R. J. (2014). A proposed framework for the study of paleopathological cases of subadult scurvy. *International Journal of Paleopathology* **5:** 18–26.

Swinson, D., Snaith, J., Buckberry, J., and Brickley, M. (2010). High performance liquid chromatography (HPLC) in the investigation of gout in palaeopathology. *International Journal of Osteoarchaeology* **20:** 135–143.

Tomczyk, J., Komarnitki, I., and Olczak-Kowalczyk, D. (2013). Brief communication: A pilot study: Smooth surface early caries (caries incipiens) detection with KaVo DIAGNODent in historical material. *American Journal of Physical Anthropology* **150:** 475–481.

Tsutaya, T., Shimomi, A., Nagaoka, T., Sawada, J., Hirata, K., and Yoneda, M. (2015). Infant feeding practice in medieval Japan: Stable carbon and nitrogen isotope analysis of human skeletons from Yuigahama-Minami. *American Journal of Physical Anthropology* **156:** 241–251.

Vercellotti, G., Stout, S. D., Boano, R., and Sciulli, P. W. (2011). Intrapopulation variation in stature and body proportions: Social status and sex differences in an Italian medieval population (Trino Vercellese, VC). *American Journal of Physical Anthropology* **145:** 203–214.

von Hunnius, T. (2009). Using microscopy to improve a diagnosis: An isolated case of tuberculosis-induced hypertrophic osteopathy in archaeological dog remains. *International Journal of Osteoarchaeology* **19:** 397–405.

Wagner, D. M., Klunk, J., Harbeck, M., Devault, A., Waglechner, N., Sahl, J. W., Enk, J., Birdsell, D. N., Kuch, M., Lumibao, C., Poinar, D., Pearson, T., Fourment, M., Golding, B., Riehm, J. M., Earn, D. J. D., DeWitte, S., Rouillard, J.-M., Grupe, G., Wiechmann, I., Bliska, J. B., Keim, P. S., Scholz, H.

C., Holmes, E. C., and Poinar, H. (2014). *Yersinia pestis* and the Plague of Justinian 541–543 AD: A genomic analysis. *The Lancet Infectious Diseases* **14:** 319–326.

Watts, R. (2011). Non-specific indicators of stress and their association with age at death in medieval York: Using stature and vertebral neural canal size to examine the effects of stress occurring during different periods of development. *International Journal of Osteoarchaeology* **21:** 568–576.

Watts, R. (2013). Childhood development and adult longevity in an archaeological population from Barton-upon-Humber, Lincolnshire, England. *International Journal of Paleopathology* **3:** 95–104.

Weston, D. A. (2009). Brief communication: Paleohistopathological analysis of pathology museum specimens: Can periosteal reaction microstructure explain lesion etiology? *American Journal of Physical Anthropology* **140:** 186–193.

Wheeler, S. M. (2012). Nutritional and disease stress of juveniles from the Dakhleh Oasis, Egypt. *International Journal of Osteoarchaeology* **22:** 219–234.

Wilbur, A. K., Farnbach, A. W., Knudson, K. J., and Buikstra, J. E. (2008). Diet, tuberculosis, and the paleopathological record. *Current Anthropology* **49:** 963–977; discussion 977–991.

Wilbur, A. K., and Stone, A. C. (2012). Using ancient DNA techniques to study human disease. In Buikstra, J., and Roberts, C. (eds.), *The Global History of Paleopathology: Pioneers and Prospects*, Oxford University Press, Oxford, pp. 703–715.

Zuckerman, M. K., Garofalo, E. M., Frohlich, B., and Ortner, D. J. (2014). Anemia or scurvy: A pilot study on differential diagnosis of porous and hyperostotic lesions using differential cranial vault thickness in subadult humans. *International Journal of Paleopathology* **5:** 27–33.

Zuckerman, M. K., Harper, K. N., and Armelagos, G. J. (2014). Adapt or die: Three case studies in which the failure to adopt advances from other fields has compromised paleopathology. *International Journal of Osteoarchaeology*, DOI:10.1002/oa.2426 (accessed 12/31/14).