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# Outlining a Definition of Oral Health within the Study of Human Skeletal Remains

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*ABSTRACT* The term *oral health* is regularly used in bioarchaeological research to discuss a myriad of pathological conditions of the oral cavity. However, there is very little consensus on what conditions should be included in such a study, and some of the conditions are at odds with those in the clinical literature. In this manuscript, we outline the clinical definition of oral health and develop a strategy in which bioarchaeology can address this type of research. We argue that the terms dental disease and/or pathological conditions of the oral cavity should be used in lieu of oral health. Various conditions that can be included in such research are outlined. Finally, definitions, clinical etiologies, and recording schema for these conditions are discussed as relevant to bioarchaeological studies.

Recently the concept of "health" has been criticized in bioarchaeology (e.g., Reitsema & McIlvaine, 2014). Defining health in past populations, or even among the recently deceased, can be difficult if not impossible as this concept incorporates somewhat unknowable factors about lifestyle and well-being. In response, the term "stress" was incorporated into research, which shifted the focus to conditions of disease or growth disruption. Yet, the etiology and interpretation of these markers of stress may not fully capture the experienced life of people in the past. For example, a study based on data from the Mexico Family Life Survey found that individuals with anemia were of various socioeconomic statuses and generally did not report being in poor health (Piperata et al., 2014). As skeletal signs of anemia are generally used in bioarchaeology as indicators of stress, this study of living individuals has highlighted the actual role of anemia in the lives of people currently experiencing it. Based on recent critiques, the incorporation of stress was cited as merely being a replacement for "poor health", while still failing to address the issues inherent in interpreting the levels of health and stress in past populations.

These critiques about quantifying general health and stress in bioarchaeology can be extended to the concept of oral health. A term that has been used in various contexts within the bioarchaeological literature to describe numerous conditions of the teeth and their surrounding bony structures. Despite its common use, there is currently no consensus on what should constitute oral health within the bioarchaeological record, and multiple indicators of stress, growth disruption, infection, oral pathology, and non-specific disease may be included. A more comprehensive discussion of oral health within the bioarchaeological record is warranted given inconsistencies in discussion of oral conditions and advances in the clinical literature.

In 2014, the American Dental Association (ADA) House of Delegates adopted the following definition of oral health as "a functional, structural, aesthetic, physiologic and psychosocial state of well-being… essential to an individual's general health and quality of life" (http://www.ada.org/en/about-the-ada/ada-positions-policies-and-statements/ada-policy-definition-of-oral-health). In 2016, the World Dental Federation (FDI, once called the Fédération Dentaire Internationale) adopted a new definition of oral health that echoes the sentiment of the ADA in that oral health is much more than the mere absence of disease. The FDI defines oral health as "the ability to speak, smile, smell, taste, touch, chew, swallow, and convey a range of emotions through facial expressions with confidence and without pain, discomfort, and

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disease of the craniofacial complex" (Glick et al., 2016:916). This work further emphasizes the interaction of disease status, physiological function, and psycho-social function along with determining and moderating factors that influence overall oral health (Glick et al., 2016).

From a research perspective, and in a clinical setting, it is critical to understand treatment outcomes and levels of oral health, as poor oral health can have further health and social implications. In recent clinical literature poor oral health has been linked to Type 2 diabetes (Leite et al., 2013), obesity (Östberg et al., 2012), and eating disorders (Johansson et al., 2012). Further, oral health has been related to school performance (Abanto et al., 2011; Jackson et al., 2011), quality of life, self-esteem (Bennadi & Reddy, 2013; Gerritsen et al., 2010), and depression (Okoro et al., 2012). The concept of Oral Health-Related Quality of Life (OHRQoL) has grown over the last decade and is being recognized as a critical part of dental research and clinical dental practices (Sischo & Broder, 2011). The OHRQoL is typically studied through questionnaires and serves as a means to quantify outcomes to better evaluate treatment in a clinical setting (Bennadi & Reddy, 2013).

The definitions proposed by the ADA and FDI as well as the study of OHRQoL, raise questions about how bioarchaeologists currently use the term oral health, as it is not possible to understand the "psychosocial well-being" of past populations based only on the archaeological record. Further, the clinical research on oral health shows a disconnect with how the term is being used in bioarchaeological research. This paper proposes to address inconsistencies and misconceptions in studies of oral health on skeletal remains. We begin with a review of the current trends in the use of the term and end with a proposed outline of how the term can be used in research on skeletal remains.

**Current Use of Oral/Dental Health**

While the clinical definition of oral health includes conditions of the oral cavity that are detrimental to one's general quality of life, within bioarchaeological research this definition can vary widely. This variation is illustrated in a survey of articles published in the *American Journal of Physical Anthropology*, *International Journal of Osteoarchaeology*, and the *International Journal of Paleopathology* between 1977 and 2018. Those articles that use the term "dental health" or "oral health" in the title or abstract (n=44) were searched to identify trends in the use of this term. Two of the articles that were recovered in the search were later found to not be related to oral health and were removed from further discussion.

In these articles, oral health was quantified through various skeletal indicators to include: periodontal disease, dental caries/carious lesions, linear enamel hypoplasia, crown variation, morphology, dental/occlusal wear, calculus, enamel hypoplasia, periapical defect/lesion/granuloma/abscess, antemortem tooth loss, cleft palate, alveolar defects/lesions, chipping, dental tilting, hypercementosis, dens in dens, agenesis, and antemortem tooth loss. A word cloud was created to highlight the frequency of each type of skeletal indicator (Figure 1). By far the most commonly investigated conditions were dental caries, antemortem tooth loss, and abscesses.

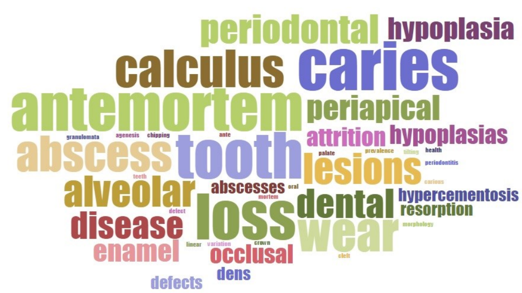


Figure 1. Word cloud highlighting use of terms in research on "oral/dental health".

Within this body of literature there is little consensus on what factors should be studied as part of oral health and may also employ varying definitions of these pathological conditions. However, these research foci are generally in line with the World Health Organization (WHO) definitions of dental disease, which include "dental cavities, periodontal (gum) disease, oral cancer, oral infectious diseases, trauma from injuries, and hereditary lesions" (http://www.who.int/mediacentre/factsheets/fs318/en/). While these dental diseases may be relatively straightforward to diagnose in a clinical setting with a well-known patient history and clinical records, similar diagnoses in archaeological populations may be impossible to assess. We therefore dedicate the following section to outlining factors that can be used in defining diseases of the oral cavity in a bioarchaeological setting.

**Proposed Use**

We propose that based on recent critiques of the use of the term *health*, conditions of the oral cavity be termed **dental disease** or **pathological conditions of the oral cavity**. These terms shift the focus from the unknowable aspects of health (i.e., psychosocial well-being) to conditions that can be identified in the maxilla, mandible, and teeth with known etiologies. Below we outline which conditions can be used as part of this definition, conditions which are less applicable, and those that should not be included in studies of this nature.

***Conditions to include as dental disease/ pathological conditions of the oral cavity:***

Dental caries is a disease process characterized by dental hard tissue destruction of tooth enamel and dentin due to the bacterial fermentation of consumed carbohydrates. There can be many contributors to dental caries, to include diet, tooth morphology, calculus, age, sex, microbiology, and periodontal disease (Fakhruddin et al., 2018; Featherstone, 2008; Larsen, 2015; Young et al., 2015). A recent study of the human oral microbiome found that the progression of dental caries was related to a multiple bacterial species, not just *Streptococcus mutans*, as was previously thought. Further, individuals without carious lesions exhibited the presence of various other bacteria (e.g., genera of *Aggregatibacter* and *Rothia*) that were found to impede the development of cariogenic bacteria (Belda-Ferre et al., 2012).

In the clinical literature, much work has focused on the prevention of dental caries and increasing outcomes for patients. A Center for Disease Control and Prevention study on the presence of dental caries in the United States from 2005-2008 found that 75% of individuals had at least one dental restoration, and that 20% had untreated dental caries. Untreated dental caries differed significantly across socioeconomic status; although, younger individuals showed more equity in terms of dental restoration presence (Dye et al., 2012). These patterns are in line with recent studies in Canada and the United States that found a decline in socioeconomic inequalities in terms of oral health (Bernabé & Marcenes, 2011; Elani et al., 2012).

Within bioarchaeological research, patterns in dental caries prevalence speak to disease loads and changing diets. The presence of carious lesions is also age dependent and will manifest differently in different teeth. There are various models for scoring dental caries in bioarchaeological research. In a clinical setting, rates of carious lesions are recorded using the DMFT method. In which the total number of diseased (D), missing due to disease (M), and filled teeth (F), is divided by the total number of teeth (T). This system would clearly have limited utility in bioarchaeology due to the lack of filled teeth, teeth missing post-mortem, and the inability to determine the cause of antemortem tooth loss (Waldron, 2009).

For skeletal remains, the Moulage system could be employed, which is a series of 85 plaster models that illustrate varying degrees of carious decay in different locations (Hillson, 2001). However, these plaques were not made widely available outside of Scandinavia, and only a few photographs are available in published manuscripts (Lindström, 1940; Rönnholm et al., 1951), which makes their broad use impractical. Hillson (2001) proposed an alternate method for recording dental caries in which efforts are made to separate data in terms of tooth type, age cohort, sex, and lesion type and location. Such an approach can account for differential preservation of tooth types and age groups – both of which have an overall effect on dental caries prevalence calculations. While the method proposed by Hillson (2001) is by far the most nuanced and accounts for a range of biological variation, the most commonly employed method of dental caries recordation is that outlined in Buikstra and Ubelaker (1994). This method relies on a visual inspection of the dentition with recording of dental caries by tooth type and surfaces affected.

Periodontal disease is actually a cluster of inflammatory diseases that affect the periodontium (Langlais et al., 2017; Lindhe & Lang, 2015). Clinically it is especially noted by the inflammatory status of gingiva and other soft tissues. The diseases are generally chronic and slow progressing in nature; although, more aggressive and acute forms do exist. The primary cause is a complex community of microbes that form a biofilm on tooth surfaces and interact with the host response systems to create an inflammatory response. There are many contributing factors that include local tooth anatomy, virulence of the biofilm, and systemic conditions that modify the host response. There are also various biological, social, and behavioral risk factors, which include: socioeconomic status, tobacco use, hormones, stress, excessive alcohol consumption, diabetes, obesity, osteoporosis, root abnormalities, enamel pearls, impacted third molars, and trauma, among many others (Jin et al., 2011). The WHO estimates that between 5 and 20% of adults globally have severe periodontitis (Jin et al., 2011). Periodontal disease remains a major cause of tooth loss in both developed and developing countries

(Pihlström et al., 2005).

Disease limited to the gingiva often does not cause attachment loss and is usually reversible. Disease that affects the deeper structures of the periodontium lead to irreversible loss of connective tissue attachment and bone loss. Clinically, diagnosis is made based on a combination of measurable factors including pocket depth, clinical attachment loss, anatomical variations, tooth mobility, quantity and position of dental calculus, radiographic changes, and quantity of inflammation. The only factors that may reliably survive to the postmortem or bioarchaeological cases are quantity and position of dental calculus, attachment loss, and radiographic changes. A combination of these data is needed to assess the periodontal status of osseous specimens. Much evidence is currently available that links active periodontitis with numerous acute and chronic systemic diseases, including cardiovascular diseases, diabetes, pulmonary diseases, a cerebrovascular diseases (Albandar et al., 2018; Jepsen et al., 2018; Gerry J. Linden & Herzberg, 2013; Gerard J. Linden et al., 2013)

There are multiple methods to score periodontal disease. In an epidemiological setting periodontal disease may be recorded using the Community Periodontal Index of Treatment Needs (CPITN), which requires a special probe to document the status of disease and treatment needs (Ainamo et al., 1982). (Comment: In fact, this system is somewhat flawed and not often used currently, but there is a long history in the literature). As there is no soft tissue in the bioarchaeological record, Karn et al. (1984) described a series of deformities of the alveolar process that include crater, moat, ramp, and plane to describe the disease process. Nearly a decade later, Kerr (1991) proposed an alternate scoring system in which the top of the interdental wall was described as flat/curved, porous, or with breakdown of the contour. Most recently, Waldron (2009) suggested the presence of periodontal disease should be recorded in individuals with 3 mm or greater distance between the cemento-enamel junction (CEJ) and the alveolar crest (AC) and recommended that the distance be documented with a periodontal probe. This is the method that most closely approximates the clinical gold standard for measuring the clinical attachment loss associated with periodontal disease, which is the diagnostic basis for defining periodontitis in humans (Eke et al., 2012; Holtfreter et al., 2015; Papapanou et al., 2018). However, when measuring skeletal remains it is also necessary to consider that the connective tissue component of the periodontal attachment apparatus is missing, and a 1mm subtraction from the measured distance from the CEJ to the AC is necessary to allow for this missing portion of the biological width of tissue attachment (Gargiulo et al., 1961). The epidemiological threshold to define early periodontitis for human studies is 3mm of attachment loss (Eke et al., 2018), which would be measured as 4mm of distance from the CEJ to the AC. The clinical threshold that is often used is 2mm of attachment loss (Papapanou et al., 2018) (3mm measured from the CEJ to the AC), which encourages clinicians to diagnose and treat periodontitis at the earliest stages in order to prevent continued irreversible attachment loss.

Periapical lesions are related to pulpitis when an infection penetrates the pulp cavity. The term periapical lesion is a general term to describe a disturbance of the skeletal tissue around the apex of the tooth that may be related to a granuloma, cyst, or an abscess (Figure 2). The general term of 'periapical lesion' is preferred as the specific etiology is not possible to diagnose or differentiate without a soft tissue biopsy or a definitive patient history (Langlais et al., 2017). Even in a clinical setting these distinctions can be difficult to make (Stockdale & Chandler, 1988), again underscoring the need to keep terminology general in bioarchaeological research. These lesions are merely recorded by location and as present or absent.

Figure 2. Example of a periapical lesion of the right maxillary fourth premolar.

Trauma to the oral cavity could be included under dental disease as it is a disorder of function. Further, it could affect the overall well-being of the individual and is included in clinical definitions of oral health. Traumata to the oral cavity could include acute trauma such as fractures to the mandible, maxilla, or teeth; or, more long-term trauma such as damages due to bruxism, or issues with the temporomandibular joint.

Cancers of the oral cavity affecting bone are relatively rare in the bioarchaeological record, but could be included in a general study of oral disease according to the clinical definition of the WHO. The most common contemporary type of cancer in the oral cavity is squamous cell carcinoma, which may or may not leave a signature on bone. The incidence of oral cancer is also relatively low globally according to the Atlas of Oral Health (Beaglehole et al., 2009). Oral cancers also tend to have a greater prevalence in older humans, which should be considered in archaeological samples.

***Conditions to potentially include:***

Abscess/granuloma/cyst are terms that should generally be avoided individually as they require soft tissue and/or clinical evidence for a definitive diagnosis. As previously discussed, a more general term such as "periapical lesion" or "a certain anatomical lesion" is nearly always more accurate and includes the undetermined status of the lesion. In general, abscesses are acute lesions with purulent discharge, granulomas are chronic lesions with or without discharge, and cysts are epithelial-lined benign neoplasms. These all may look the same radiographically or as osseous lesions.

Calculus is a mineralized biofilm on the surface of teeth. The accumulation and composition of calculus can be studied to understand the oral microbiome, or may be measured in relation to other disease parameters (e.g., periodontal disease). However, the exact process of mineralization is not fully understood (Warinner et al., 2015). Therefore, calculus is thought to be more a product of disease processes rather than the cause of disease, and may be best included as part of pathological conditions of the oral cavity as opposed to dental diseases or can be included in a diagnosis of periodontal disease. In bioarchaeology, the presence of calculus is typically recorded according to the scheme developed by Brothwell (1981) in which calculus presence is scored on a scale from 1 to 3 of increasing severity.

Hypercementosis is the excessive build-up of cementum with unknown etiology (Corruccini et al., 1987). Although, it has been suggested to be linked to genes, Paget's disease, rheumatoid arthritis, thyroid goiter, acromegaly, and rheumatic fever (Mohan, 2014). As the etiology is unknown, it is not appropriate to include it as part of studies focused on dental disease. However, it may be recorded as a dental anomaly or in the differential diagnosis of other, potentially related, conditions.

Antemortem tooth loss (AMTL) should be used cautiously as there are many causes of this condition, some of which may not be related to disease (e.g., dental ablation and trauma). Care must also be taken in cases where dental agenesis may be a factor (e.g., third molars, upper lateral incisors, or lower third premolars). It is critical that radiographs are taken in ambiguous cases to ensure impaction is not a factor. Although in the clinical literature, tooth loss is largely related to dental disease, predominantly periodontal disease and dental caries (Gerritsen et al., 2010). Antemortem tooth loss can more definitively be assigned in studies of dental disease in cases where there is large gap, reactive bone, a healed alveolar ridge with a deficient volume of bone, or it is a tooth that is not typically missing due to agenesis, trauma or ablation (Figure 3). In cases of uncertainty, antemortem tooth loss should not be recorded.

***Conditions to limit or not include:***

Enamel hypoplasia is a disruption in enamel secretion during dental development (Goodman & Rose, 1990). These enamel defects can manifest as pits, furrows, or plane defects (Hillson & Bond, 1997). Enamel hypoplastic defects are linked to episodic childhood stress, such as malnutrition and fevers (Hillson, 1996). As such, they are an indication of general stress, not specific to the oral cavity, and are therefore not applicable to a study cen-

Figure 3. Example of antemortem tooth loss with reactive bone and a large gap on the right mandible.

tered on *dental disease*.

Occlusal wear is a reduction in the dental hard tissues related to traumatic injuries to teeth caused by abrasion, attrition, and/or erosion (Ibsen & Phelan, 2018; Langlais et al., 2017). Although these injuries may lead to reduced function of the dentition due to loss or alteration of dental hard tissues, the occlusal wear itself is not a disease process, but is the result of either (1) wearing away of tooth structure from a repetitive mechanical habit (abrasion), (2) wearing away of tooth structure due to tooth-tooth contact (attrition), or (3) loss of tooth structure resulting from chemical action not of bacterial origin (erosion). Unless the processes or results of occlusal wear can be specifically identified as pathological, such as there is associated pulp exposure with infection, general wear is not an indicator of dental disease. It is likely more related to the time span of life (often expressed as age), consumed foods, the use of teeth as tools, sex, bite force, malocclusion, environmental or salivary factors (Dahl et al., 1993).

Tooth size/morphology/agenesis are all conditions that are considered highly heritable and should be studied as separate conditions. Tooth size may be related to non-specific indicators of childhood or maternal stress (Pilloud & Kenyhercz, 2016), and therefore is not related to studies of dental disease. Moreover, there are no good data to show that morphology or dental agenesis are related to stress or a disease process.

Chipping is related to microtrauma and therefore a reflection of biting force and potentially diet and tool use (Scott & Winn, 2011). Chipping also may be due to blunt force, or an eventual result of wear. Unless the chipping leads to pulp exposure and infection, or possibly radiographic signs of secondary dentin formation as a result of the trauma, it is not a disease process on its own.

Cleft palate is a congenital defect that is also not related to any active disease process, and it should be considered separately. Even though it may affect overall function of the oral cavity, there is much variation in expression and severity and due to its relative rarity in the archaeological record, it should be considered independently in studies of pathological conditions of the oral cavity.

**Discussion and Conclusions**

The study of pathological conditions of the oral cavity in the past are an important aspect of archaeological research. These conditions can inform our understanding of diet, disease loads, activity, and genetic composition of past populations. We argue that this research is an important endeavor that is only lacking in a level of clinical standardization and appreciation. Measures of dental disease in the archaeological record that can conform to current measures of dental disease will improve the relevance and understanding of disease processes that can be related over the continuum of human history. This manuscript is meant to start the discussion of standardizing research on dental disease with an emphasis on clinical research. This work is not meant to be the definitive word on bioarchaeological research on oral health or dental disease; instead, we hope to generate a discussion on this research and work towards an integrated approach that fully intertwines bioarchaeological research within a clinical reality that embraces the accurate use of terms.

