**JAS Special Issue**

Stressed Out: Reconsidering stress in the study of archaeological human remains

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# Stressed Out: Reconsidering stress in the study of archaeological human remains

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## Abstract

The term “stress” remains poorly defined, often misused, and has clearly lost its meaning in the study of archeological human remains. In this special issue we reconsider the use of this term in human remains research, to untangle what we actually mean when we say “stress” in archaeology. To this aim, we looked at this topic from two broad perspectives: dental anthropology and paleopathology. Based on revision of the previous work on this topic, the new contributions of this issue, and in the light of the rapid advancement in other medical disciplines, we conclude that the term “stress” is not suitable for the study of archaeological skeletal remains unless it is precisely defined (e.g. mechanical stress).

**Key words:** stress, skeletal remains, dental anthropology, paleopathology

## 1. Introduction

The study of archaeological skeletal human remains has co-opted the term “stress”, but it has remained poorly defined. The term is often misused, and, as noted by Hillson (2014, 204) “the word has ceased to have any clear meaning in bioarchaeology”. The purpose of this special issue is to reconsider the use of this term in human remains research, and to define what we actually mean when we say “stress” in archaeology. To this aim, we looked at this topic from two broad perspectives: a) study of tooth malformations, defects, and pathology in dental anthropology; and b) non-specific indicators of disease in paleopathology.

Structure and function of teeth have been widely used in the inquiry of either ancient or modern human populations to address numerous research questions. As long as the complexity of tooth formation processes are accounted for, the study of developmental defects of teeth can provide a general snapshot of life history parameters in a population or an individual observed. When it comes to study of (micro)structures of teeth with special emphasis on specific life-history parameters reconstruction (cf. Edinborough et al., 2020) and the interpretation of developmental defects such as enamel hypoplasia (cf. Antoine et al., 1999; Antoine et al., 2009), “stress” cannot be routinely assigned as their ultimate cause. In this special issue there are several studies tackling the problematic aetiology of enamel hypoplastic defects. These studies suggest more appropriate strategies in recording and interpreting results in studies on primates, including old world monkeys, extant great ape species, fossil hominin species and humans (O'Hara and Guatelli-Steinberg, 2020; Onaindia, 2020; Towle and Irish, 2020). One of the contributions in this special issue is opening a new direction for conceptualizing and identifying mental well-being of people in the past, using bruxism as a clinically related response to physiological stress (Foley, 2020).

The examination of disease (and disease-load) in past populations is important, as it can provide answers to large scale questions about human activity and behaviour. One way in which palaeopathologists in the past have tried to explore this is by looking at so-called "indicators of stress" – especially in the remains of children. These indicators could include nutritional deficiencies, "non-specific infection", and retarded bone development. This umbrella usage of "stress" means that no effort has been made to unpick the true causative agents for these observed bony changes. We are now confronting this problem, focusing on diagnostic issues within the sub-field of palaeopathology. This special issue's contribution to this area of research is the re-evaluation of traditional markers of stress (periosteal reactions, porotic hyperostosis, and cribra orbitalia) when interpreting health through "non-specific stress indicators" in skeletal remains (Pilloud and Schwitalla, 2020).

## 2. Defining the concept of stress

The word "stress" is now quite a common part of modern vernacular, but the true or correct meaning of the concept can be difficult to tease out. Despite nearly a century of research on various aspects of stress, investigators still find it difficult to achieve consensus on a satisfactory definition of this concept. Even less of a consensus has been reached on precisely defining the concept of stress in the study of human bones – the term stress has arguably been abused as it has been used to refer to such a wide range of detected conditions. It is currently used to indicate anything from the physiological response of the body to an event, to a psychological one (emotional distress), but, clinically (in the medical community) the meaning is quite specific and refers to the Selyean Stress Concept (Selye 1936, 1951, 1973) – colloquially known as the flight or fight response. Here, the body responds in a very specific way to "threatening" external agents, via neuroendocrine responses, which, while beneficial in the short term, if experienced over a long period of time can cause enlargement of the adrenal glands and lymph nodes, as well as gastric ulcers (amongst other problems).

