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Research article

# Stressing out in medieval Denmark: An investigation of dental enamel defects and age at death in two medieval Danish cemeteries

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ABSTRACT

The influence of early life stress on later life experiences has become a major focus of research in medicine and more recently in bioarchaeology. Dental enamel, which preserves a record of childhood stress events, represents an important resource for this investigation when paired with the information from adult skeletal remains, such as age at death. The purpose of this research was to use a life history approach to the exploration of sex differences in the relationship between childhood stress and adult longevity by examining accentuated striae of Retzius (AS). A medieval Danish sample (n = 70) drawn from the rural cemetery of Sejet and the urban cemetery of Ole Wormsgade was considered for AS and age at death. The results suggest sex differences in survivorship, with more stress being associated with reduced survivorship in males and increased survivorship in females. A consideration of AS formation time also suggests a difference in the impact of developmental timing between males and females. These results are interpreted in terms of differential frailty and selective mortality, drawing in both biomedical and cultural perspectives.



## 1. Introduction

The formation of dental enamel occurs with a regular periodicity, providing a record of growth and development along with a record of any disruption during development (Antoine, 2000; Antoine et al., 2009; Goodman and Rose, 1990; Risnes, 1986; Smith, 2006). Enamel is also the hardest biological substance, with mature enamel being at least 97% mineral in composition and not remodeling once formed (Goodman and Rose, 1990; Hillson, 2014). Apart from occlusal wear and abrasion, it captures a record of growth and development that is preserved throughout the life of an individual and is less subject to degradation in the archaeological record due to the high mineral content. These characteristics make it an excellent medium for the consideration of growth patterns. In addition to the regular markers of growth formed during enamel deposition and maturation, systemic growth disruption can impact enamel growth, leaving permanent irregular markers in the enamel. The most commonly studied markers are visualized as horizontal lines known as dental (or in this case linear) enamel hypoplasia (LEH). These have been considered extensively in connection with the assessment of stress in past populations (Bennike et al., 2005; Obertová, 2005; Palubeckaitė et al., 2002; Wright, 1997). It has further been shown that even the smallest defects that cannot be distinguished without the aid of a microscope can represent stress events (Hillson, 1992) and that microscopic versus macroscopic examination can produce vastly different results (Hassett, 2012). The potential of enamel micro-defects to reflect actual events that might have impacted how an individual responded to a range of later life experiences makes them invaluable resources for the study of stress in past human populations.

The growth lines visible on the enamel surface (known as perikymata) are reflected internally by striae of Retzius, with more pronounced internal lines that may be associated with growth disruption being known as accentuated striae of Retzius (AS) or alternatively as Wilson bands or pathological striae of Retzius (FitzGerald and Rose, 2008; Hillson, 2014). The consideration of internal enamel microstructure makes it possible to observe growth lines even in the cuspal area, where they do not appear on the tooth surface. It is also possible, using a variety of methods, to attain precise ages for the occurrence of any given AS, moreso than for LEH (see Hillson (2014) for recent in depth coverage). Reid and Dean (2006), using complete reconstructions of age at occurrence from daily markers (cross-striations) and long period markers (AS) have built developmental charts for each tooth type, where teeth are divided into ten different regions (deciles) from cusp to cementum-enamel junction (CEJ) and age ranges are

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associated with each region. These charts are useful for estimating developmental age across the tooth crown, and one set of age reconstructions is derived from a Northern European sample containing individuals from the medieval site of Tirup, which is located in close proximity to the cemeteries used in the current study.

There is also increasingly strong evidence for early life stress impacts on later life experiences (Barker, 2004a, 2004b, 2001; Barker and Osmond, 1986; De Boo and Harding, 2006; Gillman, 2005; Gluckman et al., 2005; Simmons, 2009). However, this connection has seldom been considered on a large scale using internal enamel microdefects (Rose et al., 1985, 1981, 1978; Thomas, 2003). The ability of dental enamel to capture early life stress events and the potential of the human skeleton to provide insight into later life experience places human osteological studies of this nature in a strong position to provide a life course perspective reflecting developmental plasticity and adaptive response (Armelagos et al., 2009).

This study investigates the number of AS observed in mandibular canines in relationship to adult mortality (i.e., mortality in individuals who survived childhood stress events) in archaeological samples from medieval Denmark. Two cemeteries dating broadly to between mid-12th and mid-16th centuries, representing both rural and urban populations from in and around the medieval market town of Horsens were used in this investigation (Fig. 1). The aim of the study is to identify how stress early in life might correlate with longevity, with a particular focus on possible sex differences in the samples. More specifically, it tests three hypotheses:

i) The number of stress events during growth and development, as reflected by dental enamel microdefects, will be associated with changes in adult mortality. It is predicted that individuals with more AS across the total crown (total AS) will show reduced age at death. The null hypothesis predicts that there will be no correlation between the number of enamel defects and mortality.
ii) There will be sex-specific difference in the response to early life stress experiences and so any pattern that emerges between enamel defects and adult mortality will vary between males and females. The null hypothesis proposes that there will be no difference between the sexes, and so any patterns observed between enamel defect occurrence and age at death will show no significant difference between the males and the females in the sample.
iii) The relationship seen between episodes of enamel growth disruption and age at death will fluctuate based on the timing of occurrence of the stress experience. The null hypothesis proposes that the developmental age at which the stress experience occurs will not have a variable influence on age at death. Different timings of occurrence will therefore show no significant differences in their correlation with age at death.