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# Periodontal Health and the Lifecourse Approach in Bioarchaeology

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*ABSTRACT* Healthy periodontal tissues are essential to maintaining attachment, stability, and retention of teeth. The concept of 'health' is problematic however and includes both physical and psycho-social characteristics. The challenge for bioarchaeologists is defining what physical expression begins to affect an individual's well-being. Here we apply a lifecourse approach to periodontal tissue health in a prehistoric sample (N = 166) from the American Southwest to test the hypothesis that age and sex differences bear the greatest impact on the expression of periodontitis. Tooth loss, tooth wear, periodontal depth (CEJ-AC), and alveolar crest (AC) morphology were recorded at M1. T-tests identify that females exhibit significantly higher values across each variable. In addition, general linear modeling analyses demonstrate that values increased significantly across five age stages (15-20yo, 20-30yo, 30-40yo, 40-50yo, 50+yo) with females exhibiting significantly higher values in the fourth and fifth decades of life. Results support the hypothesis that periodontal tissue loss differentially affects females across the lifecourse. Bacterial infection, chronic gingivitis, and attachment loss cause the physical symptoms of periodontal disease but may not be accompanied by pain or altered functionality. The outcome of the disease process is tooth loss, which can affect functionality and quality of life. Periodontal 'health' is therefore best interpreted in bioarchaeological samples around the point that attachment loss results in tooth loss and altered functionality.

Periodontal tissues historically receive little attention in bioarchaeological research. Periodontal 'health', however, is essential to maintaining a foundation for attachment, stability, and retention of teeth. The concept of 'health' is more than the absence of disease and is therefore problematic among both clinicians and bioarchaeologists (see Pilloud and Fancher, this issue). Mariotti and Hefti's (2015) call for redefinition of periodontal health among clinicians, using a modified wellness model, includes both physical (functional dentition and periodontal attachment stability) and psycho-social (pain and individual well-being) characteristics. The challenge for bioarchaeologists is defining what physical expression/degree within a disease process would begin to affect an individual's well-being. Here we therefore apply a lifecourse approach to the measurement of periodontal disease in a prehistoric sample from the American Southwest to test the hypothesis that age and sex differences bear the greatest impact on the expression of periodontitis.

Periodontal disease (PD) is the clinical characterization of destruction of the periodontium—the oral structure containing the teeth, composed of both fibrous (gingival and periodontal ligament) and mineralized (cementum and alveolar bone) tissues. Periodontal disease has a multifactorial etiology, but is primarily associated with inflammatory host response resulting from bacterial infection of periodontal tissues. Many bacterial species have been associated with the pathogenic colonization of subgingival biofilm (dental plaque) (Adriaens, De Boever, & Loesche, 1988; Boutin et al., 2017; Socransky & Haffajee, 2005) and the periodontal pocket provides an ideal eco-system for these organisms, containing a diverse microbiota of up to 700 prokaryote species (Boutin et al., 2017; Chen et al., 2010). Martelli and colleagues (2017) identify that the progression and severity of PD depends on the aggressiveness of the subgingival

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plaque biofilm and individual host immune response, which can be further affected by genetic and epigenetic contexts and environmental factors (i.e., age, sex, smoking, oral hygiene, etc.). Today, PD is also correlated with various systemic disorders, including cancer, diabetes, rheumatoid arthritis, cardiovascular diseases, and preterm birth (Jepsen et al., 2018; Martelli et al., 2017).

Studies of modern and prehistoric patterns of periodontal disease demonstrate that men generally have a higher prevalence than women (DeWitte, 2012; Shiau & Reynolds, 2010; Wasterlain et al., 2011). DeWitte (2012) proposes that this is likely due to immuno-buffering from estrogen among women (Klein and Huber, 2010). But there is other clinical evidence to suggest that hormonal fluctuations, particularly associated with pregnancy, may have adverse effects on periodontal health (Carrillo-de-Albornoz et al., 2010; Laine, 2002; Lukacs and Largaespada, 2006; Silk et al., 2008; Wu, Chen, & Jian, 2015). During pregnancy, production of estrogens and progesterone is increased. Estrogen levels rise to over 100 times more than pre-pregnancy levels, with progesterone levels surpassing this even more. During labor, hormone concentrations drop, reaching their pre-pregnancy levels within 2-3 days after delivery (Laine, 2002). After the second trimester, the placenta begins regulating hormone production to maintain the pregnancy, including maintenance of the endometrium, preparation for lactation, increase in basal metabolic rate, and regulation of the immune system. The affiliated vascularization of bodily tissues often causes the gingiva to become inflamed and retain fluid, resulting in pregnancy gingivitis and edema (Bobetsis et al., 2006; Laine, 2002).

While pregnancy does not actually cause gingivitis or periodontitis, the hormonal activity in gingival tissues can exacerbate pre-existing periodontal disease. With increased gingival inflammation and edema, the periodontium can become weakened (Laine, 2002; Silk et al., 2008). Especially in the presence of accumulated plaque and calculus, the gingiva can become detached from the tooth exposing the periodontium (Coventry et al., 2000). When bacteria infiltrate the weakened periodontium, their toxins activate a chronic inflammatory response, causing the ligaments and bone supporting the teeth to break down (Silk et al., 2008).

Current research has identified some specific pathophysiology that may contribute to PD associated with hormonal activity during pregnancy. Pregnant women experience pronounced fluctuations in the sex hormone estrogen. Estrogen acts as a ligand for estrogen receptor ß (ERß), which plays an important role in periodontal ligament cell function and proliferation (Jönsson et al., 2004; Liang et al., 2008; Mamalis et al., 2011; Wattanaroonwong et al., 2011). The periodontal ligament (PDL) is a connective tissue that bonds the cementum of the tooth to the alveolar bone. Collagen-producing PDL cells restore mineralized tissue and thus are essential in maintaining the structural and functional integrity of the periodontium. Human PDL cells have receptors for estrogen (ERß), which in turn has an inhibitory effect on bone-resorbing osteoclast formation in the periodontium (Wattanaroonwong et al., 2011). Fluctuations in estrogen levels during pregnancy may affect subsequent PDL cell proliferation and consequently periodontal integrity (Mamalis et al., 2011).

Changes in progesterone levels associated with pregnancy can make the subgingival microbiota significantly more anaerobic (Kornman & Loesche, 1982; Paropkari et al., 2016). Less well explored is how salivary sex hormones affect the supragingival microbiota, which also experiences an ecological shift in association with pregnancy. Recently, Lin et al. (2018) explored the bacterial diversity and ecological shifts in the supragingival plaques of pregnant women and observed it is highly correlated with the subgingival microbiota and may equally contribute to oral dysbiosis during pregnancy. Lin et al. (2018) posited that consistent with surges in progesterone and estradiol during the third trimester, pregnancy constructs an environment conducive to some bacterial strains including members of the *Neisseria* and *Poryphromonas* genera. Progesterone may also downregulate IL-6 production by gingival fibroblasts, resulting in gingival inflammation and bacterial proliferation (Lapp et al., 1995).

Other hormones associated with significant fluctuations during pregnancy have also been explored as possible contributors to PD in women. Parathyroid hormone, a calcitropic hormone responsible for calcium metabolism, decreases in early pregnancy. This is followed by a spike in the first trimester, a decline at the middle, and another rise towards the end of a pregnancy (Hameedi, 2017). Osteocalcin, an osteoblastic hormone, mirrors parathyroid hormone fluctuations throughout pregnancy with corresponding effects on bone-formation processes (Seki et al., 1991). Progesterone levels also are negatively associated with calcium levels in pregnant women (Hameedi, 2017).

*Fertility in prehistoric agricultural communities*

The Holocene is characterized in part by the substantial increase in human populations that occurred in a relatively small amount of time, markedly in areas that adopted agriculture (Larsen, 1995). Although the transition from foraging to farming is generally characterized by a decline in overall health (including a decline in skeletal robusticity and dental health), the archaeological record displays evidence of a "Neolithic demographic transition" (Ndt), wherein populations expanded in most agricultural communities throughout the world (Bocquet-Appel, 2002; Bocquet-Appel & Dubouloz, 2004; Bocquet-Appel & Naji, 2006). While population growth is apparent, sedentary settlement is also commonly associated with a reduction in mean age-at-death and high prevalence of skeletal lesions, often ascribed to nutritional deficiencies or infectious disease (Cohen & Armelagos, 1984). A decline in health and mean age-at-death coupled with an increase in population seems paradoxical, but many contend that this trend indicates an increase in fertility rather than an increase in mortality due to poor general health (Wood, 1992). In addition, the greater prevalence of skeletal lesions evidenced in agricultural samples could alternatively reflect enhanced resilience to illness and stress (Wood, 1992).

Multiple causes for an increase in fertility among sedentary agriculturalists have been proposed. Cultivation of domestic crops such as maize in the New World would not only increase the carrying capacity of the environment, but also result in lifestyle shifts leading to increased fertility (Lukacs, 2008). More dependable, higher calorie food supplies, a reduction in workload, and more readily available weaning foods would both increase the energy available to mothers and decrease the necessary weaning time. Fecundity (the biological potential for childbearing) can be sensitive to energetic stress, and even moderate energetic stress appears to suppress ovarian hormone levels (Ellison et al., 2012). With decreased mobility associated with an agricultural lifestyle and a carbohydrate-based, calorie-dense diet, women would likely be under less energetic stress and thus more fecund.

A shorter weaning period may also influence fertility by a reduction in interbirth intervals. Lactation suppresses ovulation and often has a contraceptive effect due to the results of lactational amenorrhea (Kennedy & Visness, 1992; WHO, 1999). However, variation in the contraceptive effect seems to be related to maternal energetic state. Research shows that maternal physiology acts to lower the chance of another conception when energetic investment in the current child is still high. Lactation is energetically expensive, and if the weaning age is decreased due to supplementation of weaning foods, the mother may return to a fecund state more quickly (Ellison, Bogin, & O'Rourke, 2012). Ethnographic comparisons with modern foraging societies show that they generally exhibit longer interbirth intervals (generally 3-4 years) and decreased fertility due to longer breastfeeding periods, higher mobility/activity level, and seasonal weight fluctuations with resource availability (Eshed et al., 2004; Hitchcock, 1982; Howell, 1979). In addition, higher rates of infant mortality (as experienced by early agricultural populations) can increase fertility by returning a mother to a fecund state after the loss of a breastfeeding child (Ellison, Bogin, & O'Rourke, 2012).

Given the complex interplay between reproductive hormones and the reproductive burden associated with burgeoning population growth among prehistoric agricultural groups, the cumulative effects of high fertility rates would differential affect women in these prehistoric communities. We therefore suggest that age and sex differences have the greatest impact on the expression of periodontal disease, which may be a function of high fertility. Here we apply a lifecourse approach to the measurement of periodontal disease in a prehistoric sample from the American Southwest to test this hypothesis.

**Materials and Methods**

The samples analyzed in this study were recovered from a series of archaeological sites associated with the Mogollon archaeological culture (Fig. 1). The Mogollon archaeological culture is associated with Ancestral Puebloan occupation of the rugged intermontane region of east-central Arizona and west-central New Mexico (Reid & Whittlesey, 1997). The Mogollon area is physiographically diverse with low valleys containing desert and grassland ecosystems and high elevations (~6,000 feet) characterized by large, Ponderosa pine forests and juniper/piñon woodlands (Reid, 2006; Woodbury, 1961). Although agriculture, particularly reliant on maize, was the foundation of their subsistence economy, a variety of local wild resources continued to provide an important role in the diet (Reid & Whittlesey, 1997; Woodbury, 1961).

The Pueblo Period of Mogollon development in Arizona began around A.D. 1100 with the transition from pit houses to masonry construction and

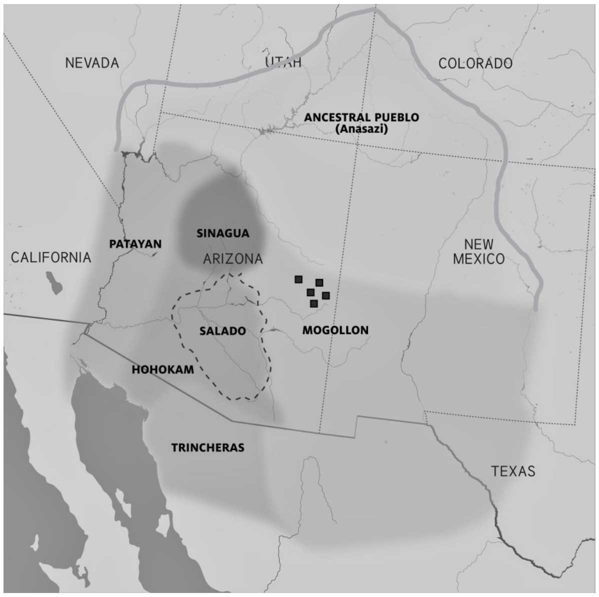


Figure 1. Map of Southwest US/Northwest Mexico with the Mogollon archaeological culture area defined by dashed line, and location of sites plotted (marked by squares). Map reproduced with permission from Arizona State Museum.

lasted until about A.D. 1400 when the pueblos were abandoned and populations became effectively archaeologically invisible (Reid & Whittlesey, 1997). This period is characterized by rapid population growth and nucleation into fewer, larger villages. Nucleation resulted in denser population concentrations within groups but larger distances between groups (Tuggle, 1970). As population densities increased, pueblo residents became more dependent on cultivated crops and relied less on foraging wild resources. Sometime around A.D. 1400, as most communities neared the maximum population density that could be supported by available agricultural technologies and exhausted their wild resources, Mogollon villages were largely abandoned. Environmental pressure was aggravated by several periods of drought, resulting in migration out of the region (Reid & Whittlesey, 1997; Tuggle, 1970). There is also evidence of significant economic and social tensions (Reid and Whittlesey, 1997).

Skeletal remains from five Mogollon sites were analyzed for evidence of periodontal disease. The sites include Point of Pines, Turkey Creek, Kinishba, King Ruin, and AZ:W:10:52(ASM), which represent a series of large, multi-room pueblos that emerged in the Mogollon region with occupations that ranged between A.D. 1225 to 1450 (East, 2008; Haury, 1989; Lowell, 1991; Welch, 2016). Together these samples represent a 225-year sequence of population growth, until social collapse, reorganization, migration, and partial abandonment of the Mogollon area. Based in successful agricultural adaptations, it is likely that a combination of environmental and social stressors led to eventual collapse. The demographic profile, including generally a higher infant mortality fits the curve proposed by Bocquet-Appel (2002) as representing high fertility populations and therefore make ideal samples to test the relationship between periodontal disease and sex across the lifecourse.

The Mogollon samples are part of the Bioarchaeology Collection at the Arizona State Museum (ASM), University of Arizona in Tucson, Arizona. Sex and age data were obtained from the Arizona State Museum Human Remains Database, estimated previously by ASM curators using macroscopic aspects of the pelvis and/or cranium for sex (Buikstra and Ubelaker, 1994), and macroscopic changes in the pubic symphysis (Buikstra & Ubelaker, 1994) and relative rates of dental attrition (Brothwell, 1989) for age. Individuals of indeterminate sex or age were excluded from the analysis.

Table 1 displays the distribution of samples by site, age, and sex. The 166 individuals were separated into five decadal age sets representing the sequence from late juvenile to senescence. We focused our analysis on the first permanent mandibular molar (M1) because periodontal disease differentially affects posterior teeth (Kerr, 1989) and the first molar is in occlusion the longest among the posterior teeth, thereby having the greatest potential for the expression of PD over the lifecourse. The remains were analyzed at the ASM by James Watson and Theodora Burbank and included 1) an inventory of teeth including antemortem loss, 2) recording occlusal surface wear (Wear) according

*Table 1. Archaeological samples used in analysis*

| Site | Sex | 15-20 | 20-30 | 30-40 | 40-50 | 50+ |
|---|---|---|---|---|---|---|
| Point of Pines | M | 1 | 9 | 9 | 3 | 1 |
| | F | 5 | 12 | 10 | 3 | 0 |
| Turkey Creek | M | 2 | 4 | 10 | 13 | 4 |
| | F | 2 | 5 | 9 | 11 | 6 |
| Kinishba | M | 3 | 5 | 7 | 0 | 1 |
| | F | 7 | 4 | 4 | 2 | 0 |
| King Ruin | M | 0 | 0 | 0 | 1 | 0 |
| | F | 0 | 1 | 1 | 1 | 0 |
| AZ:W:10:52 | M | 0 | 3 | 3 | 1 | 0 |
| | F | 0 | 2 | 0 | 1 | 0 |

to Scott (1979), 3) measuring distance of the alveolar crest (AC) from the cemento-enamel junction (CEJ) on the buccal surface of M1 (CEJ-AC) with a periodontal probe (Hu-Friedy UNC-15 color-coded periodontal probe), and 4) alveolar crest (AC) morphology according to Kerr (1988).

Independent samples *t*-tests are used to compare mean values for Wear, CEJ-AC, and AC and a Mann-Whitney U test to compare frequency of tooth loss between sexes. In addition, general linear modeling analysis (Gill, 2001)—with age as the covariate and sex as the grouping factor—compares mean values between sexes across age groups. All statistical procedures were performed using IBM SPSS Statistics for Windows, v25.0 (SPSS Inc., Chicago, IL., USA).

**Results**

Preliminary comparisons by sex identify significant differences in mean values, with females exhibiting higher rates of wear, deeper CEJ-AC depths, and more compromised alveolar crest morphology (Table 2). In addition, the Mann-Whitney U test indicates that tooth loss was greater for females (mean rank: 76.01) than males (mean rank: 91.55), $U$= 6537.0, $p$= .006.

Comparisons across age groups demonstrate the general age-related progression of periodontal attachment loss that is typical of the general trend in clinical studies (Billings et al., 2018; Eke et al., 2018). The results of the general linear modeling analysis show similar significant differences in tooth wear, alveolar crest depth, and alveolar crest morphology between males and females across age grades (Table 3). Figures 2-4 plot the means and 95% confidence intervals of each variable across age groups demonstrating similar patterns over the life course. Mean values are similar between males and females in the youngest age cohorts but begin to separate in the fourth and fifth decades of life, only to return to closer values in the final decade (s).

In addition to measurable attachment loss of the alveolar crest, tooth loss at M1 was significant. Tooth loss is again more pronounced among females compared to males in the middle decades of life; 30-40yo and 40-50 (Fig. 5).

**Discussion**

Our results support the hypothesis that periodontal disease can be measured across the lifecourse (using the proxy measurements observed here) and demonstrate that females suffered disproportionately from tooth and periodontal tissue loss. Periodontal attachment loss differed over the lifecourse; however, with both sexes experiencing similar (non-significant) periodontal tissue depths and morphology in the early age grades and experiencing significant increases after roughly age 30. Males appear to display a steady, age-related decline in periodontal tissue quality that only again approaches higher female levels in the oldest age

*Table 2. Results of independent samples t-tests for variables by sex*

| Variable | Sex | N | Mean | s.d. | *t* | *df* | Sig. |
|---|---|---|---|---|---|---|---|
| Wear | M | 80 | 3.59 | 1.17 | -4.682 | 164 | <0.001 |
| | F | 86 | 4.58 | 1.53 | | | |
| CEJ-AC | M | 80 | 2.11 | 1.21 | -3.695 | 164 | <0.001 |
| | F | 86 | 2.81 | 1.23 | | | |
| AC | M | 80 | 2.09 | 0.93 | -5.656 | 164 | <0.001 |
| | F | 86 | 2.94 | 1.01 | | | |

*Table 3. Results for general linear modeling by sex and age groups*

| Variable | Sex | 15-20 | 20-30 | 30-40 | 40-50 | 50+ | *F* | *df* | Sig. |
|---|---|---|---|---|---|---|---|---|---|
| Wear | M | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 31.030 | 2 | <0.001 |
| | F | 3.0 | 4.0 | 5.0 | 5.0 | 6.0 | | | |
| CEJ-AC | M | 1.0 | 2.0 | 2.0 | 2.0 | 3.0 | 20.659 | 2 | <0.001 |
| | F | 2.0 | 2.0 | 3.0 | 3.0 | 4.0 | | | |
| AC | M | 2.0 | 2.0 | 2.0 | 2.0 | 3.0 | 30.433 | 2 | <0.001 |
| | F | 2.0 | 3.0 | 3.0 | 3.0 | 4.0 | | | |

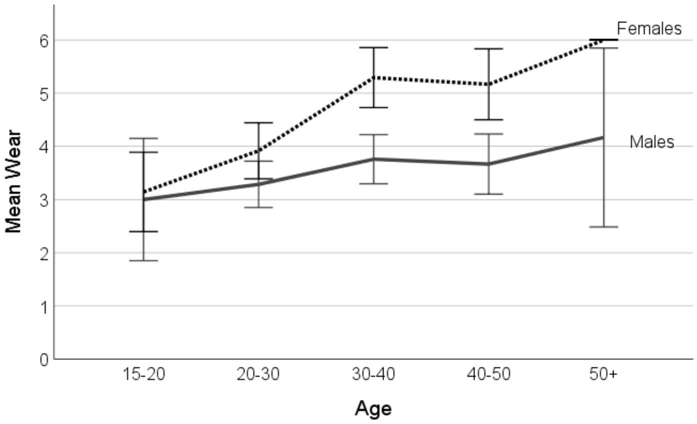


Figure 2. Mean wear score (from Scott, 1979) at M1 plotted by age groups for males and females. Error bars represent 95% confidence intervals.