Most of the “stress” studies simply define *stress* as circumstances that most people would find stressful, that is, stressors. On the other hand, Elliot and Eisdorfer’s (1982) taxonomy to characterize these stressors has the advantage of distinguishing among five precisely defined categories of them, from the acute time-limited stressors to the distant stressors. Not all of these stressors will leave a trace on bones, and not all the lesions on bones could be linked to stress, but all of the stressors could produce appropriate physiological responses. For example, exposure to chronic stressors might contribute to the course of diseases involving excessive nonspecific inflammation (e.g., multiple sclerosis, rheumatoid arthritis, coronary heart disease) and thereby increase risk for excess morbidity and mortality. For all these reasons, we have opened a two-folded discourse to better define the use of this term in bioarchaeology with the aim of more accurately identifying different types of stressors in our material, if possible.

Numerous studies on teeth, belonging to fossil hominis, great apes and present humans, have shown that they record valuable information about the both regular development and various developmental disturbances. The identification of these macro- and microscopic defects of teeth is appealing, but it is a slippery road in terms of accurate scientific interpretation. An example of this is use of enamel defects in reconstruction of childhood development, as there are around 100 identified conditions which can cause enamel hypoplasia (cf. Goodman and Rose, 1991; Hillson, 2014; Smith 2018). Having hundreds of studies published on the topic, it is possible to group these causes of enamel hypoplasia in several broad categories, including specific illnesses; nutritional deficiencies; and metabolic disturbances caused by life events (Smith, 2018: 55, 229). Some of these causes have been discovered based on studies undertaken on captive primates (Schwartz et al., 2006; Smith, 2013), while only a small number of studies rely on results obtained from humans with documented life histories (e.g. Birch and Dean, 2014). When it comes to bioarcheological research of enamel defects, weaning process (e.g. Katzenebrg et al., 1996) and childhood malnutrition have been investigated in various specific contexts (Goodman and Rose, 1991; Larsen, 1995; Hillson, 2014; Lieberman, 2013). The main difficulty in such studies is to demonstrate or prove a causal relation between enamel defects and suspected disruptors. However, many bioarcheologists choose to attribute those disruptors simply to a stressful childhood. Unfortunately, they are not telling us anything new and due to the abovementioned problem of equifinality we argue that using term “stress” is utterly inappropriate in those instances.

Complex aetiology of enamel hypoplasia is not the only troublesome problem we face. Other dental tissues and bones also undergo complex formation processes and influences during development and ageing. Many more conditions will leave traces on bones which are recognized as paleopathological lesions. Identifying the aetiology of these skeletal conditions has significant implications for the interpretations of malnutrition and disease in past populations. Therefore, researchers should refrain themselves of attributing it all to unqualified “stress”. An excellent example of how to reconstruct the complex aetiology of porotic hyperostosis and cribra orbitalia in a bioarcheological context can be found in work done by Walker and colleagues (2009). Their convining aetiological argument drew upon multiple evidential strands, namely clinical studies, historical data, and the bioarcheological context from which material derived. The term “stress” is not used a single time in the entire study (Walker et al 2009).

There are studies when the use of term “stress” cannot be avoided due its precise definition, for instance when investigating mechanical stress loaded to bone. However, based on the extensive literature review presented above and the new contributions of this Special Issue, we argue that the non-specific or unqualified term should be avoided in future studies of bioarchaeological human remains. It is becoming more obvious that significant additional research needs to be done to better understand aetiology of various defects and pathological conditions of teeth and bones. To work toward solving these issues, we suggest undertaking of more cautious clinical studies on humans with documented life histories (cf. Birch and Dean 2014; Edinborough et al., 2020). Until then, it would be satisfying to design future questions in the studies of archaeological human skeletal remains in a conservative manner, having in mind what can and cannot be understood from archaeological human remains.

