Reconciling "Stress" and "Health" in Physical Anthropology: What Can Bioarchaeologists Learn From the Other Subdisciplines?

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ABSTRACT The concepts of "stress" and "health" are foundational in physical anthropology as guidelines for interpreting human behavior and biocultural adaptation in the past and present. Though related, stress and health are not coterminous, and while the term "health" encompasses some aspects of "stress," health refers to a more holistic condition beyond just physiological disruption, and is of considerable significance in contributing to anthropologists' understanding of humanity's lived experiences. Bioarchaeological interpretations of human health generally are made from datasets consisting of skeletal markers of stress, markers that result from (chronic) physiological disruption (e.g., porotic hyperostosis; linear enamel hypoplasia). Non-specific indicators of stress may measure episodes of stress and indicate that infection, disease, or nutritional deficiencies were present in a population, but in assessing these markers, bioarchaeologists are not measuring "health" in the same way as are human biologists, medical anthropologists, or primatologists. Rather than continue to diverge on separate (albeit parallel) trajectories, bioarchaeologists are advised to pursue interlinkages with other subfields within physical anthropology toward bridging "stress" and "health." The papers in this special symposium set include bioarchaeologists, human biologists, molecular anthropologists, and primatologists whose research develops this link between the concepts of "stress" and "health," encouraging new avenues for bioarchaeologists to consider and reconsider health in past human populations. Am J Phys Anthropol 155:181–185, 2014.

In physical anthropology, understanding stressors implicit in human interactions with the environment and with each other is a key component of interpreting, and even anticipating, human health. Human skeletal remains offer a deep well of information about human variation, activity patterns, use of landscapes, diet and food distribution, demography, disease, and stress. Extrapolating from skeletal data sets, bioarchaeologists make inferences about health and lifestyle of past populations. Yet, the relationship between skeletal stress and health is difficult to pinpoint. "Stress" can be defined as a physiological change caused by strain on an organism from environmental, nutritional, and other pressures (Huss-Ashmore et al., 1982; Goodman et al., 1988), and is a useful proxy for estimating some aspects of past health. "Health" is a holistic concept used colloquially to encompass elements of quality of life, daily functioning, and community interaction, and is at the crux of evolutionary and biocultural approaches in anthropology. Although "health" has broad colloquial recognition, it has been difficult to quantify. In practice, health is perhaps most commonly understood to be something that is compromised when any number of factors, including disease, infection, nutritional quality, or psychological factors, affect an individual's quality of life. However, the World Health Organization includes the stipulation that health is "a state of complete physical, mental, and social well-being and not merely the absence of disease, or infirmity" (WHO, 1999). Even a new infant with ten fingers, ten toes, and all of their organs in place is recovering from the trauma of birth and cannot be said ideally to represent health (Goodman and Armelagos, 1989). Expressions of "health" exist on a continuum, meaning that even if consensus is reached over the meaning of health as a concept, the meaning of "healthy" remains vague. As difficult as health, lifestyle, and well-being are to define and measure in living populations, these aspects of human existence become even more elusive when dealing with past populations, whose symptoms and etiologies are less apparent and more difficult to interpret (Wood et al., 1992).

Although we may never be able to agree on what represents "healthy," we may be able to agree that physiological changes in the body as a result of stress are "unhealthy"; although they are examples of human adaptation and adaptability (Seckler, 1980; Stuart-MacAdam, 1992), physiological changes often exert a tax on the human body. Viewed in this manner, stress is a useful proxy for health in past populations (Goodman et al., 1988; Goodman and Armelagos, 1989). Generally speaking, bioarchaeologists are aware that stress and

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health are not coterminous (McIlvaine and Reitsema [2013] report a metanalysis of authors' use of these terms in leading journals during past decades). Bioarchaeological stress models account for synergistic interactions of environmental constraints, biology, cultural buffering systems, and psychological disruption in contributing to a physiological stress response (Goodman et al., 1988; Temple and Goodman, this issue). Other proxies for interpreting health may include a population's access to proper sanitation and nutrition, changes in living conditions within a person's lifetime, the particular timing of onset of disease or malnutrition, community structure and family or community support, and traits of resistance or susceptibility to stress and disease from the genome and epigenome. Contextual elements such as these may or may not be available to the bioarchaeologist, but should be included in all assessments of skeletal remains, where possible, to better understand the etiology and pathophysiology of skeletal stress markers (Goodman, 1993; Goodman and Leatherman, 1998).