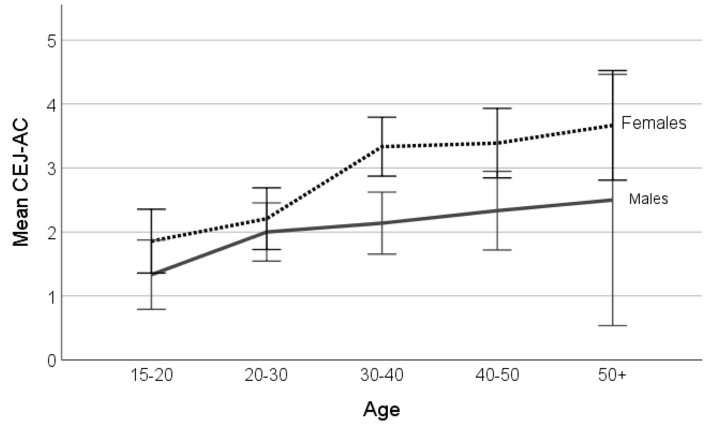


Figure 3. Mean distance (mm) from the cemento-enamel junction on the buccal surface of M1 to the alveolar crest plotted by age groups for males and females. Error bars represent 95% confidence intervals.

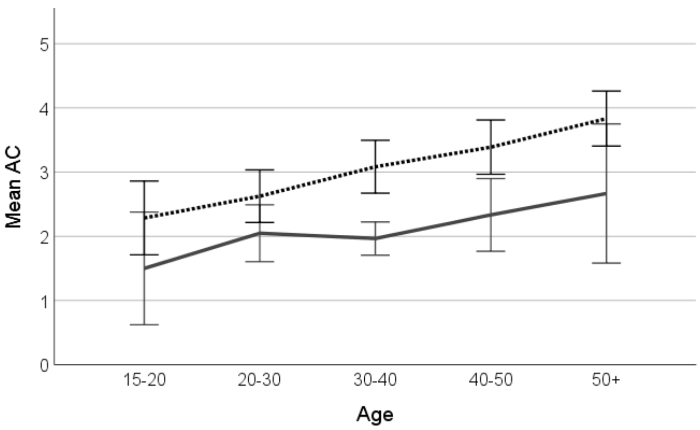


Figure 4. Mean alveolar crest morphology score (from Kerr, 1988) at M1 plotted by age groups for males and females. Error bars represent 95% confidence intervals.

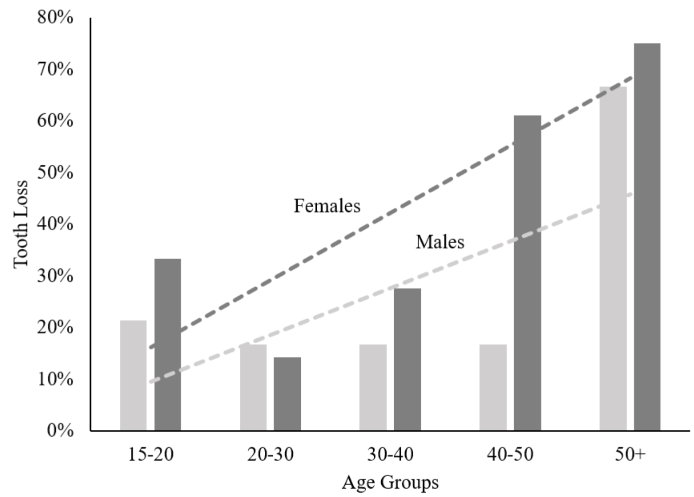


Figure 5. Frequency (%) of tooth loss at M1 plotted by age groups for males and females.

grade; and this is more related to greater variability in expression among males rather than a final spike in tooth and tissue loss. Significant differences between sexes from 30 to 50 years suggests an underlying biological phenomenon negatively affecting women's oral health.

We propose that hormonal fluctuations associated with reproduction and higher parity in prehistoric Mogollon communities are the cause of disparities in periodontal retreat and tooth loss between sexes. Tooth loss specifically can also result from dental caries, pulp exposure from heavy wear, and trauma; but the co-occurring trends observed in the data suggest inter-related processes contributing to tooth loss. It is likely that trends in caries frequency in the sample would mirror those observed in periodontal tissues but is beyond the scope of the current study. Tooth wear also appears to have played a role in destabilizing periodontal tissues through continuous eruption in response to heavy tooth wear. Yet, tooth wear also increases significantly in the interval from 30 to 50 years where female periodontal health incrementally declines compared to males and is perhaps exacerbated by tooth loss, loss of contact, and malocclusion.

Clinical and epidemiological research shows that the hormonal fluctuations associated with reproductive physiology play a substantial role in maintaining healthy periodontal tissues (Laine, 2002; Wu et al., 2015). Evidence from ethnographic accounts and the archaeological record suggests a general pattern of increased fertility with the adoption of agriculture in most areas (Bocquet-Appel & Naji, 2006; Eshed et al., 2004). Sedentism is associated with lifestyle changes that could critically impact fertility, including increased availability of energy-dense foods, decreased mobility, and shorter interbirth intervals (Ellison et al., 2012; Lukacs, 2008). A cariogenic diet reliant on maize undoubtedly played a crucial role in the overall decline in oral health observed in prehistoric agricultural populations of the Southwest US/Northwest Mexico. Dietary composition and high fertility likely led to an environment in which women experienced exacerbated oral pathology (Watson et al., 2009). This study contributes some insights into the oral health of women in prehistoric agricultural communities in Arizona.

The impact of pregnancy and reproduction has been largely avoided in archaeological literature, in part due to the difficulty associated with its study. While this study barely scratches the surface of the problem, it highlights a need to engage with life history theory and acknowledge the influences of reproductive life history on women's health in archaeological research. Although current medical and dental therapy place emphasis on improving the well-being of pregnant women and their unborn children (Jared & Boggess, 2008; Russell & Mayberry, 2008; Sanz & Kornman, 2013), data show that increased parturition is still related to increased tooth loss in a woman's lifespan (Christensen et al., 1998; Russell et al., 2008). This trend of increased tooth loss extends across cultural and socio-economic boundaries. It probably is related to the ongoing problem of untreated dental disease, which includes maternal periodontitis (Jeffcoat et al., 2001; Offenbacher et al., 1996).

Our results specifically demonstrate that cumulative effects among reproductive-age and post reproductive-age females caused disproportionate tooth and periodontal tissue loss. Hormone fluctuations associated with reproductive physiology play a substantial role in maintaining healthy periodontal tissues (Wu, Chen, & Jiang, 2015). Bacterial infection, chronic gingivitis and attachment loss cause the physical signs and symptoms of periodontal disease. However, this inflammatory destruction of the periodontium often is not accompanied by pain or altered function until advanced degrees of destruction. The penultimate outcome of the disease process is tooth loss, which can affect functionality and quality of life.

Periodontal 'health' is therefore best interpreted/conceptualized in bioarchaeological samples around the point that attachment loss destabilizes the tooth and results in loss and altered functionality. Although still stemming from a 'disease-focused' approach, we consider how functional occlusion plays a significant role in health. In addition, the pain and process involved in tooth loss and removal will significantly impact quality of life, followed by altered functionality and differential wear. This allows bioarchaeologists to relate past people's physical conditions to modern clinical and epidemiological understandings of health and pathology.

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# A Sub-Continent of Caries: Prevalence and Severity in Early Holocene through Recent Africans

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**Keywords:** dental caries, Africa, environment, sex, subsistence

*ABSTRACT* The most recognizable pathological condition of the human oral cavity is, arguably, dental caries. Beyond a direct impact on oral health, caries presence (or absence) provides important data for bioarchaeologists—to help reconstruct the diet of past populations and individuals. This study explores such data in 44 samples (n=2,119 individuals, 33,444 teeth) dating between 10,000 BP and recent times across the African sub-continent. It is, to date, the most extensive investigation of its kind in this part of the world, entailing descriptions and quantitative comparisons of caries by period, environment, subsistence strategy and sex.
Mann-Whitney U tests and factorial ANOVA results provide expected and some unexpected findings, including: 1) a diachronic increase in caries prevalence across the sub-continent, likely related to diet change from widespread population movement; 2) savanna peoples exhibit more caries than those from other environmental regions; 3) subsistence strategy plays a major role in caries occurrence; and 4) males and females do not evidence significant differences in caries frequencies, but variation does exist in several regional groups. These findings reveal that global trends described by previous researchers often apply, though not always—so it is prudent to consider regions independently.

Here we assess how dental caries frequencies differ by time period, sex, environment, and subsistence strategy among a range of populations across sub-Saharan Africa. Severity is also briefly discussed. Carbohydrate intake, adoption of agriculture, and behavioral and biological differences between the sexes and among populations all influence dental decay, so the latter can be highly informative (Turner, 1979; Newbrun, 1982; Larsen, 1997; Lukacs and Largaespada, 2006; Lukacs and Thompson, 2008). Yet, relatively few dental pathology studies have been conducted within this vast region (Irish, 1993). Those that have, focus largely on qualitative data or are small in spatiotemporal scope (Flower, 1889; Shaw, 1931; Frencken et al., 1986; Morris et al., 1987; Solanki et al., 1991; Sealy et al., 1992; Mackeowen et al., 1995; Steyn et al., 1998; Cleaton-Jones et al., 2000; Ohinata and Steyn, 2001; Pistorius et al., 2002; Steyn, 2003). The present study is much more comprehensive, covering the sub-continent from 10,000 years ago to present. At this large scale, the trends observed can work to support and/or refute those observed elsewhere in the world. The findings are discussed in terms of diet and other biocultural practices known to affect dental health.

The present study focuses on four research questions:

1) How did dental caries frequencies change through time? The samples were divided into Late Stone Age, Iron Age, or Recent. Each period was marked by a major shift in diet as new foods were introduced.

2) Is there a significant difference in caries between the sexes? The literature indicates a global trend for higher frequencies in females, particularly with the advent of agriculture (Caselitz, 1998; Lukacs and Largaespada, 2006; Lukacs, 2008; Lukacs and Thompson, 2008; Ferraro and Vieira, 2010). The present results will help test whether the trend holds in sub-Saharan Africa.

3) How do environmental differences affect the dental caries frequencies? Such differences limit what foods are present, so should have an influence. Samples are divided by the ecosystem from

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which they were derived: coastal, desert, savanna/ grassland, and tropical rainforest.

4) How does subsistence strategy affect the caries rates? Sub-Saharan Africans used a range of strategies to procure food, including hunting and gathering, pastoralism, and agriculture. Because diet is determined by subsistence strategy there should be an impact. To address this likelihood and place sub-Saharan African peoples in broader spatiotemporal context, samples from the current study are compared to Turner's (1979) meta-analysis of populations with different subsistence strategies.

**Materials and Methods**

Data on caries prevalence, as well as severity in some instances, were collected from 44 samples (n=2,119 individuals; 33,444 teeth, Table 1) throughout the African sub-continent by Irish during the course of his dental morphological research (1993, 1997). These samples date from ca. 10,000 BP to the 20th century.

The location and severity are recorded for each of the carious lesions present. Caries are ranked on a scale of 1 to 4, with 1 being a small pit that does not penetrate the enamel and 4 being pulp perforation (Buikstra and Ubelaker, 1994). Location is designated as mesial, distal, buccal, occlusal, lingual or a combination in the event of large or multiple lesions. Sex was determined as M, M?, ?, F, F? by the second author using standard methods (e.g., Buikstra and Ubelaker, 1994). Only adults (i.e., ≥18 years of age) were included in the analyses.

Lukacs' (1992, 1996) caries index was calculated to adjust for antemortem tooth loss (AMTL):

$$\frac{\text{(AMTL) (\% teeth with severe caries) + (teeth with caries)}}{\text{(teeth present) + (AMTL)}}$$

This method takes into account the number of teeth present with pulp exposure (severity level 4) due to dental caries. The present study compares the percentage of teeth with carious lesions; therefore, results could be skewed if AMTL were not accounted for, since many teeth are removed due to toothache resulting from serious carious lesions or abscesses (Lukacs, 1996).

The caries data were compared using three common statistics. First, Mann-Whitney U tests were used to compare the percent of teeth with carious lesions for the four major categories of independent variables (i.e., period, sex, environment, subsistence). Second, factorial ANOVA accounted for significant differences among subsistence strategy, environment, time period, between- sex, or any combination of these four on the dependent variable (percentage of teeth with caries per individual). The null hypothesis of consistency was tested, followed by a series of post hoc tests (i.e., Tukey) to identify significance between all combinations of the independent variables. Lastly, the Spearman's Rho correlation coefficient was used to simply determine any relationship between attrition and caries. Higher levels of wear should correlate with fewer caries because normal attrition wears away the tooth surface before caries can form (Brothwell, 1963; Scott & Turner, 1988; Hillson, 1996; Caselitz, 1998).

**Results**

The Mann-Whitney U (Table 2) and Tukey (Table 3) test results show a statistically significant difference ($p<0.05$) for each pair of time periods. The factorial ANOVA found time period to be a significant factor for caries counts with a value of 0.005 (Table 4)

Mann-Whitney U (see Table 2), Tukey (see Table 3) and factorial ANOVA (see Table 4) tests show no statistically significant values for caries frequency differences between the sexes. However, the bar graph (Figure 2) does display a general trend of females with more carious lesions—at least for the Late Stone Age (LSA) and Iron Age samples. In the Recent samples males and females have equal percentages; the only significant difference is among pastoralists (not shown).

ANOVA (see Table 4) results show that environment has a significant impact on caries for the LSA (0.000), Recent (0.009), and Combined groups (0.004). The Mann Whitney U (see Table 2) results reveal no significant difference among environments in terms of caries counts for the Iron Age samples, but some differences do exist for LSA and Recent samples. Tukey (see Table 3) results show significant difference only among the LSA samples. Figure 2 illustrates the different counts of affected individuals for each environment category. Not all environmental categories are represented by time period; as such, some effect on results may occur and these should be interpreted with caution.

Factorial ANOVA (see Table 4) results suggest that subsistence contributes to caries counts for the Recent samples (0.060) and all periods combined (0.000). Outcomes from the Mann-Whitney U (see Table 2) and Tukey (see Table 3) tests show a difference between hunter/gatherers and pastoralists among the LSA samples (0.043) and hunter/ gatherers and agriculturalists when all periods are

*Table 1. Summary of samples including the current country the sample was collected from, the environment, time period, and subsistence strategy category the sample was found to best fit with, and the number of individuals from each sample.*

| Code | Full Name | Country | Environment | Time Period | Subsistence | n |
|---|---|---|---|---|---|---|
| ADR | Adrar Bous | Niger | Savanna | Late Stone Age | pastoralism | 10 |
| CHA | Chad | Chad | Savanna | Recent | pastoralism | 31 |
| CON | Congo | Congo | Tropical Rain Forest | Recent | agriculture | 34 |
| DBI | Republic of the Congo | Congo | Tropical Rain Forest | Iron Age | agriculture | 20 |
| DCB | Lower Congo | Congo | Tropical Rain Forest | Recent | agriculture | 27 |
| DCH | Upper Congo | Congo | Tropical Rain Forest | Recent | agriculture | 24 |
| DCR | Democratic Republic of Congo and Ruanda | Democratic Republic of the Congo | Tropical Rain Forest | Recent | agriculture | 72 |
| ETH | Ethiopia | Ethiopia | Savanna | Recent | agriculture | 40 |
| FVR | Fernand Vaz River | Fernand Vaz | Tropical Rain Forest | Iron Age | agriculture | 50 |
| GAB | Gabon | Gabon | Tropical Rain Forest | Recent | agriculture | 39 |
| GHA | Ghana | Ghana | Tropical Rain Forest/ Savanna | Recent | agriculture | 48 |
| HAY | Haya | Tanzania | Savanna | Recent | agriculture | 51 |
| IBO | Ibo | Nigeria | Tropical Rain Forest/ Savanna | Recent | agriculture | 54 |
| KEN | Kenya | Kenya and Tanzania | Savanna | Recent | agriculture | 96 |
| KHE | Holocene Early Kenya | Kenya | * | Late Stone Age | hunter/gatherers | 80 |
| KHOI | Khoikhoi | South Africa | Desert | Recent | pastoralism | 56 |
| KKU | Kikuyu | Kenya | Savanna | Recent | agriculture | 60 |
| KHL | Rumuniti in Vaso Narok Va-lley | Kenya | * | Late Stone Age | * | 69 |
| MAT | Matjes River Cave | South Africa | Coast | Late Stone Age | hunter/gatherers | 51 |
| NDB | Ndebele | | Savanna | Recent | pastoralism | 38 |
| NGO | Ngorongoro | Tanzania | Savanna | Late Stone Age | * | 26 |
| NGU | South Africa | South Africa | Savanna | Recent | agriculture | 35 |
| NIC | Nigeria/Cameroon | Nigeria and Cameroon | Tropical Rain Forest/ Savanna | Recent | agriculture | 54 |
| NLT | Nilotic | Kenya and Tanzania | Savanna | Recent | pastoralism | 24 |
| PYG | Pygmy | Congo, Gabon, and Bot-swana | Tropical Rain Forest | Recent | hunter/gatherers | 34 |
| SAN | San | Botswana and South Afri-ca | Desert | Recent | hunter/gatherers | 52 |
| SEN | Senegambia | Senegal and Gambia | Tropical Rain Forest/ Savanna | Recent | agriculture | 42 |
| SHO | South Africa | South Africa | * | Recent | hunter/gatherers | 85 |
| SML | Shum Laka | Cameroon | Savanna | Late Stone Age | hunter/gatherers | 10 |
| SOM | Somalia | Somalia | Desert | Recent | pastoralists | 77 |
| SOT | Sotho | South Africa | Savanna | Recent | agriculture and pastoralism | 66 |
| SPH | South Africa | South Africa | * | Iron Age | hunter/gatherers | 70 |
| SWZ | Swazi | South Africa | * | Recent | agriculture | 58 |
| TAN | Tanzania and Zanzibar | Tanzania | Savanna | Recent | agriculture | 45 |
| TEI | Taita | Kenya | Savanna | Recent | agrictulure | 51 |
| TOD | Togo and Dahomey | Togo and Benin | Tropical Rain Forest/ Savanna | Recent | hunter/gatherers | 26 |
| TSW | Tswana | Botswana and South Afri-ca | Desert | Recent | hunter/gatherers | 63 |
| TUK | Tukulor | Senegambia | Savanna | Recent | agriculture | 40 |
| UPB | Upemba Valley | Democratic Republic of the Congo | Tropical Rain Forest | Iron Age | agriculture | 56 |
| VEN | Venda | South Africa | Savanna | Recent | agriculture | 51 |
| WOL | Wolmarnstad | South Africa | Grassland | Recent | agrictulre | 26 |
| XOS | Xosa | South Africa | Savanna | Recent | agriculture | 66 |
| YOR | Yoruba | Yoruba | Tropical Rain Forest/ Savanna | Recent | agriculture | 28 |
| ZUL | Zulu | South Africa | Savanna | Recent | pastoralism | 66 |