## 3. Health and “stress” in bioarcheology

In the study of archaeological skeletal remains the terms “health” and “stress” seem almost indivisible. That is based on one of the main preconceptions in paleodemography that there is a direct relationship between (statistically) calculated “stress markers" and health of the individuals

(Wood et al., 1992). There are several issues with this approach, such as unclear definitions of both concepts in bioarchaeological studies, unresolved aetiologies of various “non-specific stress” markers, and ultimately the issue of osteological paradox as pointed by Wood and colleagues (1992). We have tackled the terminology regarding the “stress” both in bioarcheology and in a broader context in the text above. When it comes to the health of people in the past, it is even harder to estimate it than with living individuals. The World Health Organisation’s definition of health, which remains unchanged from 1948, states: “Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” (Official Records of WHO, no. 2, p. 100[1]). In the study of skeletal remains, it is almost impossible to reconstruct health as defined above. Starting with physical well-being, we are able to estimate only the lack of disease to a certain measure when examining teeth and bones. The social well-being interpretation in bioarcheology relies on our insight into an individual's socio-economic status from associate material culture remains and various evidence of diet.  Estimating mental well-being in past populations and individuals is an even riskier endeavor. For example, the relationship between chronic depression and bone mineral density has been suggested in a number of studies (e.g. Furlan *et al*. 2005; Yirmiya 2009; Williams *et al.* 2008), but there is no method in bioarcheology to extrapolate this sort of information from skeletal remains. As pointed out in Hillson (2014), in a chapter on this topic, the concept of health will be defined in different ways among doctors, evolutionary biologists, or physiologists, depending on their particular concerns. In the same chapter, he also explains how measuring health through “unhealth”, an approach taken by WHO (World Health Organization, 2010), is almost impossible in bioarcheology, primarily due to complexity of archeological assemblages.

The current view of many anthropologists regarding the relationship between health and stress is reflected in the Special Issue of the American Journal of Physical Anthropology (2014). This issue resulted from a symposium organized for the 2013 meeting of the American Association of Physical Anthropologists and attempted to reconcile “stress” and “health”, using a multidisciplinary approach in the interpretation of these concepts in physical anthropology. They state that a “middle ground built by communicating across anthropology’s subfields” is required

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[1] Preamble to the Constitution of WHO as adopted by the International Health Conference, New York, 19 June - 22 July 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of WHO, no. 2, p. 100) and entered into force on 7 April 1948.

to infer past human health from skeletal stress (Reitsema and McIlvaine, 2014). Based on previous work on the topic, they define “stress 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)”. They suggest this as a useful proxy for estimating some aspects of past health (Reitsema and McIlvaine, 2014). Whilst they agree that the concept of health is hard to define in physical anthropology, they suggest that physiological changes in the body as a result of stress are can be observed as “unhealthy” although there are successful examples of human adaptation and adaptabilitive responses (Seckler, 1980; Stuart-MacAdam, 1995; Reitsema and McIlvaine, 2014). They recommended that we should work on a better understanding of physical manifestations of poor health, disease, malnutrition, and stress, and severity of their functional consequences to better estimate stress and human health in the past (Reitsema and McIlvaine, 2014).

In our opinion, we need to shift our attention from “reconstruction of health” to better identification of disease and human adaptations to the external influences in the past. With the rapid advancement of many analytical techniques in biology, medicine and chemistry, we also need to develop more robust recording systems for the study of skeletal remains. By working with known aspects of the pathological process from the cellular level upward, we will be able gain new insights into the evolution of important human diseases.

## 4. Contribution of this issue

One of the topics tackled in this special issue is the use of dental defects as indicators of “non-specific stress” during dental development in studies of paleoanthropological and archaeological samples. The defect that is most commonly associated with “stress” in childhood is enamel hypoplasia for various reasons. One of the reasons is certainly the fact that enamel hypoplasia is a defect which can be easily observed macroscopically. As there exist standardized and straightforward ways for scoring this defect, it gave many researchers, dare we say, the false confidence to interpret its etiology in a very simplified manner. That is how the presence of enamel hypoplasia became an ultimate measure of childhood stress.