To infer past human health from skeletal stress requires a middle ground. Conveniently for physical anthropologists, this middle ground can be built by communicating across anthropology's subfields. The articles in this issue stem from a symposium organized for the 2013 meeting of the American Association of Physical Anthropologists, conceived initially by the authors as a means to draw together interdisciplinary perspectives on stress. The effort to understand ancient stress and health scientifically crystallized notably with the 1984 publication of the edited volume, "Paleopathology at the Origins of Agriculture" (Cohen and Armelagos, 1984). Enthusiasm for this topic is evidenced by the continued scholarly work undertaken and published in the decades that followed. The goal of the symposium was to re-cast light on the relationship between stress and health, and refocus researchers on the symposium's theme—fleshing out the skeletal record with insights from the other anthropological subdisciplines—such that this theme could be revisited as a concrete conceptual target to guide and inspire future, focused, holistic research in bioarchaeology. The original 2013 symposium comprised human biologists and bioarchaeologists whose research specifically addresses the imperfect relationship between stress and health. Additional papers contributed here include considerations of stress and health in primatology, molecular anthropology, and biomechanics.

This symposium set and additional contributed papers bridge the concepts of stress and health in two ways: (1) incorporating perspectives from modern humans and non-human primates to link the past with the present, and (2) highlighting recent bioarchaeological work that specifically addresses an imperfect relationship between stress and health. The papers drawn together here provide new insight into our current understanding of stress and health in bioarchaeological populations.

REVISITING THE RELATIONSHIP BETWEEN STRESS AND HEALTH: INTRODUCTION TO PAPERS IN THE SPECIAL ISSUE

The purpose of this issue is to promote cross-subdisciplinary awareness, in order to account for the synergistic interactions of environmental constraints, biology, cultural buffering systems, and psychological disruption in contributing to a physiological stress response. Links with human biologists, primatologists, and geneticists help to identify those social and cultural conditions that contribute to physiological stress, but that cannot be directly observed in bioarchaeological samples. Two papers in this issue use a molecular approach to address the effects of very early life conditions—particularly, social stressors—on growth, development, health, and well-being using epigenetic proxies (Kinnally [this issue]; Rodney and Milligan [this issue]). Erin Kinnally examines the relationship between early maternal care quality, DNA methylation, and later-life health outcomes among rhesus macaques. Kinnally's data show that better maternal care, in the form of positive contact, relates to lower methylation of a possible stress pathway gene (serotonin transporter, *5-HTT*). Furthermore, among rhesus infants whose *5-HTT* region was methylated, poor health outcomes were observed later in their lives. These outcomes include low body weight, overall poor body condition, and lifetime incidence of inflammatory disease (diarrhea). Studies of DNA methylation in osteoclasts, which are related to white blood cells, may play a role in bioarchaeology.

Very early life and intergenerational effects play a considerable role in health and stress. Sobering evidence of this phenomenon is presented by Rodney and Mulligan (this issue), who explored the biological consequences of war stress on mothers and their infants in the Democratic Republic of Congo. Exposure to war stress, and especially experience of rape, is associated with low infant birth weight and methylation levels. The authors find that effects of war stress on the epigenome are not genome wide, but targeted at specific genes—in this case, glucocorticoid receptor gene NR3C1. The relationship between glucocorticoids and skeletal growth implies that psycho-social stress has effects on the growth and development of subsequent generations. In addition to providing new perspectives on the relationship between early life stressors and health outcomes, the papers by Kinnally and Rodney and Mulligan in this issue are testaments to the importance of social stress in long-term adverse physiological consequences, and a reminder that age, sex, status, ancestry, etc. do not present a complete contextual framework for interpreting skeletal stress. Kinnally and Rodney and Mulligan demonstrate that very early life and generational effects play an important role in manifestations of health and stress.

A complication when using physiological stress markers to measure health in past populations is that self-perceptions of health and quality of life may not track well with a person's physiological state. For this reason, it is important to use living populations to examine critically the relationships between perceptions of health and (skeletal) indicators of stress. The work of Piperata and colleagues (this issue) and Tanner (this issue) provide a cautionary tale for bioarchaeologists who assume a one-to-one association between a single skeletal stress marker (e.g., porotic hyperostosis; infection) and economic status, quality of life, and/or life experiences. However, these papers also demonstrate the possibilities for addressing health in skeletal populations through the assessment of multiple stress indicators (Steckel and Rose, 2002), and the need for addressing individual frailty within skeletal assemblages (see also Wilson, this issue). Piperata and colleagues' (this issue) paper demonstrates disconnects between self-perception of health and anemia status at the individual and household levels. The authors report that despite a statistical

association of anemia status with economic status, self-perceptions of health, and work capacity, there was significant variation within the anemic and non-anemic groups as the result of individual frailty stemming from both biological and cultural risk factors. This observation indicates that porotic hyperostosis should not be taken as a direct indicator of health or economic status. Piperata et al. (this issue) also show that biological and cultural factors place children under the age of five at the highest risk for anemia. As porotic hyperostosis typically is representative of a childhood condition (Stuart-MacAdam, 1985), it may not accurately estimate physiological status of an individual at the time of death, suggesting that greater care should be taken by bioarchaeologists to document active versus healed lesions (Walker et al., 2009) and to control for age-at-death (DeWitte, this issue; Wilson, this issue).