* information not available

*Table 2. Results of Mann-Whitney U tests*

| Variable | Groups | Significance* LSA | Iron Age | Recent | Combined |
|---|---|---|---|---|---|
| **Time Period** | LSA & Iron Age | n/a | n/a | n/a | 0.003 |
| | LSA & Recent | n/a | n/a | n/a | <0.001 |
| | Iron Age & Recent | n/a | n/a | n/a | <0.001 |
| **Sex** | Male & Female | 0.113 | 0.113 | 0.564 | 0.803 |
| **Environment** | Desert & Savanna | 0.942 | n/a | 0.016 | 0.625 |
| | Desert & Rainforest | 0.127 | n/a | 0.84 | 0.771 |
| | Desert & Coastal | 0.397 | n/a | n/a | 0.206 |
| | Savanna & Rainforest | <0.001 | 0.226 | 0.007 | 0.842 |
| | Savanna & Coastal | 0.018 | n/a | n/a | 0.131 |
| | Rainforest & Coastal | 0.031 | n/a | n/a | 0.162 |
| **Subsistence** | Hunting/Gathering & Pastoralism | 0.043 | n/a | 0.546 | <0.001 |
| | Hunting/Gathering & Agriculture | n/a | n/a | 0.975 | <0.001 |
| | Pastoralism & Agriculture | n/a | 0.51 | 0.134 | 0.654 |

*significant at p<0.050

*Table 3. Tukey results*

| Variable | Groups | Significance* LSA | Iron Age | Recent | Combined |
|---|---|---|---|---|---|
| **Time Period** | LSA & Iron Age | n/a | n/a | n/a | 0.057 |
| | LSA & Recent | n/a | n/a | n/a | <0.001 |
| | Iron Age & Recent | n/a | n/a | n/a | 0.041 |
| **Sex** | Male & Female | 0.295 | 0.415 | 0.327 | 0.5 |
| **Environment** | Desert & Savanna | 0.965 | n/a | 0.156 | 0.941 |
| | Desert & Rainforest | <0.001 | n/a | 0.538 | 0.583 |
| | Desert & Coastal | 0.607 | n/a | n/a | 0.639 |
| | Savanna & Rainforest | <0.001 | n/a | 0.682 | 0.679 |
| | Savanna & Coastal | 0.255 | n/a | n/a | 0.424 |
| | Rainforest & Coastal | <0.001 | n/a | n/a | 0.243 |
| **Subsistence** | Hunting/Gathering & Pastoralism | n/a | n/a | 0.323 | 0.002 |
| | Hunting/Gathering & Agriculture | n/a | n/a | 0.752 | <0.001 |
| | Pastoralism & Agriculture | n/a | n/a | 0.236 | 0.125 |

*significant at p<0.050

*Table 4. Factorial ANOVA results*

| Variable | LSA | Iron Age | Re-cent | Combined |
|---|---|---|---|---|
| **Time Period** | n/a | n/a | n/a | 0.349 |
| **Sex** | 0.082 | 0.675 | 0.708 | 0.836 |
| **Environment** | <0.001 | 0.609 | 0.009 | 0.004 |
| **Subsistence** | n/a | 0.789 | 0.069 | 0.037 |

*significant at p<0.050

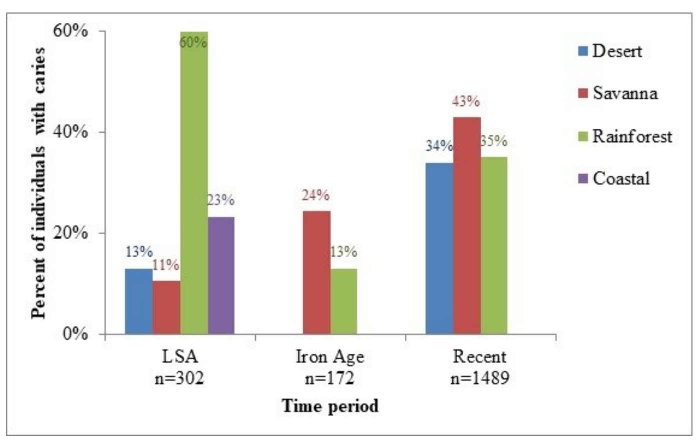


Figure 2. Percent of individuals affected by caries for each environment category in LSA, Iron Age, and Recent sub-Saharan African samples. See text for details.

combined (0.000). There is no significant difference in caries number between pastoralists and agriculturalists for any time period. Figure 3 visually represents the differences between subsistence strategies by time period.

Lastly, the correlation between wear and caries prevalence was calculated using Spearman's Correlation Coefficient. The correlation of 0.012 indicates a very weak, yet positive relationship. An insignificant p-value of 0.400 was calculated.

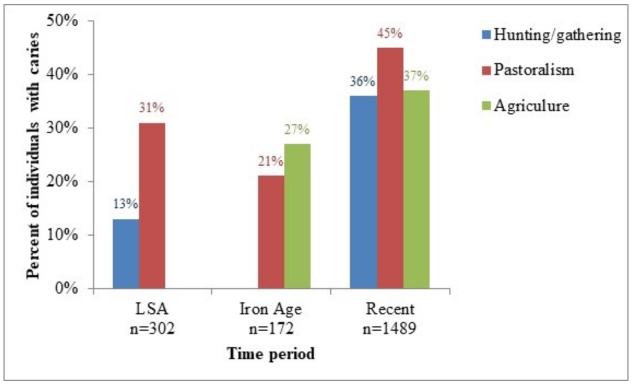


Figure 3. Percent of individuals affected by caries for each subsistence strategy in LSA, Iron Age, and Recent sub-Saharan African samples. See text for details.

## Discussion

*1) Did caries frequencies change through time?*
Results show a definite increase in caries rate through time. Many new crops were introduced through time that may have had an impact. Asian sugarcane and bananas appeared as early as the Iron Age and via the Portuguese in the 17th century (Frencken et al., 1989; Irish and Turner, 1997). Sugarcane has a negative impact on health not only because of high sucrose levels but because of the manner in which it is eaten, which causes severe crown wear (Dreizen & Spies, 1952; Frencken et al., 1989; Irish & Turner, 1997). Bananas and plantains, both a significant crop in central and eastern Africa (Ehret, 2002), are moderately cariogenic due to their sticky and sugary structure (Mundorff-Shrestha et al., 1994; Aurore et al., 2008).

Several cariogenic crops from the Americas were also introduced, including maize and cassava (Larsen et al., 1991; Hillson, 1996; Ehret, 2002); most did not become widespread until the 18th century, which may account for the rise in caries between the Iron Age and Recent samples (Ehret, 2002). Overall, these soft, often sticky high carbohydrate foods are much more cariogenic than the traditional African diet (Hillson, 2008).

*2) Is the rate of caries higher among females than males?*
All tests suggest that an individual's sex did not significantly contribute to the caries frequencies; that said, an examination of the bar chart (Figure 1) reveals a general trend for higher frequencies in females. A common explanation for the disparity is that females collect, prepare and consume more cariogenic foods than do males (Mulder, 1992). Other potential causative factors include genetic and hormone differences; all are said to be accentuated in agriculturalist groups (Lukacs and Largaespada, 2006; Lukacs, 2008), though this is not evident in the present African samples—for reasons we are continuing to investigate.

*3) Are there environmental differences in the caries frequencies?*
Observing patterns is difficult because not all environmental groups are present by time period. In the Iron Age and Recent periods, caries are more prevalent among those on the savanna. Many of them would have relied on grain foods or pastoralism, i.e., the latter peoples often trade with agriculturalists for grains made into sticky porridge (Forde & Jones, 1950; Skinner, 1973). The naturally high cariogenicity of corn and wheat (Dodds, 1960; Okazaki et al., 2013) combined with the sticky nature of the grain porridge potentially contributes to higher instances of caries in savanna dwellers.

A high caries percentage (23%) occurs in coastal LSA samples. Coastal peoples generally have fewer caries because of grit and fluoride from marine foods (Walker & Erlandson, 1986). Sealy et al. (1992) report similar results with the Oakhurst sample from the Southern Cape. Contradictory to their results with other coast dwellers, where only 2.6% of teeth exhibit caries, 17.7% of teeth from Oakhurst are affected, despite a diet rich in marine resources; the authors state that the explanation for the high rate is the lack of fluoride in local ground water.

*4) Does subsistence strategy affect dental health?*
The results obtained by factorial ANOVA suggests that subsistence strategy is a contributing factor to caries counts when all time periods are combined. No clear pattern is evident in the bar chart (Figure 3), perhaps because not all strategies are present by period. However, the high rate for Recent pastoralists is interesting. As noted, pastoralists eat grains plus milk and other animal byproducts (Forde &

Jones, 1950; Skinner, 1973). As well, many Recent pastoralists are actually agro-pastoralists (Krige & Krige, 1954; Skinner, 1973; Zeleza, 1997). Grain porridge combined with maize apparently had a negative impact on dental health (Larsen et al., 1991; Scherer et al., 2007). Cassava would also be a starch source (Ehret, 2002) that prevents carbohydrates being cleaned away to give bacteria more time to feed (Lingstrom et al., 1989, Larsen, 1997; Hillson, 2008).

A comparable caries percentage is evident in the Recent hunter/gatherers and agriculturalists. Perhaps this similarity is related to the fact that modern hunter-gatherers, like the San, are not limited to this lifestyle as they once were. After the arrival of Europeans, many Khoisan worked on farms, where they ate crop- rather than wild foods (Reader, 1997; July, 1998). Modern pygmies also often rely on agriculturalists for trade (Afolayan, 2000). The increase in domesticated foods apparently caused both groups to have caries rates like those of agriculturalists.

Relative to Turner's (1979) analysis of different economies, the sub-Saharan results are complementary. He reports 0.0-5.3% for hunter/gatherers; the sub-Saharan LSA samples fall within this range (2%), but not for recent hunter-gatherers (8%). Most of Turner's samples are from early archaeological sites, so were generally not influenced by an agricultural diet. Recent hunter-gatherers fall within Turner's range for mixed economies (0.4-10.3%), which is likely a more adequate descriptive category. Sub-Saharan pastoralists (5-7%) fall within the mixed economy category, and the agriculturalists (4.0-7%) fit Turner's agriculturalist category (2.3-26.9%).

Finally, caries severity was only recorded in 469 of the total 2119 dentitions; thus, on that basis the Spearman's Rho value of 0.012, though positive, is only very weakly correlated, i.e., essentially random. These results suggest here that while of interest individually, such data may be less useful in a broader study.

**Conclusions**

Statistically significant differences in dental caries frequencies have been observed between time periods, environmental groups, and subsistence strategies among 44 sub-Saharan African samples. The introduction of new foods through time, regional specializations, and food collecting strategies have been found to potentially affect dental decay. The results from the current study imply that cultural differences can have major implications for dental health.

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# Periodontal Disease and "Oral Health" in the Past: New Insights from Ancient Sudan on a Very Modern Problem

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**Keywords:** Periodontal disease, Kerr method, interdental septum, Sudan, bioarchaeology

*ABSTRACT* As one of today's major oral health issues, periodontal disease affects populations worldwide. Here, methods used to record its past prevalence are reviewed, indicating that clinical and bioarchaeological research offers strong support for the Kerr method, recording morphological changes of the interdental septum as a means of identifying periodontal disease. Using Kerr's approach, four assemblages from Sudan dating from the Neolithic, Kerma, and Medieval periods are examined to track the prevalence of the disease through time. Results show a significantly lower prevalence and limited oral distribution of periodontal disease in the Neolithic period. At Medieval period sites, significantly higher prevalence is seen with increasing age in male individuals, which is not seen in females. With no patient history and the cumulative effects of a dynamic and episodic disease, the effects of periodontal disease on the concept of 'oral health' may be hard to apply in archaeological remains. At best it provides an insight into the periodontal status at death - a 'snapshot' that reveals differences across the mouth, over time and between sexes in these Middle Nile Valley collections, giving insight into periodontal status in this region and advancing current understanding of the history of periodontal disease.

Today, periodontal disease is a major health issue worldwide, with the World Health Organisation (WHO) reporting it as the eleventh most prevalent disease in the world (Global Burden of Disease, 2017). Periodontal disease is the inflammation of the gingival (gum) tissues leading to destruction of the supporting soft and hard tissues of the teeth. It is one of the foremost causes of tooth loss and without access to dentures or dental implants edentulism can become a huge problem (Petersen et al., 2005). Recent investigations show that both gingivitis (the inflammation of the gums) and periodontal disease (Global Burden of Disease, 2017) are highly prevalent. In nearly every region of the globe, the Community Periodontal Index (CPI), aimed at monitoring periodontal health, shows that 40-60% of 35-44 year olds have small or large periodontal pockets (CPI scores 3 or 4), due to inflammation, loss of attachment of the gingivae and possible bone loss. This is accompanied by a 35-60% gingivitis prevalence (CPI scores 1 and 2; [Global Burden of Disease, 2017, p. 2189]). Gingivitis is also found to be highly prevalent in adolescents between the ages of 15-19 (Global Burden of Disease, 2017; Petersen et al., 2005). Periodontal disease, its distribution and effects on systemic - as well as oral - health, are a current and global concern (Barnett, 2006; Bawadi et al., 2011; Geethika & Chava, 2016; Hajishengallis & Korostoff, 2017; Hujoel & Lingström, 2017; P. Petersen & Ogawa, 2012). Bioarchaeological methods can be used to explore the prevalence of this disease in past populations and, as shown here, provide new data on Nile Valley archaeological collections against which modern prevalence and distribution rates can be compared. This new study investigates if the Kerr method (Kerr, 1988), which has seldom been applied to archaeological assemblages, is an appropriate method to record periodontal status. It also assesses differences in the prevalence of periodontal diseases between the Neolithic and Medieval periods in the Middle Nile, if these results vary by sex and age and how this study compares to published data from other archaeological assemblages and modern populations. Few large-scale bioarchaeological studies of periodontal disease in the Nile valley have been published and this study adds to our understanding of its past prevalence in a manner that accounts for the variable preservation of archaeological collections, allowing comparisons with modern clinical data.

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## Materials

The Nile Valley offers some of the largest pre-modern cemetery collections found in Africa (Friedman, 2007; Irish, 2010; Salvatori & Usai, 2008b). Large skeletal assemblages from a range of time periods were recently recovered in Sudan (Welsby, 2003), several of which were generously donated by Sudan's National Corporation for Antiquities and Museums and are currently curated at The British Museum. These include two large Medieval burial sites from the Fourth Cataract region of the Middle Nile Valley (Figures 1 and 2) dating to the Medieval (c. AD 550 -1500 – site 3-J-23) and the Late Medieval (c. AD 1100-1500 – site 3-J-18) periods. Preservation is excellent at both sites, including some remarkable examples of natural mummification, providing insights into the state of periodontal disease in pre-industrial Northeastern Africa. The older sites of H29 (*Kerma Ancien* - 2050-1750 BC) and R12 (Neolithic - 3500 BC) were also included to explore the progression of the disease over time and contextualise the data gathered within the wider temporal framework. Despite poorer preservation at the earlier sites, a reasonably high number of individuals were analysed for evidence of periodontal disease (Table 1). Table 2 shows the number of individuals included in the study by sex and age group. Both Medieval sites had proportionately different numbers of males and females in each age category. At 3-J-23 a greater number of females were assigned to the young adult category (n=22). At 3-J-18 a greater proportion of males were assigned to the middle adult category (n=31). Sites H29 and R12 had roughly equal numbers in each sex and age group. Where results have been divided by age and sex it should be noted that adolescents have been grouped into the young adult category while old adults have been grouped with middle adults. Sex estimations of probable female and female have been grouped together, as have probable male and male individuals. These grouping meant that the numbers involved were larger and more representative of the whole.

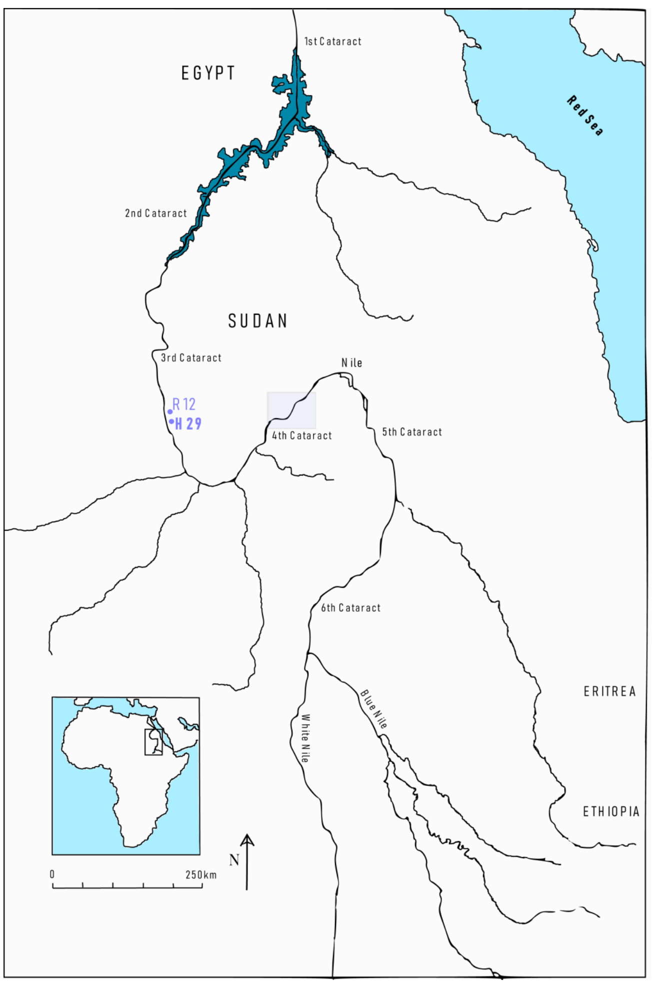


Figure 1: Map of the Nile Valley, from the First Cataract to south of the confluence of the White and Blue Niles, demonstrating the location of sites H29 and R12. The region of the 4th Cataract, including sites 3-J-18 and 3-J-23, is also highlighted within the box and is shown in greater detail in Figure 2.

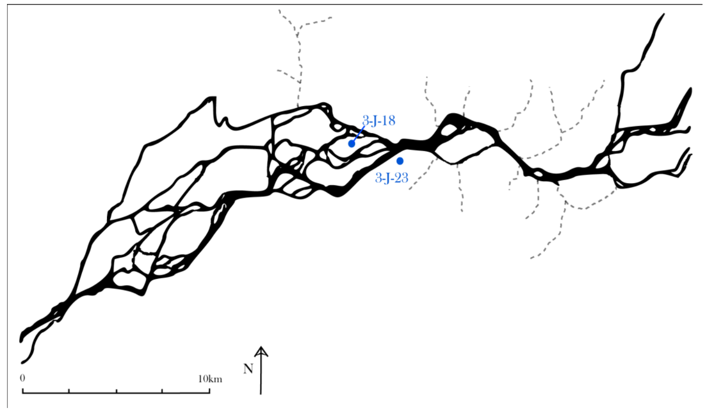


Figure 2: Map of the Fourth Cataract region, with the location of sites 3-J-18 and 3-J-23 shown. Original image copyright of A. Davies-Barrett.