When it comes to studies of enamel defects among fossil hominins and understanding the relationships among perikymata spacing, enamel extension rate, striae of Retzius angles at the outer enamel surface, enamel formation time, and enamel defect expression, are important for inter-specific comparisons as pointed out in O'Hara and Guatelli-Steinberg (2020) in a contribution to this issue. They argue that the influence of enamel growth variables on linear enamel hypoplasia (LEH) expression needs to be understood more clearly before LEH can be used as an informative stress indicator in bioarchaeology and paleoanthropology. They based their hypothesis on the large body of work exploring fossil hominin enamel formation mode and tempo in relation to the location in a tooth. These studies include comparisons between Paranthropus and Australopithecus canine lateral formation time, which is shorter in Paranthropus (Bromage and Dean, 1985; Beynon and Dean, 1988; Dean and Reid, 2001; Dean et al., 2001). It has also been suggested that they also have fewer defects per canine (Guatelli-Steinberg, 2008), as well as the shallower enamel defects. This can be indicative of the more acute angles Retzius planes form with the outer enamel surface in Paranthropus as compared to Australopithecus (Beynon and Dean, 1988). When enamel formation time is compared between anatomically modern humans and Neandertals, it differs for most teeth (Smith et al., 2010), but significant differences have been identified in their perikymata distributions (Ramirez-Rozzi and Bermudez de Castro, 2004; Guatelli-Steinberg et al., 2007). In their study, they evaluate the influence of these intrinsic factors of enamel on enamel defect expression (e.g., linear enamel hypoplasia) on canines, by comparing two sympatric primate species *Macaca fascicularis* and *Trachypithecus cristatus*, accounting for the sexes of each species. They found that lateral enamel formation time is not associated with total defect counts per tooth and that perikymata spacing does not explain species-level differences in defect counts. Between sexes of the same species, they found that females acquired more defects faster and had more tightly packed perikymata, which may be related to underlying striae of Retzius angles and enamel extension rates. They conclude that enamel growth variables may be playing a large role in enamel defect expression and should be considered further in both bioarchaeology and paleoanthropology studies.

There is an ongoing debate if different types of enamel defects, when observed in a single dentititon, have different aetiologies or they occur as consequence of the crown position and tooth involved (Goodman and Rose, 1990; Hillson and Bond, 1997; Lovell and Whyte, 1999; Guatelli-Steinberg, 2004; Bocaege et al., 2010; Radović and Stefanović 2013; Hassett, 2012; 2014; Hillson, 2014; Lorentz et al., 2019). The contribution by Towle and Irish (2020) to this issue is offering a way forward when it comes to recording and interpreting different types of enamel defects in samples from archaeological and palaeoanthropological contexts. In their study undertaken on two extant great ape species and three fossil hominin species, they recorded all types of macroscopic enamel hypoplasia, including pitting, linear, plane and localised type defects. Based on their results, they highlighted how proportions of different kinds of enamel hypoplasia varies substantially between samples. They also showed how tooth properties (e.g., tooth morphology, developmental timing/speed, and enamel structure) affect the likelihood of specific types of enamel hypoplasia forming along with environmental and genetic factors. All these can heavily influence frequencies of the observed defects. They urge that future studies do not include only one form of enamel hypoplasia or focus on only one tooth type when comparing developmetal defects between populations as they may miss crucial information. Their suggestion is to record different types of defects separately, for all teeth, and then consider how genetic, environmental and tooth property factors may influence population differences. In our opinion, this strategy in recording enamel defects will ensure there is enough information for the authors worldwide dealing with this issue to make statistically informed and valid comparisons, before there is enough data on precise aetiology of these defects.