Anthropologists are uniquely capable of appreciating how socioeconomic and environmental changes related to human health. However, these relationships are mediated by individual, household, and community factors that bioarchaeologists may not be able to reconstruct fully, but which should be appreciated as variables affecting, and frequently muddying, the relationship between stress and health in the past. The work of Susan Tanner (this issue) on helminth infections among the Tsimane' of lowland Bolivia examines individual, household, and community factors that explain why people's infection by widespread soil-transmitted helminth worms is not clearly associated with general nutritional status. Her work shows how proximity to a regional market center mediates the severity of helminth infection and malnutrition, albeit not in straightforward ways. Despite the potential that childhood infections have to adversely affect growth and health adversely, Tanner's work shows how this near-ubiquitous source of nutritional and energetic stress is only loosely related to reduced functionality and skeletal markers of stress. Tanner's results also demonstrate the importance of considering health in the context of communities and regional settlement structures: among the participants in her study, individuals living farthest from the modernizing effects of a market center exhibit the highest prevalence of helminth infection, followed by people living closest to the market center. The communities midway from the market center exhibit the lowest rates of infection, possibly reflecting a mix of traditional subsistence and modern sanitation that fostered better health—at least, in terms of infection burden.

Bioarchaeology in this special issue builds on work of others who have shown that taking a population approach, standardizing for skeletal age, appreciating sociodemographic context, and analyzing multiple indicators of stress may mitigate errors in our interpretations of health, using stress indicators as proxies. Several papers in this issue emphasize the importance of critically evaluating commonly accepted indicators of stress and health, such as stature (Robbins-Schug, this issue, Vercellotti et al., this issue) and skeletal lesions (DeWitte, this issue; Wilson, this issue), in light of population approaches, updated techniques, and complementary lines of evidence.

Stature is a commonly used proxy for stress and adverse health, yet has multiple etiologies. Giuseppe Vercellotti and colleagues (this issue) highlight the complex relationship between stature and early life conditions in both living and archaeological populations. Their work provides a cautionary tale for researchers making simple correlations between stature and life experiences, and demonstrates that ultimate adult stature results from a combination of genetic, cultural, and environmental factors, including genetic height potential, environmental quality and nutrition early in life, catch-up growth, social and economic inequality, and cultural buffering. To circumvent the issues inherent in associating terminal adult stature directly with life conditions, Vercellotti and colleagues bridge the gap between bioarchaeological and human biological analyses of stature to examine the many dimensions of stature.

As Vercellotti et al. (this issue) discuss, stature is commonly used as a proxy for stress and adverse health, yet body size is influenced by other factors, including genes. Gwen Robbins-Schug (this issue) tests the hypothesis that reduced body size observed in a population post-dating abandonment of traditional agricultural methods and depopulation of agglomerated centers was, in fact, the result of homeostatic disruption from health challenges by evaluating bone geometry and histology among subadults. Speculatively, reductions in body size with sociodemographic change are the result of growth faltering and health challenges (for which stature is a proxy). However, a low prevalence of gross bone pathology reported for the population complicated an association between health challenges and growth faltering. Histological evidence indicates children under the age of ten did not acquire or maintain bone mass expected for their age and their demonstrated mobility patterns, supporting the hypothesis that body size is the result of poor health during growth in this case. This work underscores a theme in the special issue; namely, that commonly used indicators of stress should not uncritically be accepted as evidence of poor health.

Equal in importance to evaluating the underlying etiologies of skeletal manifestations of stress critically is the appreciation of context in the skeletal record. When inferring stress and health from subadults in archaeological contexts, a cross-sectional approach is commonly taken, wherein many individuals in a population who died at different ages are interpreted to represent the life history trajectory of the population at large. With their publication on the osteological paradox, Wood et al. (1992) noted that selective mortality (the fact that all people who are dead are inherently *unhealthy*, thereby overestimating the prevalence of skeletal lesions in each age category) and hidden heterogeneity (essentially, the problem of interpreting individuals who survived long enough to develop skeletal stress markers as unhealthy when their survival may be a testament to their survivability and *good* health) complicate the assessment of physiological markers of stress in human skeletal remains. The problems of selective mortality and differential frailty are salient considerations in cross-sectional approaches, because subadults who died at young ages may have experienced different circumstances than the subadults who lived past a young age (i.e., the adults in a population).