*Table 1. Sites included in the current study, number of individuals and time period for each site are given*

| Sites | n | Time period |
|---|---|---|
| 3-J-18 | 111 | Late Medieval (AD1100-1500) |
| 3-J-23 | 69 | Early Medieval (AD500-1000) |
| H29 | 62 | *Kerma Ancien* |
| R12 | 70 | Neolithic |
| Total | 312 | |

*Table 2. Age and sex distributions for each site*

| Site | | Adolescent | Young Adult | Middle Adult | Old Adult | Unknown Age | Total |
|---|---|---|---|---|---|---|---|
| R12 | Male | - | 4 | 6 | - | 12 | 22 |
| | Female | 1 | 4 | 3 | - | 3 | 11 |
| | Indt. sex | - | 2 | 2 | - | 33 | 37 |
| | **Total** | **1 (1.4%)** | **10 (14.3%)** | **11 (15.7%)** | **- (0.0%)** | **48 (68.6%)** | **70** |
| H29 | Male | - | 8 | 9 | - | 2 | 19 |
| | Female | - | 10 | 6 | - | 12 | 28 |
| | Indt. sex | 2 | 2 | 1 | - | 10 | 15 |
| | **Total** | **2 (3.2%)** | **20 (32.2%)** | **16 (25.8%)** | **- (0.0%)** | **26 (38.8%)** | **62** |
| 3-J-23 | Male | 1 | 10 | 13 | - | 1 | 25 |
| | Female | 2 | 20 | 10 | - | 1 | 33 |
| | Indt. sex | 2 | 3 | 3 | - | 3 | 11 |
| | **Total** | **5 (7.2%)** | **33 (47.8%)** | **26 (37.8)** | **- (0.0%)** | **5 (7.2%)** | **69** |
| 3-J-18 | Male | - | 15 | 30 | 1 | 1 | 47 |
| | Female | 6 | 23 | 21 | 2 | 3 | 55 |
| | Indt. sex | 1 | 5 | 1 | - | 2 | 9 |
| | **Total** | **7 (6.4%)** | **43 (38.7%)** | **52 (46.8%)** | **3 (2.7%)** | **6 (5.4%)** | **111** |

These skeletal collections provide a unique opportunity to investigate periodontal disease in groups from a range of environmental, social, and cultural backgrounds. The Neolithic period in Nubia was characterised by semi-nomadic pastoralism combined with hunting and gathering (Bard, 2008; Gautier & Van Neer, 2011; Hassan, 1986; L. Krzyżaniak, 2004; Wengrow et al., 2014). Increasing social complexity may have led to a range in craftsmanship, much of which could have involved the use of the mouth and dentition (Haaland, 1987; A. Krzyżaniak, 2011; Salvatori & Usai, 2008a). During the Kerma period, small sedentary groups appear to have formed and there is evidence for urbanisation and socioeconomic centralisation at the town of Kerma (Bonnet, 2004, 2010; Chaix & Grant, 1992). Pastoralism remained an important part of cultural practice and was also accompanied by an increase in the cultivation of crops (Chaix, 1984, 2007; Grant, 2002; D. Welsby, 1996). During the Medieval period settlements consisted of larger rural and urban groups, with centralised socioeconomic control, in particular as part of the Kingdom of Makuria in Upper Nubia (Godlewski, 2010; D. Welsby, 2002; D. Welsby & Daniels, 1991).

There is also a pattern of increasing aridity across the Saharan region from the Middle Holocene (5000 BC) onwards (Kuper & Kröpelin, 2006; Kuper et al., 2007; Macklin & Woodward, 2001; Welsby, Macklin, & Woodward, 2002). Before and during the Neolithic, shifting rain-belts and higher humidity meant that Upper Nubia was a savannah-like environment and swamps and marshes may have been present, particularly in the areas surrounding the river, with paleochannels running into and around the main tributary of the Nile. This wetter environment underwent progressive desertification and, by around 1500 BC, was similar to the desert landscape of modern northern Sudan (Kuper & Kröpelin, 2006, p. 806). The sites examined here represent a range of ecological niches. 3-J-18 was located on Mis Island, within the rocky and changeable land of the Fourth Cataract, and nearby 3-J-23 was situated on the banks of the Nile (Thomas, 2008; Welsby, 2003, 2012). Both H29 and R12 were in the Northern Dongola Reach, further downstream than the Fourth Cataract, after the Nile turns north towards the Third Cataract. Site H29 was between the Alfreda and Hawawiya Niles (paleochannels) (Welsby, 2001; Whiting, 2018) and R12 at the southern end of the Seleim basin – a natural basin where water collected during high flood and rain fall (Salvatori & Usai, 2008b). Differing environmental pressures and socio-cultural practices may have influenced the disease status, immune responses, behaviour, and diet of the individuals living in these different areas of the Middle Nile, which may have led to differences in the prevalence rate of periodontal disease. These collections allow for valuable comparisons at key points in time that may reveal shifts in 'oral health' and disease load. Results will also be compared with similar studies from around the globe, further aiding our modern understanding of the social, environmental and biological factors that affect susceptibility to periodontal disease and changes to the state of oral health over time.

***Clinical and anthropological background***

Periodontal disease is the result of the body's immune response to the long-term presence of large numbers of microorganisms in dental plaque deposits on the teeth. It is a hypersensitive reaction in which the immune response damages the tissues of the periodontium. In their seminal paper, Page and Schroeder (1976) described the four stages of periodontal disease as they were understood at the time, the main notions of which are still relevant to this day:

> The *initial lesion* is described as inflammation and vascularisation involving infiltration of neutrophils (elements of the immune system) through the gingival tissue to the junctional epithelial cells lining the periodontal pocket (the periodontal pocket is formed around the tooth as the supporting tissues are destroyed). This is accompanied by movement of other immune elements such as T-cells, into the area but few B-cells.
>
> The *early lesion* sees a change to macrophage and T-cell domination with lymphocyte proliferation and the beginnings of a loss of connective tissue, such as the periodontal ligament.
>
> The *established lesion* involves further collagen (connective) degradation, detachment of the periodontal ligament and a clear increase in B-cell involvement.
>
> The *advanced lesion* is associated with alveolar bone loss and a further increase in B-cell proliferation.

The authors also noted that the apical extension of junctional epithelial cells leads to an extension/ expansion of the periodontal pocket, and that a susceptible host was necessary for the progression of the disease at all stages. As observed by Hajishengallis and Korostoff (2017), these concepts are still correct and relevant today. Advances since Page and Schroeder's original paper include an increased understanding of the interaction of the innate and acquired immune system, as well as a greater appreciation of the role and "functional plasticity" - or changeability of the role - of neutrophils in the initiation of the immune response and progression to periodontitis (Hajishengallis & Korostoff, 2017, p. 119). This latter point highlights the importance of neutrophil homeostasis, with the related immunodeficiency or the overstimulation of these cells leading to destructive periodontitis (Cekici et al., 2014; Kornman, Page, & Tonetti, 1997). Since Page and Schroeder's work, a clearer understanding of the interactions and synergism of episodes of immune response and bone formation and resorption has also been made – a field known as osteoimmunology. This has shown that T-cells and B-cells express RANKL (signalling protein) that contribute to the process of osteoclastogenesis, tipping the balance of bone homeostasis towards resorption (Kikuta et al., 2013). Many advancements in the understanding of this disease process were set out in a series of papers penned in part by one half (Page) of the original duo of Page and Schroeder (Darveau, Tanner, & Page, 1997; Dennison & Dyke, 1997; Kornman et al., 1997). These subsequent papers highlight the dynamic nature of the disease as it goes through periods of progression and healing, with destructive lesions developing early on in life in some cases, or much later in others, and the role of host susceptibility in its progression.

Clinical methods used to record and monitor periodontal disease and gingivitis have changed little over the past decades. The study by Belting, Massler, and Schour (1953), of over 5000 men from Chicago, measured the distance between the cemento-enamel junction (CEJ) and the alveolar crest (AC) using a dental probe to determine the point of alveolar attachment within the periodontal pocket. A measurement of >2mm was deemed to indicate bone loss resulting from periodontal disease. Additionally, gingival inflammation was recorded as bleeding/ presence of pus in the periodontal pocket. The World Health-Organization (2013) published a similar method to establish periodontal health that utilises the same kind of dental probe. Gingival bleeding was scored as 0 (none) or 1 (bleeding upon insertion of probe), while periodontal pocket depth was assessed in increments: 0 (absence <3.5mm), 1 (4-5mm depth), 2 (≥6mm depth) (World-Health-Organization, 2013, pp. 48-50). This clinical approach is commonly used to diagnose periodontal disease in both humans and animals (Björnsson et al., 2003; Person, 1961; Tilakaratne et al., 2000; von Wowern, Klausen, & Kollerup, 1994; Watson, 1994). Radiography has also been used to determine alveolar resorption. Papapanou, Wennström, and Gröndahl (1988) looked for both 'horizontal' and 'vertical' bone loss. Horizontal bone loss refers to the loss of height in the alveolar crest while maintaining a normal periodontal ligament space between root and socket. Vertical bone loss denotes a morphological change in the vertical edges of the alveolar crest where the ligament space is expanded through vertical bone resorption (Papapanou & Wennström, 1991; Papapanou et al., 1988; Persson, Rollender, Laurell, & Persson, 1998). In Papapanou et al. (1988), the horizontal bone loss was recorded through the AC/CEJ measurement (after Bjorn, Hailing, and Thyberg 1969). Vertical bone loss was recorded as any morphological change seen as an oblique radiolucency ≥2mm apically from the highest point of the AC, with signs of bone resorption. Similar techniques are still used in radiography to determine horizontal (Bahrami, Vaeth, Wenzel, & Isidor, 2017) and vertical bone loss (Rams, Listgarten, & Slots, 2018).

These clinical methods, including the concept of horizontal and vertical bone loss, have been adapted in human bioarchaeology when only the bones of the jaws and the teeth survive (Davies & Picton, 1969; Davies, Picton, & Alexander, 1969). In particular, the measurement between the CEJ and AC (after Russell 1956) proposed that AC levels of more or less than half the length of the root may indicate horizontal bone loss at different stages. The results are often averaged across the mouth to obtain a Tooth Cervical Height Index (TCH index). Initially, Davies et al. (1969) compared TCH index results to visual examination in the same individuals, concluding that a measurement >2.5mm suggests alveolar bone loss consistent with periodontal disease. This compares well with modern radiographic standards of >3mm (Bahrami et al., 2017) or >1.9mm (Hausmann, Allen, & Clerehugh, 1991; Persson et al., 1998), but less than manual examination suggested in the WHO standard of >3.5mm (World-Health-Organization, 2013). The measurement of horizontal bone loss (AC/CEJ distance) has been taken up by many anthropologists and archaeologists (for example, Alexandersen, 1967; Eshed, Gopher, & Hershkovitz, 2006; Lavigne & Molto, 1995; Lukacs, 1989; Masotti et al., 2013; Meller et al., 2009). However, this empirical method of measurement, which appears to be an objective, repeatable, and straightforward approach, bears a fundamental problem when applied to skeletal remains. As demonstrated by Levers and Darling (1983), Murphy (1959), and Newman and Levers (1979), extensive occlusal wear can lead to the continuous eruption of a tooth to maintain an occlusal plane, extending CEJ/AC distance independently of alveolar resorption and periodontal disease. Davies and Picton (1969), two of the first to apply this method to archaeological remains, noted the impact of attrition on AC/CEJ distance; as attrition increased, so did the measurement. In a second paper, Davies and Picton (1969b) discuss the link between AC/CEJ distance and dental wear, while rarely referring to pathological change related to periodontal disease. Watson (1986) also demonstrated a clear correlation between increasing AC/CEJ distance and dental wear in Anglo Saxon to Tudor individuals. However, each of these papers referred to this process as 'alveolar recession' rather than the extension of the AC/CEJ distance (due to continuous eruption). It may be the misunderstanding of this term that has led to the persistent of the use of the AC/CEJ measurement to record alveolar resorption connected to periodontal disease in skeletal remains. In archaeological collections – where dental wear is ubiquitous – measurement between the AC and CEJ is unreliable and unsuitable. Lavigne and Molto (1995, p. 269), cited by many as a basis for the technique, quite clearly stated that "the relationship of dental wear and over-eruption is not considered in the development of this system". For example, Eshed et al. (2006) noted a higher prevalence of horizontal bone loss in Natufian remains, interpreted as indicative of a higher prevalence of periodontal disease. However, high levels of dental wear were also recorded in this group, which is likely to have impacted the results and interpretations of the periodontal disease prevalence. It is unfortunate that, without the presence of soft tissue, this straightforward method, so useful in modern clinical research, cannot be applied to archaeological material due to the impact of dental wear. This is particularly true of ancient populations, where dental wear was almost ubiquitous.

Although tried and tested, measuring horizontal bone loss is not an appropriate approach in archaeological populations with high dental wear. However, observation of vertical bone loss has also been utilised in archaeology. This approach assesses morphological changes and the vertical loss of bone around the tooth root(s), thus recording changes in the contour (rather than height) of the interdental alveolar crest. Such changes are often recorded in clinical research (Hausmann et al., 1991; Papapanou et al., 1988; Persson et al., 1998; Rams et al., 2018), with perhaps the clearest definition made by Papapanou et al. (1988): any morphological change seen as an oblique radiolucency in a radiograph, extending apically beside the tooth root, from the highest point of the AC, with signs of bone resorption. In archaeology, the most commonly used method for recording vertical bone loss was developed by Kerr (1988). Kerr recognised the fundamental problem of using the AC/CEJ distance in archaeological material, stating that such measurements "do not adequately observe the disease entity they purport to" (Kerr, 1986, p. 191). Kerr followed on from work started by Costa (1982), recording altered bone architecture, looking at infra-bony pockets and porosity (termed osteoporosis by Costa). Costa, however, had not accounted for the episodic nature of the disease, instead implying that it was progressive. In 1988, Kerr examined the Aberdeen Carmelite archaeological remains, drawing close parallels to histological changes seen in modern clinical sections of alveolar bone with periodontal disease at various stages. From this work, Kerr created the following interdental septum/alveolar crest) scores (adapted from Kerr 1988):

0. *Unrecordable*. Tooth on either side of the septum lost ante-mortem or the septum damaged post-mortem
1. *Septal form characteristic of its region* (convex in incisor region, grading to flat in the molar region). The cortical surface is smooth and virtually uninterrupted by foramina, depressions or grooves.
2. *Septal form characteristic of the region*. Cortical surface showing a range of morphology, from many small foramina/shallow grooves to a cortical surface showing larger foramina and/or prominent grooves or ridges.
3. *Septal form showing breakdown of contour with bone loss* in the form of a shallow depression extending across the interspace from the buccal to lingual aspect, or as one or more smaller discrete areas of bone destruction, the essential and distinguishing features being a sharp and ragged texture to the bone.
4. *Septal form showing breakdown of contour with bone loss* similar to that seen in score 3, the essential difference being the bone surface. Instead of being ragged in appearance, the bone has a porous or smooth honeycomb effect with all defects rounded.
5. *Presence of deep infra-bony defect* with sides sloping at 45 degrees or more and with a depth of 3mm or more. The surface may be sharp and ragged or smooth and honeycombed.

Clinical measurements tend to focus on the periodontal pocket depth (Gingival margin/AC) and attachment loss (CEJ/AC). In archaeological material, the absence of soft tissue (or, if present, highly altered) prevents an assessment of the pocket depth. In Kerr's system – although not a measurement – attachment loss is indicated in scores 3 to 5, where the original architectural contour of the bone has been lost. Whether seen as a shallow change (score 3), a deep pocket (score 5), or a quiescent (healing) phase (score 4), this would 'clinically' be recorded as an attachment loss and measured by probing. Therefore, it may be possible to compare the prevalence of Kerr scores 3 to 5 with that of attachment loss – independent of the extent – recorded in modern clinical data. Comparing Kerr scores 3 to 5 with radiographic data poses a greater problem. Many papers mention the limitations of visually examining radiographs as they may only show demineralisation in bone once it has reached 30-50% or more (Page & Eke, 2007; Research-Science-Therapy-Committee, 2003). Thus, subtle changes (i.e. Kerr Scores 2 or 3) may, perhaps, not easily be detected in radiographs; particularly the slight changes in vascularity proposed with gingivitis (see below). However, the recent use of subtraction imaging might compare well with Kerr's earlier stages, with demineralisations as low as 5% being detected (Gröndahl & Gröndahl, 1983). However, subtraction imaging techniques focus on treatment rather than diagnosis (Corbet, Ho, & Lai, 2009; Page & Eke, 2007; Research-Science-Therapy-Committee, 2003) and do not include scores or stage-like evaluations, making like-for-like comparisons difficult. The higher Kerr scores, such as 4 or 5, indicate clearer vertical bone loss. Score 4 - the 'quiescent' phase - is likely to correspond to the periods of healing or reduced inflammation seen by Page and Schroeder (1976), reflecting the dynamic nature of periodontal disease. Radiographs published by Fish (1948, pp. 388, Figure 175), for example, show a case of Kerr scores 4 or 5 (dependent on depth - no scale given) with a deep angular defect with smooth edges visible on the radiograph.

Perhaps most controversially, Kerr (1988) argues that gingivitis may be recognised in the alveolar bone (Score 2). Prior to Kerr's work, and since its publication, researchers have suggested that the initial inflammation only effects the soft tissues and cannot be detected in archaeological material as it involves no loss of attachment (Page & Schroeder, 1976; Schwartz et al., 1997). However, Kerr suggests that the porosity frequently seen in the alveolar crest (Costa, 1982; Kerr, 1986, 1988) reflects the increased vascularisation associated with gingival inflammation in gingivitis (Hajishengallis & Korostoff, 2017; Page & Schroeder, 1976). In chronic gingivitis, neutrophils have the ability to influence the bone remodelling process (Page & Schroeder, 1976; Schwartz et al., 1997); however, Schwartz et al. (1997) note that ultrastructural changes in bone do not occur in gingivitis - only as it progresses to periodontal disease. This is not supported by earlier research from Kennedy (1974), Hausmann, Ortman, and Sedransk (1979), and Heijl, Rifkin, and Zander (1976); and, the paper by Schwartz et al. (1997) may actually be referring to the structural resorption of bone and the loss of attachment, rather than remodelling to account for increased vascularity as Kerr has suggested. Indeed, Kennedy (1974) found that with gingivitis there was a significant increase in vascularity after only 2 weeks, including an increased number of vessels perforating the alveolar crest. Hausmann et al. (1979) supports this finding, revealing a decrease in alveolar bone mass using $^{125}$I absorptiometry in cases of gingivitis in monkeys. Heijl et al. (1976) and Kennedy and Polson (1973)also found increases in osteoclast activity and bone loss and remodelling in cases of induced gingivitis. While these studies support Kerr's idea, further clinical and radiological work may be required to clarify the impact of gingivitis on the alveolar crest. The subtle loss of bone density associated with the remodelling of the alveolar crest, when there is no attachment loss, is unlikely to be seen radiographically without the aid of subtraction imaging. Yet some histological studies support Kerr's findings. Fish (1948), in a comprehensive study of the surgical pathology of the mouth, showed that osteoclast activity had resorbed bone prior to any loss of attachment (Fish, 1948, pp. 317,331). Kronfeld (1933) also found that inflammation of the gingival tissue, with little to no attachment loss, was accompanied by some resorption of alveolar bone (Kronfeld, 1933, pp. 309, Figure 249). Kerr's (1988) method allows the recording of vertical bone loss in archaeological material. Though subjective, it is clearly defined and parallels clinical, radiographic, and histological understanding of both gingivitis and periodontal disease. It was developed to allow for detailed and meaningful comparisons between past and present prevalence of periodontal disease (Kerr, 1986), and thus was employed as the most appropriate method for recording periodontal disease in the current study.

**Methods**

Age and sex have been shown to affect the prevalence of periodontal disease and gingivitis (Amar & Chung, 1994; Kinane, Podmore, & Ebersole, 2001; Löe, 1965; Page & Schroeder, 1976; Shiau & Reynolds, 2010; Ziskin & Nesse, 1946). In this study, age was recorded using the stages of pubic symphysis (Brooks & Suchey, 1990) and auricular surface (Lovejoy etal., 1985) joint degeneration. Sex was recorded using sexually dimorphic features of the skull and pelvis, after Acsádi, Nemeskéri, and Balás (1970) (nuchal crest, mental eminence, glabella, orbital margin, mastoid process), Phenice (1969) (ventral arc, sub-pubic concavity, ischiopubic ramus ridge), Buikstra and Ubelaker (1994) (greater sciatic notch), and Rogers and Saunders (1994) (pubic body shape). The following categories were used:

**Sex:** Male; Male?; Undetermined; Female?; Female

**Age:** Adolescent - < 20 years (with third molars in occlusion); Young Adult - 20-34 years; Middle Adult - 35-49 years; Old Adult - 50+ years; Adult - 20+ (age not assigned)

Pathological changes to the periodontium were recorded using the Kerr (1988) method described above, scoring vertical bone loss through changes in the texture and contour of the interdental alveolar crest. These changes were observed using a good light source and a 10x magnification hand-lens. An example of the changes associated with each of Kerr's scores can be seen in Figure 3. Results are divided into three alveolar regions: the anterior region comprising the alveolar crests between the left mesial canine and right mesial canine; the premolar region from the mesial first premolar to the mesial second premolar; and the molar region from the mesial first molar to mesial third molar. This approach records the distribution of pathological changes across the mouth and takes into account preservation bias (Antoine, 2017). Upper and lower dentitions were grouped together for the purpose of this study. Unobservable interdental septa were accounted for, allowing a true prevalence to be calculated for each group and the results are divided by age and sex (individuals assigned to the 'probable male' or 'probable female' categories were combined with those in the 'male' and 'female' categories respectively). The 95% confidence intervals were calculated, as well as the confidence interval of difference (CID), which shows a true statistical difference in prevalence when the confidence interval range does not pass through zero (Altman, 2000). Additionally, the more traditional Fisher's exact test (two-tailed) was used to provide a further test of statistical significance. A p-value of $<0.05$ was used to identify significant differences between groups.