### 1.1. Childhood stress and adult mortality

Research in bioarchaeology has demonstrated a connection between indicators of childhood stress experiences (such as enamel hypoplasia) and age at death (Armelagos et al., 2009; Boldsen, 2007; Cook and Buikstra, 1979; Goodman and Armelagos, 1988; White, 1978). Beyond bioarcheology, there is a growing body of clinical literature providing insight into the long-term impacts of early life experiences (Barker, 2004a, 2004b, 2001; Barker and Osmond, 1986; De Boo and Harding, 2006; Gillman, 2005; Gluckman et al., 2005; Simmons, 2009). Central to this research is a theory that was initially formulated as the Barker Hypothesis (Barker and Osmond 1986) and later reformulated as the Developmental Origins of Health and Disease Hypothesis (Barker, 2004a; De Boo and Harding, 2006). This hypothesis proposes that physiological disruption early in life can have a negative impact on adult health, some focusing on the foetal period with its associated rapid growth. However, this period of rapid growth continues postnatally through the infant and childhood periods (albeit with a gradual slowing down) (Bogin, 1999). Systems developing during this period, such as the immune system, can be negatively impacted by physiological stress (MacGregor, 2008). Epigenetic research, which may be defined as the science of heritable biological adaptation involving the epigenome, also plays a central role in the investigation of this concept (Devaskar and Raychaudhuri, 2007). Through such research, the mechanisms by which environmental factors can influence genome function are being revealed.

Parameters such as neonatal birth weight, childhood obesity, growth rate, infectious disease and breastfeeding duration have frequently been considered in relation to adult obesity, diabetes, asthma, and cardiovascular health to explore a possible impact of early life experiences on later life health (Barker, 1995; Barker et al., 1993; Cianfarani et al., 1999; Eriksson et al., 2002, 2001; Forsen et al., 1999; Freedman et al., 2001; Gern et al., 1999; Lemanske, 2002; Ong et al., 2000; Openshaw et al., 2004). Bioarcheologists do not have access to any of these modern health parameters in their investigations of past populations. However, they do have access to the record of nonspecific stress markers preserved in dental enamel, and they do have certain indicators reflecting more recent physiological experiences that can allow them to take a life course perspective on long-term responses to stress (Armelagos et al., 2009). By taking a microscopic rather than a macroscopic approach to this research, it becomes possible to capture enamel growth disruption more fully, even down to the finer and potentially more acute experiences that might not be apparent macroscopically. Age at death can provide insight into how human populations respond in later life to early life physiological impacts. Engaging in archaeological studies makes it possible to gain insight into historic patterns of response, here focusing upon the environmental and social changes seen in medieval Denmark, including those associated with the late medieval agrarian crisis and the changes brought about by the mid-14th century Black Death epidemic. Such bioarchaeological studies not only provide insight into the biological non-specific stress response, but also into how human populations respond to different circumstances over time. The populations considered in this investigation lived in a pre-antibiotic era and experienced periods of famine along with both endemic and epidemic disease loads (Benedictow, 2004, 1996; Bennike et al., 2005; Boldsen, 2009, 2008; Qvist and Grøntved, 2001; Yoder, 2006). Thus, the developmental records captured by dental and skeletal remains allow us to track stress exposure and impact over the life course prior to modern medical intervention.

## 2. Materials and methods

This study examined the skeletal remains from two Danish medieval cemeteries currently curated at the Anthropological Database, Odense University (ADBOU) in trust from the Horsens Museum (Denmark). Sejet is a rural parish cemetery lying just outside of the medieval town of Horsens, while Ole Wormsgade was an urban parish cemetery located in Horsens (Fig. 1). A total of 37 individuals from Sejet (19 females, 15 males, and 3 of undetermined sex) and 36 individuals from Ole Wormsgade (17 females and 19 males) were sampled for this research. Both cemeteries were in use from roughly the mid-12th to the mid-16th centuries, with use of Ole Wormsgade likely ending by A.D. 1536 and use of Sejet terminating around A.D. 1574 (Johanssen et al., 2004; Kjærgård, 2006). No significant changes in AS counts were detected between sites or over the period of cemetery use. Unfortunately, if subdivided by