DeWitte (this issue) and Wilson's (this issue) research highlights the importance of modeling physiological lesions against age-at-death to assess frailty better (after Boldsen et al., 2002). Sharon DeWitte's paper emphasizes the need for new methods (transition analysis to estimate age) and detailed contextual information when assessing health outcomes from skeletal remains. On the

surface, DeWitte's data seems to suggest that health declined following the Black Death in England. However, standardization for age shows that while the prevalence of periostitis is higher in her post-Black Death sample, this sample includes a larger proportion of older adults who were able to live long enough to accumulate periosteal lesions throughout their relatively longer lives. Her work shows that a major selective pressure (the Black Death) targeted the frailest individuals, leaving a generally healthier population with greater survivorship following the Black Death.

Like DeWitte (this issue), Jeremy Wilson's paper in this special issue demonstrates the importance of examining age- and sex-specific mortality patterns in association with physiological markers of skeletal stress. His work uses hazard models to explore variation in risk of death with age in order to address the issues of selective mortality and differential frailty in skeletal assemblages. The results of Wilson's (this issue) research show that women of reproductive age had an increased risk of death, yet surviving these reproductive years is associated with increased survivorship into old age, when compared with their male counterparts. Risk of death in the reproductive years among females increased through time and likely contributed to depopulation of the lower Midwest around A.D. 1500. Concurrently, individuals who experienced childhood stress, as evidenced by linear enamel hypoplasia, had an increased risk of death at all ages for both males and females. Wilson's (this issue) research demonstrates how childhood experiences impact health outcomes later in life (also see Kinnally, this issue).

Other papers in this issue emphasize the importance of interpreting stress and health from a life-history perspective. Paul Sandberg and colleagues (this issue) examine weaning age of subadults from the Kulubnarti collection of Sudanese Nubia using a longitudinal approach, achieved via incremental sampling of tooth dentine from individuals. In creating a refined life history of diet and weaning behavior, the authors are able to report that the timing of stress (estimated from linear enamel hypoplasias) accords with the period of weaning, rather than the period before or after weaning. The authors also compare dentine stable isotope ratios of subadults with rib stable isotope ratios of adults from the same population. The comparison of weaning behavior of subadults who lived (i.e., adults), and subadults who died, reveal weaning may have occurred earlier for individuals who lived past childhood, suggesting "healthy" benefits of a life history strategy involving earlier weaning, helping to clarify the role of weaning in infant mortality bias. Sandberg and colleagues' work shows how a life history approach to bioarchaeology taps a deeper well of data from skeletal samples toward informing our assessment of "health" in the past, addressing issues implicit in the osteological paradox.

A goal of the symposium from which this issue developed was promoting cross-disciplinary awareness in physical anthropology. Haagen Klaus' (this issue) paper embraces this theme by combining multiple lines of evidence, not only within physical anthropology, but drawing from a wide array of cross-disciplinary perspectives on stress. Klaus provides a thoughtful and comprehensive discussion of the molecular signaling factors involved in the development of periostitis; implications of epigenetic phenomena on disease and other health outcomes; the role of the microbiome in altering hormone levels, levels of inflammation, and the development of the immune system as underpinnings of future health outcomes; and the importance of examining the influences of age-at-death on disease prevalence (see also Wilson, this issue). Klaus' work should serve as a model for all bioarchaeologists in considering the epidemiology and pathophysiology of skeletal stress markers they study.

CONCLUSION

The impetus for this symposium is straightforward: the most meaningful understanding of health possible comes from work with living humans and non-human primates. This special issue set facilitates a better appreciation of the meanings and definitions of "stress" and "health," the biocultural context of "health," innovative approaches in bioarchaeology, and the meaningful impact of stress on actual day-to-day functioning. Rather than serving as a check to bioarchaeology, the papers in this issue show that greater collaboration among human biologists and bioarchaeologists will permit greater, not less, liberty in accurately estimating past health. By improving our understanding of physical manifestations of poor health, disease, malnutrition, and stress, and by studying the functional consequences of these conditions in their varying degrees of severity, we can assess more confidently not only stress in the past, but also legacies and prospects in human health.

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