Intra-observer error for Kerr's (1988) scoring method was tested on 60 interdental alveolar crests. These data were divided by score 0 (unobservable), score 1 (no pathological change), score 2 (porosity) and scores 3-5 (vertical bone loss). Table 3 shows the crosstabulation for the two intra-observations. Intra-observations matched in 53/60 instances. Cohen's κ test showed good agreement between observations (according to Altman, 1999), with $\kappa = 0.765$ and $p = <0.0005$, demonstrating significant agreement between observations. Table 4 shows the crosstabulation for the two inter-observations. Inter-observations matched in 52/60 instances. Cohen's κ test showed good agreement between observations (according to Altman, 1999), with $\kappa = 0.800$ and $p = <0.0005$, demonstrating a significant agreement between observations.

The majority of error seen in the intra and inter-observations were between scores 1 and 2, the difference between no pathological changes and increased porosity. The application of more light and better magnification was used to limit this error. However, this distinction is problematic. A minimal amount of porosity may be present in bone that has neither gin-

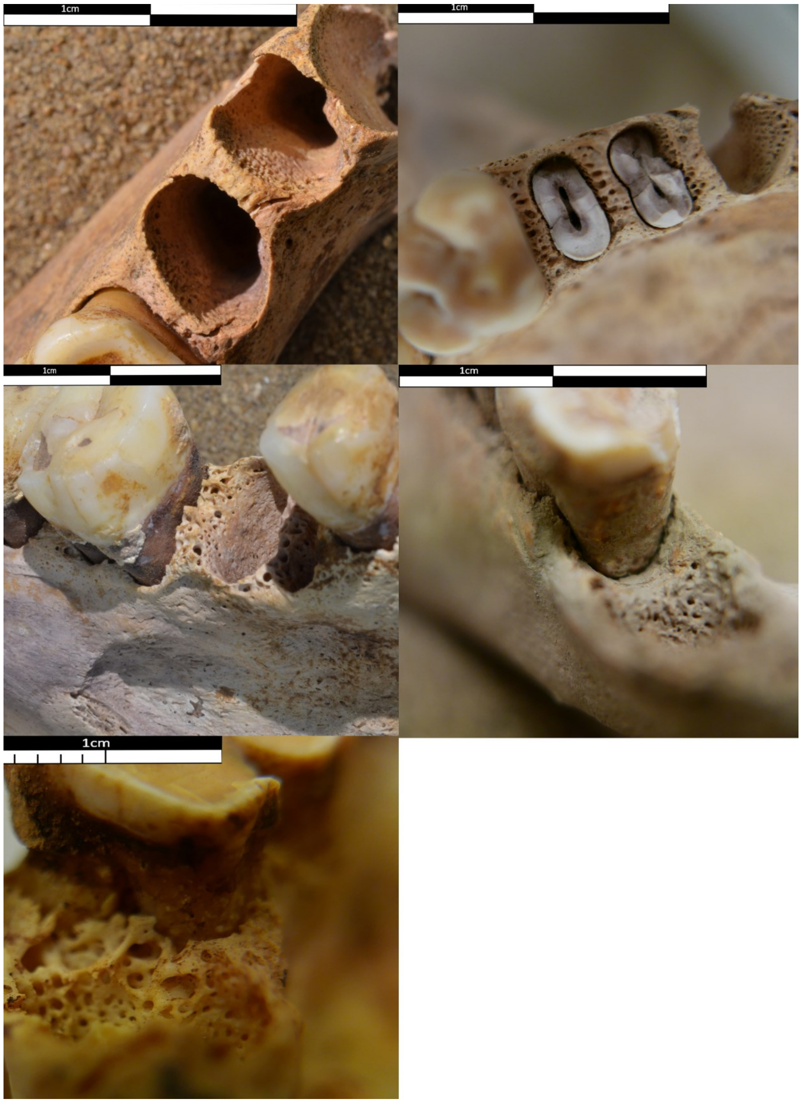


Figure 3. Examples of the different Kerr stages from the current study: **Top left - Score 1 -** Septal form characteristic of its region with no pathological change; **Top right - Score 2** - Septal form characteristic of the region. Cortical surface showing a range of morphologies, from many small foramina/shallow grooves to a cortical surface showing larger foramina and/or prominent grooves or ridges; **Middle left – Score 3** - Septal form showing breakdown of contour with bone loss in the form of a shallow depression extending across the interspace from the buccal to lingual aspect, or as one or more smaller discrete areas of bone destruction, the essential and distinguishing features being a sharp and ragged texture to the bone; **Middle right - Score 4** - Septal form showing breakdown of contour with bone loss similar to that seen in score 3, however, instead of being ragged in appearance, the bone has a porous or smooth honeycomb appearance; **Bottom left – Score 5** - Presence of deep infra-bony defect with sides sloping at 45 degrees or more and with a depth of 3mm or more. The surface may be sharp and ragged or smooth. Photographs by R. Whiting, courtesy of the Trustees of The British Museum.

givitis nor periodontal disease (Berkovitz, Holland, & Moxham, 1977, p. 191) and this limitation should be taken into account when interpreting results.

**Results**

Clear differences in the prevalence of Kerr scores 3-5 can be seen between the assemblages examined (Figure 4). Site R12 (Neolithic) has the lowest prevalence of all the sites in all tooth classes and for both sexes, as well as in its overall prevalence. The only exception is the anterior region of male jaws, which shows a Kerr score 3-5 prevalence of 0% of interdental alveolar crests (CI 0-18) at R12 and at H29 (CI 0-11). The Late Medieval site of 3-J-18 has the second lowest prevalence at 6.7% (CI 4.6-9.7) for Kerr scores 3-5. Again, this is seen in all tooth classes, for both sexes, and overall (with the previous exception applying). Conversely, the Medieval site of 3-J-23 shows the highest prevalence in all tooth classes for both sexes and overall. The highest prevalence is that of the molar region of male individuals, with 47.5% (CI 41.1-53.6) of all interdental alveolar bone showing pathological change consistent with Kerr scores 3-5. The prevalence at site H29 falls between those of the two Medieval sites.

Tables 5-10 demonstrate the statistically significant differences between all sites in all tooth regions, with only two exceptions. The interdental bone in the premolar region of sites H29 and 3-J-23 do not show a statistically significant difference. Here 16.2% (CI 12.1-22.7) and 20.2% (CI 16.9-24) were recorded, respectively. The difference in prevalence between these sites is 3.5% (CID -9.5 to 3.4, P=0.3300). The interdental bone in the anterior region from sites R12 and 3-J-18 also show no significant difference. Here 0.0% (CI 0.0-5.3) and 3.3% (CI 2.3-4.6) were recorded, respectively. The difference in prevalence between these sites is 3.3% (CID -4.6 to 2.1 P=0.2617).

*Distribution comparison*

In both male and female individuals, as well as overall, each site shows a similar distribution of Kerr

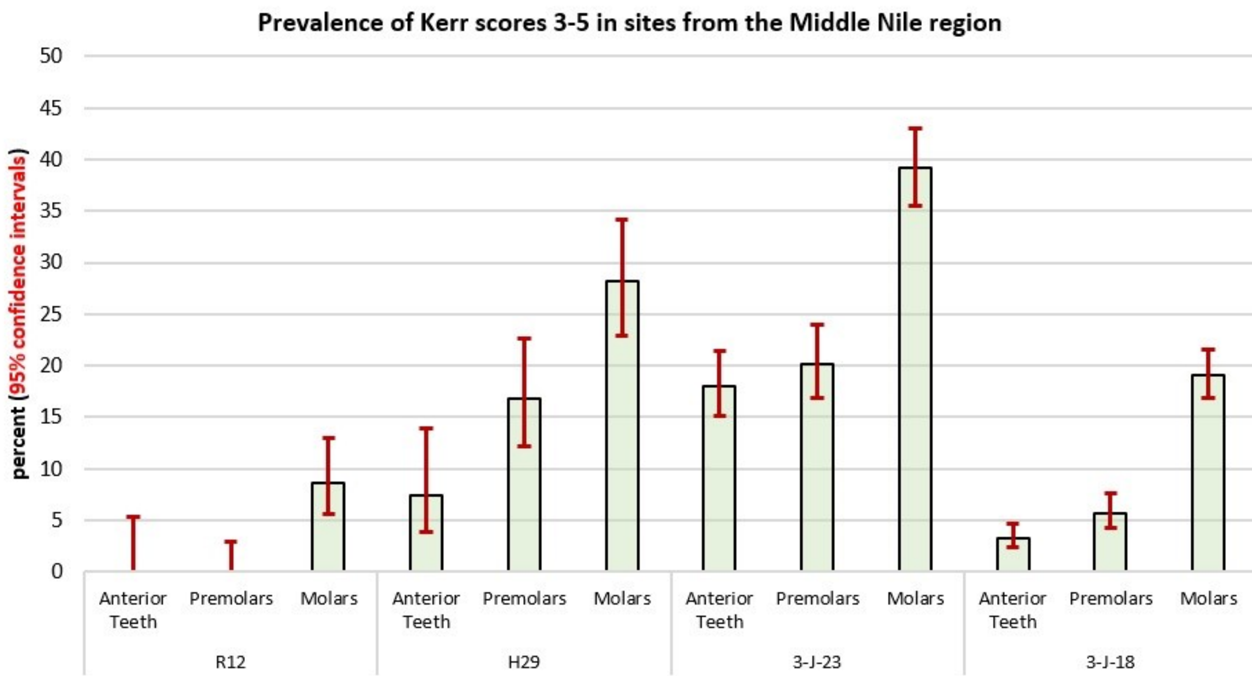


Figure 4: Box and whisker plot showing the prevalence of periodontal disease at sites R12, H29, 3-J-23 and 3-J-18. Box plot indicates prevalence in each tooth region. Whiskers indicate the confidence intervals for each group based on the calculations set out in Altman, Machin, Bryant, and Gardner (2000, p. 47).

*Table 3. Crosstabulation for intra-observer error for observations of Kerr scores. Numbers indicate counts of the Kerr Scores allocated in observation #1 and #2.*

| | | Observation#2 | | | | |
|---|---|---|---|---|---|---|
| | | Unobservable | Kerr 1 | Kerr 2 | Kerr 3-5 | Total |
| Observation#1 | Unobservable | 13 | 0 | 0 | 0 | 13 |
| | Kerr 1 | 0 | 37 | 4 | 3 | 44 |
| | Kerr 2 | 0 | 0 | 2 | 0 | 2 |
| | Kerr 3-5 | 0 | 0 | 0 | 1 | 1 |
| | Total | 13 | 37 | 6 | 4 | 60 |

*Table 4. Crosstabulation for inter-observer error observations for periodontal disease recording. Numbers indicate counts of the Kerr Scores allocated by observer #1 and #2.*

| | | Observer#2 | | | | |
|---|---|---|---|---|---|---|
| | | Unobservable | Kerr 1 | Kerr 2 | Kerr 3-5 | Total |
| Observer#1 | Unobservable | 6 | 0 | 0 | 1 | 7 |
| | Kerr 1 | 0 | 24 | 3 | 0 | 27 |
| | Kerr 2 | 0 | 3 | 16 | 0 | 19 |
| | Kerr 3-5 | 0 | 0 | 1 | 6 | 7 |
| | Total | 6 | 27 | 20 | 7 | 60 |

*Table 5: Site comparisons between R12 and H29 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| R12/H29 | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|
| Raw Data | 0/68 (0.0%)<br>8/108 (7.4%) | 0/128 (0.0%)<br>32/191 (16.7%) | 20/232 (8.6%)<br>68/241 (28.2%) | 20/428 (4.7%)<br>108/540 (20%) |
| CID | **-13.9 (-7.4) -1.0** | **-22.7 (-16.8) -11.3** | **-26.3 (-19.6) -12.8** | **-19.3 (-15.3) -11.3** |
| Fisher's exact test | **P=0.0239** | **P=<0.00001** | **P=<0.00001** | **P=<0.00001** |

*Table 6: Site comparisons between R12 and 3-J-23 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| R12/3-J-23 | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|
| Raw Data | 0/68 (0.0%)<br>101/559 (18%) | 0/128 (0.0%)<br>97/480 (20.2%) | 20/232 (8.6%)<br>251/640 (39.2%) | 20/428 (4.7%)<br>449/1679 (26.7%) |
| CID | **-21.5 (-18.1) -12.0** | **-24.0 (-20.2) -15.8** | **-35.5 (-30.6) -24.9** | **-24.8 (-22.1) -18.9** |
| Fisher's exact test | **P=<0.00001** | **P=<0.00001** | **P=<0.00001** | **P=<0.00001** |

*Table 7: Site comparisons between R12 and 3-J-18 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| R12/3-J-18 | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|
| Raw Data | 0/68 (0.0%)<br>31/939 (3.3%) | 0/128 (0.0%)<br>45/788 (6%) | 20/232 (8.6%)<br>203/1063 (19%) | 20/428 (4.7%)<br>279/2790 (10%) |
| CID | -4.6 (-3.3) 2.1 | **-7.6 (-5.70 -2.5** | **-14.3 (-10.5) -5.6** | **-7.3 (-5.3) -2.7** |
| Fisher's exact test | P=0.2617 | **P=0.0015** | **P=0.0001** | **P=0.0002** |

*Table 8: Site comparisons between H29 and 3-J-23 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| H29/3-J-23 | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|
| Raw Data | 8/108 (7.4%)<br>101/559 (18%) | 32/191 (16.7%)<br>97/480 (20.2%) | 68/241 (28.2%)<br>251/640 (39.2%) | 108/540 (20%)<br>449/1679 (26.7%) |
| CID | **-15.6 (-10.7) -3.5** | -9.5 (-3.5) 3.4 | **-17.6 (-11.0) -4.0** | **-10.9 (-6.7) -2.6** |
| Fisher's exact test | **P=0.0044** | P=0.3300 | **P=0.0028** | **P=0.0017** |

*Table 9: Site comparisons between H29 and 3-J-18 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| H29/3-J-18 | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|
| Raw Data | 8/108 (7.4%)<br>31/939 (3.3%) | 32/191 (16.7%)<br>45/788 (6%) | 68/241 (28.2%)<br>203/1063 (19%) | 108/540 (20%)<br>279/2790 (10%) |
| CID | **0.3 (4.1) 10.7** | **6.1 (11.0) 17.1** | **3.3 (9.1) 15.5** | **6.6 (10.0) 13.7** |
| Fisher's exact test | **P=0.0529** | **P=<0.0001** | **P=0.0021** | **P=<0.0001** |

*Table 10: Site comparisons between 3-J-23 and 3-J-18 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| 3-J-23/3-J-18 | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|
| Raw Data | 101/559 (18%)<br>31/939 (3.3%) | 97/480 (10.2%)<br>45/788 (6%) | 251/640 (39.2%)<br>203/1063 (19%) | 449/1679 (26.7%)<br>279/2790 (10%) |
| CID | **11.5 (14.8) 18.3** | **10.7 (14.5) 18.6** | **15.7 (20.1) 24.6** | **14.4 (16.7) 19.2** |
| Fisher's exact test | **P=0.00001** | **P=<0.00001** | **P=<0.00001** | **P=<0.00001** |

scores 3-5. The anterior region of the jaws has the lowest prevalence, followed by the premolar region, with the molar region displaying the highest prevalence in every site. In male individuals from both Medieval sites (3-J-18 and 3-J-23), a similar prevalence is present in the anterior and premolar regions. Overall, the premolars from site 3-J-23 show a 4.8% higher prevalence than the anterior region (CID -13.5 to 3.7, P=0.2966), while at site 3-J-18, there is a difference of 0.6% between the tooth regions (CID -4.6 to 3.2, P=0.7684). In contrast, there is a statistically significant difference in prevalence between the anterior and premolar regions in the males from site H29 – 15% (CID -26.1 to -2.0, P=0.0254). The difference in prevalence between the anterior and premolar regions at all three sites is less pronounced in female individuals (Figure 5). At R12, Kerr scores 3-5 are only found in the molar region, this was true of both sexes and in overall prevalence.

*Comparisons of age and sex*

Figure 5 shows the prevalence of Kerr Scores 3-5 in each of the groups examined, divided by age and sex. In nearly every tooth region of each assemblage, the middle adult category shows a higher prevalence of Kerr Scores 3-5 than the young adults– with the exception of the premolar region at H29 where young adult males show a slightly higher prevalence than middle adult males. However, not all these differences are statistically significant (Tables 11-18). In fact, in the earlier periods, the Neolithic and Kerma groups show no statistical significance between age categories for either sex. Yet, in the Medieval groups, middle adults show a statistically higher prevalence than young adults in every tooth region for male individuals. However, this is not the case for female individuals, where a statistical difference between age categories is only seen in the molar region at 3-J-18, and in the molars and premolars at 3-J-23. In addition, middle adult males, at both Medieval sites, show a significantly higher prevalence of Kerr Scores 3-5 than middle adult females in the anterior dentition.

**Discussion**

The sites examined in this study reveal a wide range in the prevalence of Kerr scores 3 to 5 (from 4.7% at R12 to 26% at 3-J-23), which represents destructive bone loss relating to periodontal disease (Kerr, 1988). In modern populations from across the globe, P. E. Petersen (2003) reports periodontal disease ranging from 5 to 15%. Petersen's data, however, only include individuals with periodontal pockets ≥6mm, and cannot be directly compared with the higher prevalence rates reported here as the latter include a greater range of periodontal remodelling. The current study also differs in that it records changes per interdental septum rather than per individual. It should be noted that due to varying levels of preservation, the numbers of individuals with age-at-death and sex estimates were small at sites R12 and H29, but relatively large at the two Medieval sites. The results from these earlier sites are thus less likely to be as representative as those from the later sites.

The Neolithic site of R12 shows the lowest prevalence of periodontal disease in all tooth regions and overall for males, females, and both age categories. Periodontal disease is only present in the molar region, with none observed in the anterior or premolar teeth. Prevalence at H29 is higher than that of R12, with pathological changes found in all regions of the dentition. Site 3-J-23 has considerably higher prevalence rates than both R12 and H29. However, at the later Medieval site of 3-J-18, prevalence rates are lower than those at both the earlier Medieval and *Kerma Ancien* sites. Current understanding of the biological processes contributing to periodontal disease suggest that a range of factors can contribute to the initiation and progression of the condition. Its association with systemic inflammation is particularly relevant here (Barnett, 2006; Page, 1998; P. E. Petersen et al., 2005; Thoden van Velzen, Abraham-Inpijn, & Moorer, 1984), with greater inflammation in the body causing susceptibility to the hypersensitive response involved in periodontal disease and *vice versa*. The archaeological record suggests that during the Neolithic period, settlement may have been more temporary and communities more mobile, in part due to the more humid environment and

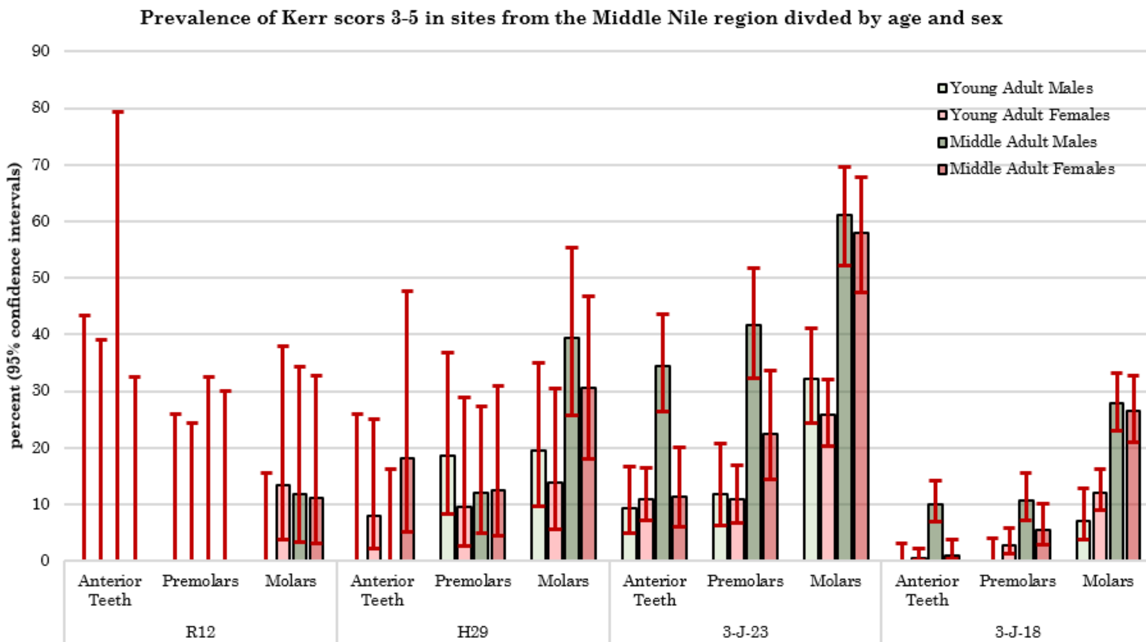


Figure 5. Box and whisker plot showing the prevalence of periodontal disease at sites R12, H29, 3-J-23 and 3-J-18. Box plot indicates prevalence in each tooth region, for young and middle adult males and females. Whiskers indicate the confidence intervals for each group based on the calculations set out in Altman et al. (2000, p. 47).