In her contribution to this special issue Foley (2020) is opening a new path for conceptualizing and identifying stress in past populations using bruxism as a clinically related response to physiological stress. A strong relationship between psychosocial stress and bruxism has been reported in a number of clinical studies (Manfredini and Lobbezoo, 2009; Abekura et al. 2011; Wieckiewicz et al., 2014; Karakoulaki et al., 2015; Yap and Chua, 2016; Azevedo et al. 2018; Saczuk et al., 2019). The consequences of such habitual teeth clenching and grinding (i.e bruxing behaviour), and associated severe attrition, are often the loss of dental hard tissue, and formation of a flat occlusal plane. This may lead to exposure of sensitive dentine tissue, and can induce hypercementosis, muscle hypertrophy, and even temporomandibular disorders and the development of tori (Lavigne et al. 2008; Berkovitz et al 2009; Yap and Chau, 2016). Many of these features are easily observable in archaeological human remains, however bruxism is very rarely reported in bioarchaeology. Lack of a clear diagnostic criteria is one of the reasons for this under examination of bruxism in studies of past dentitions. In her review of correlation of bruxism and stress Foley also suggests (2020) some starting diagnostic approach for identification of bruxism in skeletal remains. She emphasised that “the identification of bruxism may provide novel osteobiographic insights into individual, rather than communal, experience with psychosocial stress and anxiety” which can be achieved through an “approach that considers a suite of possible indicators in concordance with careful, population-specific micro-and macro- dental wear analysis” (Foley 2020).

When it comes to interpretation of health through “non-specific stress indicators” in skeletal remains, Pilloud and Schwitalla (2020) choose to re-evaluate traditional markers of stress (periosteal reactions, porotic hyperostosis, and cribra orbitalia) when interpreting these complex phenomena. They chose to investigate this in a large archaeological collection of more than 3000 skeletons from pre- and post-contact central California (3050 BC – AD 1899). The study illustrates the methodological and theoretical issues and represent a way forward in interpretations of skeletal stress considering the role of the osteological paradox (DeWitte, 2014; Wilson, 2014; Radović et al. 2015; Kyle, et al., 2018, Marklein, et al., 2016; Yaussy, et al., 2016). Their study showed that the prevalence of and variation within periosteal reactions, porotic hyperostosis, and cribra orbitalia cannot be simply linked to episodes of external “stress” and change (e.g. environmental disruptions, European contact). They suggest that the interpretations of these skeletal lesions should rely on clinical literature, as it should also be regionally appropriate and incorporate archaeological and climatic data (Pilloud and Schwitalla, 2020).

## 5. Conclusion

In sum, we suggest avoiding the use of the term “stress” in the study of archeological human remains, unless it is precisely qualified, e.g., “mechanical stress”. As there are limits on the interpretations of causal relations between various disruptors and their traces in skeletal material, more cautious clinical studies involving humans with documented life histories are needed. In our opinion, instead of trying to reconstruct health and well-being of the people in the past, we need to focus our attention on more accurate identification of disease and human adaptation to the environment in the past, where possible. By relying on known aspects of many pathological processes at both micro- and macroscopic levels, we are now able to develop more robust recording systems for the analyses of skeletal remains. This in turn allows us to construct better research questions that achieve powerful new insights into the evolution of important human diseases. With the rapid advancement of many scientific analytical techniques, such as metagenomic analyses and the next generation sequencing (NGS), it will soon be possible to routinely identify human pathogens which do not leave visible traces on bones and teeth. Studying disease and disease loading in the past fosters a crucial understanding of the origins and transmission of modern diseases, and human adaptations and responses to them. This knowledge can help us better plan for the advent and progression of current and future epidemics which are currently the most significant threat to our species.

## Acknowledgments:

We would like to thank the UCL Institute of Archaeology for hosting the important "Stressed Out" conference in 2017, where these papers were first presented and our advisory group: Simon Hillson, Tony Waldron, Daniel Antoine, Albert Zink, and Kevan Edinborough.

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