*Table 11: Comparisons between young and middle adult males at R12 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| R12 Males | | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|---|
| Raw Data | (Young adults) | 0/5 (0.0%) | 0/11 (0.0%) | 0/21 (0.0%) | 0/37 (0.0%) |
| | (Middle adults) | 0/1 (0.0%) | 0/8 (0.0%) | 2/17 (11.8%) | 2/26 (7.7%) |
| CID | | -79.3 (0.0%) 43.4 | -32.4 (0.0) 25.9 | -34.3 (-11.8) 5.9 | -24.1 (-7.7) 3.2 |
| Fisher's exact test | | P=1 | P=1 | P=0.19 | P=0.16 |

*Table 12: Comparisons between young and middle adult females at R12 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| R12 Females | | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|---|
| Raw Data | (Young adults) | 0/6 (0.0%) | 0/12 (0.0%) | 2/15 (13.5%) | 2/33 (6.0%) |
| | (Middle adults) | 0/8 (0.0%) | 0/9 (0.0%) | 2/18 (11.1%) | 2/35 (5.7%) |
| CID | | -32.4 (0.0) 39.0 | -32.4 (0.0) 24.3 | -21.5 (2.2) 28.0 | -13.3 (0.3) 14.5 |
| Fisher's exact test | | P=1 | P=1 | P=1 | P=1 |

*Table 13: Comparisons between young and middle adult males at H29 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| H29 Males | | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|---|
| Raw Data | (Young adults) | 0/11 (0.0%) | 5/27 (18.5%) | 7/36 (19.4%) | 12/74 (16.2%) |
| | (Middle adults) | 0/20 (0.0%) | 4/33 (12.1%) | 15/38 (39.5%) | 19/91 (20.9%) |
| CID | | -16.1 (0.0) 25.9 | -12.0 (6.4) 26.0 | -38.6 (-20.0) 0.8 | -16.2 (-4.7) 7.6 |
| Fisher's exact test | | P=1 | P=0.71 | P=0.07 | P=0.54 |

*Table 14: Comparisons between young and middle adult females at H29 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| H29 Females | | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|---|
| Raw Data | (Young adults) | 2/25 (8.0%) | 2/21 (9.5%) | 4/29 (13.8%) | 8/75 (10.6%) |
| | (Middle adults) | 2/11 (18.2%) | 3/24 (12.5%) | 11/36 (30.6%) | 16/71 (22.5%) |
| CID | | -40.3 (-10.2) 11.2 | 22.3 (-3.0) 18.1 | -35.1 (-16,8) 4.2 | -24.0 (-11.9) 0.3 |
| Fisher's exact test | | P=0.57 | P=1 | P=0.14 | P=0.07 |

*Table 15: Comparisons between young and middle adult males at 3-J-23 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| 3-J-23 Males | | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|---|
| Raw Data | (Young adults) | 9/97 (9.3%) | 9/77 (11.7%) | 37/115 (32.2%) | 55/289 (19.0%) |
| | (Middle adults) | 40/116 (34.5%) | 40/96 (41.7%) | 71/116 (61.2%) | 151/328 (46.0%) |
| CID | | **-35.2 (-25.2) -14.3** | **-41.3 (-30.0) -17.0** | **-42.1 (-30.8) -18.0** | **-33.8 (-27.0) -19.8** |
| Fisher's exact test | | **P=<0.0001** | **P=<0.0001** | **P=<0.0001** | **P=<0.0001** |

*Table 16: Comparisons between young and middle adult females at 3-J-23 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| 3-J-23 Females | | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|---|
| Raw Data | (Young adults) | 20/182 (11.0%) | 16/148 (10.8%) | 53/206 (25.7%) | 89/536 (16.6%) |
| | (Middle adults) | 9/80 (11.3%) | 16/71 (22.5%) | 51/88 (58.0%) | 76/239 (31.7%) |
| CID | | -9.8 (-0.3) 7.2 | **-23.4 (-11.7) -1.6** | **-43.4 (-32.2) -20.0** | **-22.0 (-15.2) -8.7** |
| Fisher's exact test | | P=1 | **P=0.02** | **P=<0.0001** | **P=<0.0001** |

*Table 17: Comparisons between young and middle adult males at 3-J-18 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| 3-J-18 Males | | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|---|
| Raw Data | (Young adults) | 0/118 (0.0%) | 0/91 (0.0%) | 9/127 (7.1%) | 9/336 (2.6%) |
| | (Middle adults) | 26/260 (10.0%) | 23/216 (10.6%) | 81/291 (27.8%) | 130/767 (16.9%) |
| CID | | **-14.2 (-10.0) -5.6** | **-15.5 (-10.6) -5.3** | **-27.1 (-20.7) -13.2** | **-47.9 (-42.0) -35.9** |
| Fisher's exact test | | **P=<0.0001** | **P=0.0005** | **P=<0.0001** | **P=<0.0001** |

*Table 18: Comparisons between young and middle adult females at 3-J-18 for Kerr scores 3-5 in each tooth region, as well as overall. Raw data, Confidence interval of difference (Altman et al., 2000) and P-value for two-tailed Fisher's exact test are shown. Significant values are shown in bold.*

| 3-J-18 Females | | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|---|
| Raw Data | (Young adults) | 1/266 (0.4%) | 6/222 (2.75) | 37/306 (12.1%) | 44/794 (5.5%) |
| | (Middle adults) | 2/191 (1.0%) | 9/165 (5.5%) | 57/216 (26.4%) | 68/572 (11.8%) |
| CID | | -2.1 (-0.3) 1.5 | -7.6 (-2.8) 1.2 | **-21.3 (-14.3) -7.5** | **-9.6 (-6.3) -3.3** |
| Fisher's exact test | | P=0.57 | P=0.18 | **P=<0.0001** | **P=<0.0001** |

*Table 19: Comparison of the male, female and overall Kerr scores 3-5 recorded in this study with Wasterlain et al. (2011) and Kerr (1991). Raw data and prevalence (%) are provided.*

| Site/Study | Male | Female | Overall |
|---|---|---|---|
| R12 | 7/141 (5%) | 4/108 (3.7%) | 20/428 (4.7%) |
| H29 | 31/165 (18.7%) | 45/246 (18.7%) | 108/540 (20%) |
| 3-J-23 | 214/639 (33.4%) | 165/779 (21.1%) | 449/1679 (26.7%) |
| 3-J-18 | 140/1129 (12.4%) | 119/1432 (8.3%) | 279/2790 (10%) |
| Wasterlain *et al.* (2011) | 773/4980 (14.7%) | 602/4420 (13.6%) | 1335/9400 (14.2%) |
| Kerr (1991) | - | - | 702/3142 (22.3%) |

*Table 20: Comparison of Kerr scores 3-5 in this study and Kerr (1991) . Raw data and prevalence (%) provided by dental distribution*

| | Anterior teeth | Premolars | Molars | Total |
|---|---|---|---|---|
| R12 | 0/68 (0.0%) | 0/128 (0.0%) | 20/232 (8.6%) | 20/428 (4.7%) |
| H29 | 8/108 (7.4%) | 32/191 (16.7%) | 68/241 (28.2%) | 108/540 (20%) |
| 3-J-23 | 101/559 (18%) | 97/480 (20.2%) | 251/640 (39.2%) | 449/1679 (26.7%) |
| 3-J-18 | 31/939 (3.3%) | 45/788 (6%) | 203/1063 (19%) | 279/2790 (10%) |
| Kerr (1991) | 184/1041 (17.6%) | 171/1047 (16.3%) | 335/1339 (26.5%) | 702/3142 (22.3%) |

a reliance on pastoral cultural practices (Bard, 2008; Gautier & Van Neer, 2011; Hassan, 1986; L. Krzyżaniak, 2004; Wengrow et al., 2014). At this time, population clusters may have been smaller and may have had less contact with other groups, limiting the spread of disease and systemic inflammation. This may in part explain the very low levels of periodontal disease prevalence in the Neolithic Group and the much higher levels in the later groups, particularly the Medieval site of 3-J-23. Unfortunately, none of the cemeteries examined in this study had associated settlements and occupation size or patterns could not be established.

Genetic susceptibility is also likely to affect the prevalence of periodontal disease (Hajishengallis & Korostoff, 2017; Kornman & di Giovine, 1998; Kornman et al., 1997; Laine, Crielaard, & Loos, 2012; Page & Schroeder, 1976). Clinical studies have demonstrated that certain gene expressions influence patient susceptibility to both aggressive and chronic periodontal disease (Kornman & di Giovine, 1998; Laine et al., 2012; Offenbacher, Barros, & Beck, 2008). In the Nile Valley, Elamin, Skaug, Ali, Bakken, and Albandar (2010) study of the periodontal status of

Sudanese students concludes that African ethnicity and male sex are risk factors in young people aged 13-19 years. If individuals from Site R12 had a very different genetic make-up to the other sites examined, this may explain some of the very different prevalence rates observed here. However, no aDNA studies have been made. The work by Irish (2008), using dental morphology as a proxy to genetics, suggests a close biological affinity between R12 and other Nubian groups of the time, as well as with groups from subsequent periods. However, dental morphological data is not currently available for H29 or the Fourth Cataract sites.

Few clinical studies have linked periodontal disease to diet (Björnsson et al., 2003; Person, 1961; Watson, 1994). In Sudan, the archaeological record suggests an agricultural transition or intensification between the Neolithic and Medieval periods (Björnsson et al., 2003; Chaix, 1984, 2007; Clapham & Rowley-Conwy, 2007; Fuller, 2004; Fuller & Edwards, 2001; Iacumin et al., 1961; Watson, 1994). An increase in consumption of grains during this period may have affected the make-up of the oral flora within the supra-gingival biofilm and, in turn, susceptibility to periodontal disease.

When compared to Wasterlain, Cunha, and Hillson (2011), which also used the Kerr method on individuals of known age and sex from the Coimbra collection in Portugal, the overall prevalence for the Coimbra post-industrial group (14.2%; CI 13.5-14.9) falls between that of the later Medieval group from 3-J-18 (10%; CI 8.9-11.2) and the *Kerma Ancien* group from H29 (20%;CI 16.8-23.6). The Coimbra data also has a significantly higher prevalence than that of 3-J-18 (4.2%; CID -5.5 to -2.8 P=<0.00001), as well as a significantly lower prevalence than H29 (5.8%; CID 2.6 to 9.4 P=0.0003). The Coimbra data also have a statistically lower prevalence than 3-J-23 and a higher prevalence than R12. The results could not be directly compared to the Medieval Scottish collections (AD 900-1600) examined by Kerr (1991; see Table 19) due to its inclusion of sub adults. However, once Kerr's data is adjusted to exclude the sub-adults (Table 19), periodontal disease was observed in 22.3% of interdental alveolar crests. This is 2.3% higher than the prevalence observed at H29 (CID -1.5 to 5.8 P=0.2378) and significantly higher than results from sites R12 (17.7%; CID 14.9 to 19.9 P=<0.00001) and 3-J-18 (12.3%; CID 10.5 to 14.2 P=<0.00001), as well as significantly lower than 3-J-23. The Middle Nile Valley data compares well with the range seen in other collections with the exception of R12, where prevalence is much lower than all other collections, and even lower than the range observed in modern populations (Petersen, 2003).

The Medieval Scottish data by Kerr (1991) also show a prevalence of periodontal disease of 17.6% (CI 15.5-20.1) in the anterior region, 16.3% (CI 14.2-18.7) in the premolar region, and 26.5% (CI 24.2-28.9) in the molar region (Table 20). Prevalence rates in the premolar and molar regions are comparable with those found at site H29. However, the prevalence recorded in the anterior region was significantly higher than H29 (10.3%; CID -14.6 to -3.4 P=0.0044) and aligns more closely with that of 3-J-23. A similar distribution of periodontal disease across the mouth was found at Coimbra and the Sudanese sites, with a higher prevalence in the molar region and the lowest prevalence in the anterior region.

Some studies have found a close link between periodontal disease and dental hygiene (Axelsson & Lindhe, 1981; Löe, 2000; P. E. Petersen et al., 2005). In modern Sudan, Darout, Albandar, and Skaug (2000), found that miswak users - a stick or root of the species *Salvadora persica* with antibacterial properties used as a toothbrush across Africa - had less gingival bleeding in the molars than toothbrush users, as well as lower prevalence rates of ≥4mm pocketing and attachment loss. This study also found that the prevalence of attachment loss was higher in the posterior maxillary teeth, with the opposite true for the mandible. The use of the miswak appears to improve oral hygiene (Halawany, 2012), most probably by cleaning the dental plaque away from the gums and reducing the microbial load. Although little is known of dental hygiene practices in the Neolithic, Kerma, or Medieval periods in Nubia, the high prevalence seen in the molar region in these collections, as well as those of Coimbra and Scottish Medieval period, may point to a similar problem. The molar region can be hard to clean of food and plaque, with deposits building faster or more readily than in other regions of the dentition (Hillson, 2005). This would, in turn, differentially increase the microbial challenge and hypersensitive response of the host's immune system (Cekici et al., 2014; Darveau et al., 1997; Kornman et al., 1997), particularly in that part of the mouth.

The Neolithic and Kerma sites, examined in this study, also show some differences between the sexes. At site R12, the young adult males show no signs of periodontal disease, with young adult females displaying interdental changes in the molars. At the Kerma site H29, no periodontal disease was observed in the anterior teeth of both the young and middle adult males, while females present the condition in both age groups. Due to poor preservation, few individuals from R12 and H29 could be assigned age and sex, and these results may not be representative of the assemblages. In all tooth regions, the middle adults from the Medieval sites show a higher prevalence of periodontal disease in males than females. This difference is only statistically significant in the anterior teeth from both Medieval sites (3-J-23: difference = 23.2%, CID 11.3 to 33.7 P=0.0002; 3-J-18: difference = 9.0%, CID 4.9 to 13.3 P=<0.0001) and in the premolars at site 3-J-23 (difference = 19.1%, CID 4.7 to 32.0 P=0.012). Bar these differences, little appears to separate males and females at the Medieval sites in either age category. This mirrors the findings from Coimbra. Using a 3x2 Chi$^2$ test with 2 degrees of freedom, Wasterlain et al. (2011, p. 36) compared the number of interdental septa recorded as healthy, with gingivitis, and with destructive lesions between males and females. Their results indicate that males were significantly more at risk of periodontal disease and gingivitis, and less likely to have 'healthy' interdental septa. However, this particular statistical test may hide the true cause of the difference between males and females. When considered separately, males showed a lower prevalence of healthy septa than females (24.1 % and 27.5% respectively; difference = 3.4%; CID -5.1 to -1.6 P=0.0002) and a higher prevalence of gingivitis than females (61.1% and 58.9% respectively; difference = 2.3%; CID 0.3 to 2.3 P=0.0253). Conversely, periodontal disease showed a prevalence of 14.7% in males and 13.6% in females, a modest difference of 1.1% (CID -0.3 to 2.5 P=0.1312) that is not statistically significant. These results appear to indicate that males had a significantly lower prevalence of 'healthy' interdental septa and a significantly higher prevalence of septa with gingivitis, but similar levels of periodontal disease. Males and females from Coimbra, however, showed a significantly higher prevalence than observed at site R12 (males difference = 9.8%, CID 4.7 to 12.5 P=0.0006; females difference = 9.9%, CID 4.4 to 12.4 P=0.0014) and a significantly lower prevalence than recorded at site 3-J-23 (males difference = 18.8%, CID -22.6 to -18.1 P=<0.00001; females difference = 7.6%, CID -10.7 to -4.6 P=<0.00001).

Biological differences between the sexes may explain these variations in prevalence (Curilović, Mazor, & Berchtold, 1977; Hefti, Engelberger, & Büttner, 1981) and it has been suggested that female hormonal fluctuations may lead to a higher prevalence of periodontal disease (Holm-Peedersen & Löe, 1967). However, other studies do not support this finding (Amar & Chung, 1994; Kinane et al., 2001; Marshall-Day, Stephens, & Quigley Jr, 1955; Mealey & Moritz, 2003; Shiau & Reynolds, 2010; Sooriyamoorthy & Gower, 1989). Indeed, in the results presented here, females in the earlier periods show higher prevalence than males in certain areas of the mouth, however, these differences are not statistically significant and prevalence in other dental regions are similar between sexes. In the later Medieval groups, it is male individuals who show statistically higher prevalence and progress to destructive periodontal bone loss more readily than females in the older age category, particularly in the anterior dentition.

In older adults, Kerr (1991) also noted a higher prevalence of scores denoting destructive periodontal disease and suggested these were probably a reflection of a "cumulative effect" (p. 353) rather than a greater susceptibility or risk with increasing age. In essence, after destructive bone loss occurs, the loss of attachment of the periodontal ligament means that the bone is not replaced (Cochran, 2008; Hienz, Paliwal, & Ivanovski, 2015; Hillson, 2005). As age increases, there may be a cumulative effect whether or not the lesions are active. This cumulative effect may account for some of the differences seen between the young and middle adult age categories in the current study. However, these differences were not significant in the Neolithic or Kerma period assemblages, and prevalence was only significantly higher in middle adult males in both Medieval collections. Although a higher prevalence was sometimes seen in middle adult females in the Medieval period, this was not true for every region of the dentition (see Tables 15-18). In the groups examined, the results suggest that - apart from in some Medieval cases - there is little difference in the risk of developing periodontal disease, nor its cumulative effects, with increasing age.

Many factors appear to contribute to the development, progression and thus the prevalence of periodontal disease. This equifinality is further confounded by the sporadic progression and recession of the disease. Either acute or chronic progression may occur; leading to florid destruction of the alveolar bone (both localised or widespread) (Hajishengallis & Korostoff, 2017; Page & Schroeder, 1976). Periods of healing can restore bone texture to a certain extent, or there may be retention of bone loss despite an area being in a quiescent phase, with no hypersensitivity or destructive activity (Kerr, 1988; Page & Schroeder, 1976). Page and Schroeder (1976) noted that a progression from an 'established lesion' to an 'advanced lesion' may occur within a couple of weeks to several years. With a lack of patient history and the cumulative effects of an episodic disease, captured at the point of death, the role of periodontal disease on the concept of 'oral health' may be hard to apply in archaeological remains. Instead, a mere snapshot of an individual's state of 'health' is actually represented. As shown here, this 'snapshot' may vary in different parts of the mouth. Stand-alone clinical studies also encounter this limitation and focus on recording a patient's 'periodontal status', a term also used by Kerr -perhaps in an attempt to capture the flitting nature of this complex disease. Further data is required to contextualise the differences over time, and between sexes and ages observed here, such as the low prevalence of periodontal disease at the Neolithic site of R12. The Kerr method has been used in very few studies, despite appearing to offer the best route forward. The data presented in this study gives new insight into the periodontal status of the inhabitants of the Middle Nile region from the Neolithic to Medieval period. Continued application of the Kerr method in other archaeological assemblages from both the Nile Valley and farther afield may help to contextualise these findings further and advance current understanding of this complex disease.

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# Dental Caries as an Archaeological Problem-Solving Tool: Reconstructing Subsistence Patterns in Late Prehistoric West-Central Tennessee

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**Keywords:** Mississippian, maize, dental caries, carious lesions, Tennessee

*ABSTRACT* The dentition from two Middle Mississippian period (~AD 1100-1350) site samples (Gray Farm [~AD 1100-1350], Link/Slayden [~AD 1100-1400]) from the Kentucky Lake Reservoir of west-central Tennessee area are examined for caries prevalence by tooth type, lesion size, and crown-root location to assess whether a maize-intensive subsistence economy is evident. Given the paucity of local archaeological context, comparative caries prevalence and pattern operate as a critical archaeological problem-solving tool. The Middle Mississippian samples are compared to a Kentucky Lake Late Woodland period (~AD 400-900) horticulturist site sample (Hobbs) as well as three unequivocal maize-intensive agriculturalist site samples from the Late Mississippian period of East Tennessee (~AD 1300-1550). The caries patterns (tooth type, location, size) in the Gray Farm sample is consistently not statistically different from the maize-intensive samples; Link/Slayden is consistently statistically different and resembles the caries pattern and prevalence of the Hobbs sample. The adoption of maize as a primary cultigen in the Kentucky Lake Reservoir is evidently geographically variable. This may reflect local ecological contexts or differential socio-economic contacts with neighboring Mississippian economies. Or, more likely, it may reflect temporal differences in Mississippianization between the Kentucky Lake Reservoir sites.

Paleopathological data in sample-based bioarchaeological inquiry are a well-established adjunct to archaeological problem-solving (e.g., Buikstra and Beck, 2017; Larsen, 2015; Martin et al., 2013). Although the reconstruction of extinct cultures is largely the purview of archaeology, many archaeological contexts, such as mortuary sites and salvage projects, lack the associated material culture to address basic questions about subsistence, settlement pattern, and social organization. In these circumstances, bioarchaeological data can be an effective primary archaeological problem-solving tool (e.g., Armelagos, 2003; Larsen, 2015; Mosher et al., 2015; Smith et al., 2016; Stojanowski & Duncan, 2015). Dental caries prevalence and severity can be particularly effective as a benchmark of agricultural intensification and the dietary primacy of particular fermentable carbohydrates (e.g., Caselitz, 1998; Karsten et al., 2015; Larsen, 1991, 2005; Lubell et al., 1994; Lukacs, 1992; Patterson, 1986; Šlaus et al., 2011; Temple & Larsen, 2007; Turner, 1979). Carious lesions are the consequence of the demineralization of tooth enamel by the metabolic processes of certain oral bacteria (e.g., *Streptococcus mutans*) in the presence of refined carbohydrates. In the Americas, the primary cariogenic carbohydrate of agricultural intensification (post AD 900 - Contact) is maize (*Zea mays*) (e.g., Simon, 2017; Smith, 2017; VanDerwarker et al., 2017), particularly the variant known as northern "flint corn" (*Zea mays indentata*) (Simon, 2017). It is commonly asserted that caries incidence rises dramatically with the adoption of maize (e.g., Emerson et al., 2005; Larsen, 1981; Powell, 1985; Watson, 2005). However, the increase is not simply a reflection of absolute carbohydrate consumption as other, likely synergistic factors (e.g., rate of attrition, hypoplastic defects, and malocclusion), affect individual vulnerability to cariogenesis. Complicating the subsistence inferences, documentation of caries prevalence across the late prehistoric site samples from the contiguous United States can be variable and uneven. Often this

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reflects sample preservation, as dental data are differentially available: loose teeth, *in situ* presence, and antemortem (alveolar resorption) and post-mortem (empty sockets) tooth loss. Recording can consist of the prevalence of carious individuals, the prevalence of carious teeth, prevalence of carious teeth by tooth class, and/or the application of caries correction factors. The result is often a lack of inter-site comparability. This can be interpretively problematic as the temporal transition to maize-intensive agriculture is ecologically, geographically, and socio-politically variable (Emerson et al., 2005; Hutchinson et al., 1998; Scarry, 1993; Wilson, 2017). The adoption of stable isotope analysis (i.e., $C^3/C^4$ ratios prevalence) allowed archaeologists to sidestep the shortcomings of osteological preservation and the quantitative methodology issues. However, this option is not available for many pre-Columbian human osteological samples in the contiguous United States as destructive analysis is not permitted.[1]

The intensive adoption of maize as a primary cultigen across the eastern continental United States throughout the middle and lower Mississippi River Valley, the lower Ohio River Valley, and the Southeastern United States north of Florida co-occurs with the most recent pre-Columbian cultural horizon, the Mississippian Period (~AD 1000 – 1500) (Bense, 2016; King, 2017; VanDerwarker, 2017; Wilson, 2017). The horizon reflects the most complex sociopolitical organization north of Mesoamerica (Bense, 2016; Smith, 1990) and is archaeologically manifested by the presence of large aggregated village settlements, often palisaded, that were organized around a central plaza. The plaza, in turn, was flanked by one or more quadrilateral flat-topped mounds with variable functions (e.g., mortuary, domiciliary, temple) (Dalan, 1997; Kidder, 2004; King, 2001; King, 2017; Lewis et al., 1998). Some level of centralized authority (arguably chiefdom-level) is evident (Beck, 2003; Cobb, 2003; King, 2017; Pauketat, 2007). The Mississippian Period is also characterized by a complex iconography (i.e., the "Southeastern Ceremonial Complex" [SECC] or "Southeastern Ceremonial Exchange Network" [SCEN]) of sociopolitical as well as cosmological meaning (Knight, 2006; Knight et al., 2001; Muller, 1989; Reilly and Garber, 2007). The apex of Mississippian culture occurred in the Middle period (CE 1200-1400) when the hallmarks of Mississippian culture are present throughout the middle and lower Mississippi River Valley, the lower Ohio River Valley, and the Southeastern United States north of Florida.

Plant domestication has a long trajectory in the pre-Columbian eastern US (e.g., Fritz, 1990; Scarry, 2008; Smith, 2006, 2011; Smith and Yarnell, 2009). Prior to the dedicated adoption of maize, cultigens consisted of a suite of native oily (e.g., sunflower and marsh elder) and starchy seed grasses (e.g., maygrass, knotweed, lamb's quarter, little barley) referred to as the Eastern Agricultural Complex (EAC) (Scarry, 2008; Smith, 2006; Smith and Yarnell, 2009). The transition from native grasses to maize cultivation was not temporally or geographically uniform and may have been influenced by ecological constraints or peripheral geographic location relative to the Mississippian cultural heartland (e.g., Fritz, 1990; Smith, 2011; 2017). Within this Mississippian culture area, regional polities occur that differed in social complexity and the adoption of Mississippian cultural elements. One of these variants, the Middle Cumberland Culture (MCC), is physiographically concentrated in the Nashville Basin of central Tennessee (Dowd, 2008; Ferguson, 1972; Moore et al., 2006; Smith, 1992) and extends from the Cumberland River drainages between the confluence of the Caney Fork and Cumberland Rivers in the east to the confluence of the Red and Cumberland Rivers in the west (Figure 1). It has been archaeologically observed that the Nashville Basin had a high population density in late prehistory and mirrored the Mississippian socioeconomic pattern of mound centers and agriculturalization (Beahm, 2013; Jolley, 1983). Maize cultivation, likely intensive, is evident in MCC sites (Beahm, 2013; Buikstra, et al., 1988; Crites, 1984).

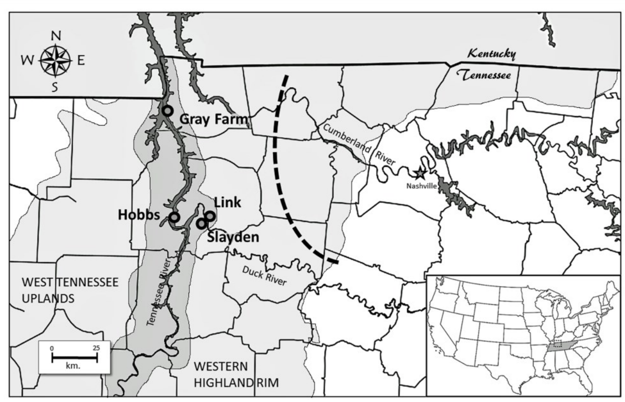


Figure 1. Map of west-central Tennessee identifying the location of the site samples in the Tennessee River Valley. The valley is flanked by two highland areas: the West Tennessee Uplands and the Western Highland Rim. The dashed line demarcates the western most extent of the middle Cumberland Culture.

There are numerous Middle Mississippian sites in the Tennessee River valley west of the highland areas and beyond the western boundary of the MCC in, and adjacent to, what is now the Kentucky Lake Reservoir. Maize-intensive agriculture is ubiquitous in the Late Mississippian period (~ AD 1350-1550) (Bense, 2016; King, 2017; VanDerwarker, 2017; Wilson, 2017), but geographically variable in the Middle Mississippian period. Identifying the subsistence patterning is particularly important in the Kentucky Lake area because there are no Late Mississippian components for any site as the region was inexplicably abandoned by circa AD 1450 (Bass, 1985; Cobb and Butler, 1992; Williams, 1990). With little evaluated archaeological material culture from Kentucky Lake, the dental caries data from sites in this apparent cultural frontier provide critical insight into the dietary importance of maize.

**Materials and Methods**

The three Kentucky Lake Reservoir sites examined for caries prevalence and patterns are physiographically located in the Western Valley of the Lower Tennessee River, which is situated between two highland areas (see Figure 1). To the west, are the Western Tennessee Uplands and to the east, the Western Highland Rim of the Nashville Basin. The sites were excavated as salvage archaeological projects prior to the completion of the Kentucky Dam (Gilbertsville, Kentucky) (1938-1944). Two of the west-central Tennessee archaeological sites, Link (40HS6) and Slayden (40HS1), are located on river bluffs above the Duck River, a tributary of the Tennessee River, at the confluence of its tributary, the Buffalo River. The sites are within twenty kilometers of the confluence of the Duck River with the Tennessee River. They are argued to be the same settlement context and are thus evaluated together. Link/Slayden was a multi-mound Mississippian context dating to the Early-to-Middle Mississippian period (~AD 1100-1350) (Bass, 1985; Dye, 2002, 2003; Kuemin Drews, 2000; Lunn, 2013). The Link site is the source of the Duck River Cache, arguably the most spectacular collection of Native American stone work (i.e., circa four dozen stone maces, stone knives, stone daggers) recovered in the Eastern United States (Brehm, 1981; Dye, 2007). The Gray Farm site (40SW1) is a Middle Mississippian multi-mound site located on the eastern bank of the Tennessee River just north of the confluence of the Big Sandy River (Bass, 1985; Kuemin Drews, 2001). Temporally it appears to be as old as Link/Slayden, but archaeological evidence (ceramics and domestic structure types) suggests it was occupied longer (Bass, 1985). It is approximately 50 air kilometers north of Link/Slayden. The third Kentucky Lake Reservoir site assessed for dental caries dates to the Late Woodland (~AD 500-900) period (Kuemin Drews, 2001). Hobbs (40HS44) is a mound mortuary context located downstream from Link/Slayden on the main channel of the Tennessee River (see Figure 1). Archaeologically it co-occurs with the cultivation of the native grasses of the Eastern Agricultural Complex (Smith and Yarnell, 2009).

The permanent dentition of adult burials from the Kentucky Lake site samples was canvassed for the presence of carious lesions. All skeletons had previously been assessed for age and sex using standard non-metric osteological criteria (e.g., Buikstra and Ubelaker, 1994). Individuals were included in the sample if they were skeletally assessed as adults (Buikstra and Ubelaker, 1994) or the preserved third molars (loose or in-situ) were present as, at least, a developmentally complete crown.

The teeth were examined for carious lesions which were scored by size and location on the crown (occlusal, smooth surface [e.g., interdental, buccal, lingual], and/or the cemento-enamel junction [CEJ]). Lesions that involved adjacent teeth were attributed to both teeth. A carious lesion was recognized by a pit measuring at least 1 mm in diameter (Figure 2a) with evidence of demineralization at the orifice (Figure 2b, 2c) to distinguish it from pit-fissure irregularities on the occlusal and buccal surfaces. Assessment was aided by a 2x-4x hand lens. Carious lesions circa 4 mm in diameter were classified as medium and non-pulp-penetrating lesions greater than 4 mm were classified as large. Pulp exposures were included based on the likelihood that they resulted from carious lesions from the crown or CEJ. Where preservation permitted, a necrotic tooth represented only by the roots or a pulp exposure associated with alveolar pocketing was not included (as periodontal disease could not be etiologically excluded). This exclusion did not seem to affect caries prevalence, as necrotic roots were isolated occurrences. Teeth exhibiting antemortem breakage were also excluded. These were identified by sharp-edged concavities with non-demineralized surfaces with evidence of masticatory use (i.e., polish or attrition) (Figure 2d, e, f).

Preservation ranged from fair to poor at all sites. Few individuals preserved complete enough maxillae or mandibles to reliably calculate dental caries

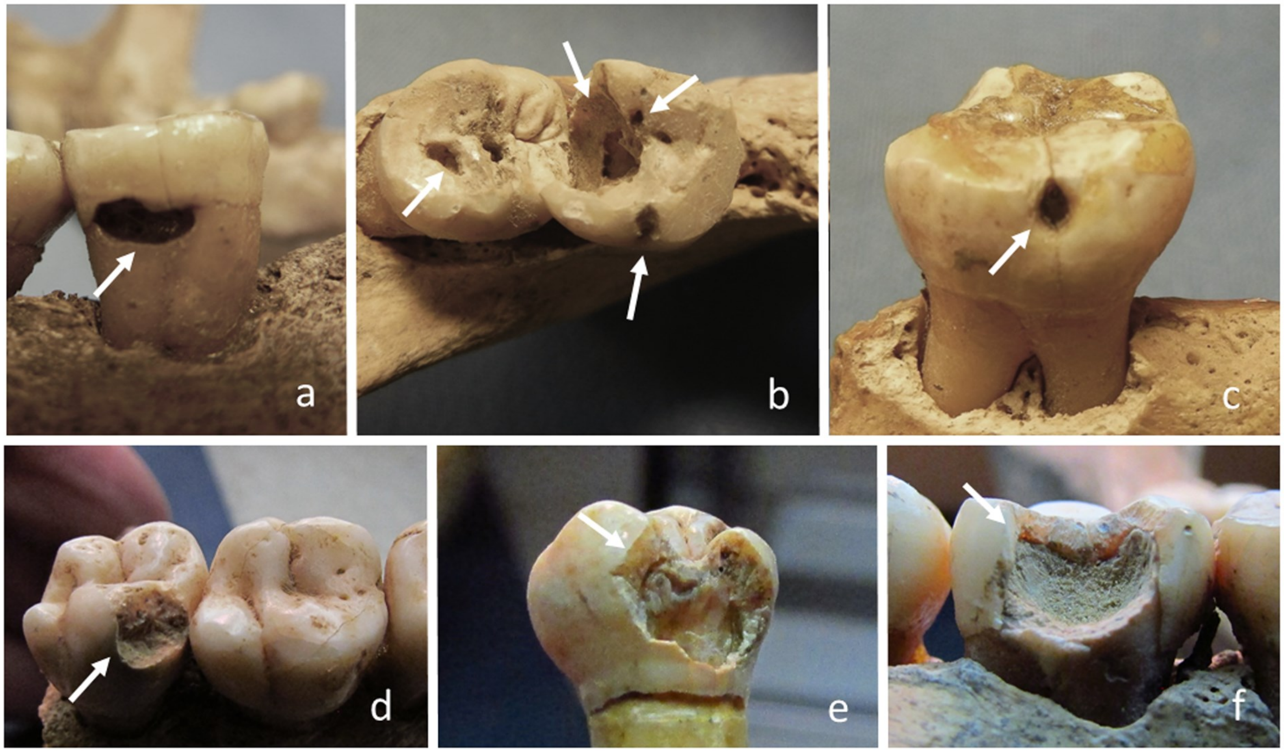


Figure 2. Examples of the extent of carious lesions from the Link (40HS6) sample. a) Burial 6 (Unit 19) exhibits a pulp-penetrating carie at the cemento-enamel junction, b) the first and second molars of Burial 3 (Unit 21) displaying (arrows) pulp exposure, pit-fissure occlusal cavities larger than 1 mm, and a carious lesion in the buccal pit, c) and Burial 3 (Unit 67) illustrates a carious buccal pit. Non-carious antemortem cusp breakage (sharp perimeter, no demineralization) is exemplified in d) Burial 30 (Unit 21) with non-carious dentin-exposing breakage exhibited in e) Burial 32 (Unit 21) and f) Burial 38 (Unit 21).

prevalence by individual or to apply a Caries Correction Factor. The present study assesses dental caries by three tooth type categories irrespective of arch or antimere: incisors and canines (I/C), premolars (PM), and molars. Molars were also assessed by position in the tooth row (M1-M3). The samples were compared for sex differences within the site sample and between site samples. Adults were also segregated into three age-at-death categories: young (18 to ~35 years), middle (35 to 50 years), and mature (50+ years) based on the skeletal age-at-death range provided in the computer database.

A local comparative context was needed to assess whether the Middle Mississippian period Kentucky Lake samples were maize-intensive agriculturalists or whether they continued to cultivate native grasses. As no data sample is available (either published or available for research) from the Middle Cumberland Culture or the Mississippi River Valley of Tennessee, three unequivocal Late Mississippian (~1300-1450 AD) period maize-intensive agriculturalist site samples from East Tennessee were utilized. The sites are also pre-reservoir archaeological salvage projects and are located along the Tennessee River or its tributary, the Little Tennessee River. The Little Tennessee River valley samples are from the sites of Toqua (40MR6) and Citico (40MR7) (i.e., Tellico Reservoir), and the Dallas (40HA1) site located along the Tennessee River (i.e., Chickamauga Reservoir) (Betsinger and Smith, 2013, 2018). The data were previously collected by the authors and reflect the same collecting protocols as the Kentucky Lake site samples.[2]

The prevalence rates of caries by the three tooth types were compared utilizing the Fisher's Exact Test ($p \leq 0.05$). Intra-site comparisons were based on sex, while inter-site comparisons were made for the entire sample, for males, for females, and by age cohort. Further segregating the samples into age categories by sex yielded sample sizes too small for statistical assessment (e.g., $n < 10$).

**Results**

*Caries by tooth type*

In the Link/Slayden total sample (Table 1), two percent of all preserved teeth exhibit at least one carious lesion. This is the lowest frequency of the three Kentucky Lake samples. When assessed by tooth class, Link/Slayden carious teeth are restricted to the posterior dentition. Over seven percent of all molars exhibit a carious lesion with the third molar the most frequently affected. However, this differential involvement is likely due to the paucity of first and second molars consequential to observed antemortem tooth loss. There are also no carious lesions in the incisiform dentition from the Late Woodland Hobbs site sample. The proportion of carious molar teeth is also circa seven percent. The percent of caries in the Hobbs premolar sample generates the only statistically significant difference between the two samples (Table 2) affecting the significant difference for all dentition (p = 0.0219). The Gray Farm sample has the highest frequency of any carious teeth (17.3%) with caries present in all the tooth classes. Gray Farm has significantly higher caries prevalence for all but the third molar (5/17, 29.4%) compared to the Link/Slayden sample (5/33, 15%). The relatively higher caries rates by tooth class in the Hobbs sample relative to Link/Slayden generate fewer statistically significant differences compared to the Gray Farm sample. Only the more frequent carious second molars in Gray Farm (33.3% vs 4.8%) are significantly different compared to Hobbs (p = 0.0448).

*Sex differences in caries prevalence*

Given that females in many agriculturalist archaeological samples are likely more predisposed to dental caries (e.g., Lukacs, 1996, 2008; Lukacs and Largaespada, 2006), each site sample was tested for

*Table 1. Caries presence, location, and severity by tooth type*

| TOOTH CLASS | all adults cases/n | all adults % | males cases/n | males % | females cases/n | females % | caries location occl | CEJ | ss[2] | caries severity s | m | l | p ex[3] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LINK/SLAYDEN** | | | | | | | | | | | | | |
| I/C[1] | 0/121 | 0 | 0/17 | 0 | 0/74 | 0 | --- | --- | --- | --- | --- | --- | --- |
| PM | 0/98 | 0 | 0/21 | 0 | 0/55 | 0 | --- | --- | --- | --- | --- | --- | --- |
| M1 | 3/55 | 5.5 | 0/6 | 0 | 3/24 | 12.5 | 2/3 | 1/3 | 0/3 | 1/3 | 1/3 | 0/3 | 1/3 |
| M2 | 2/48 | 4.2 | 0/6 | 0 | 1/15 | 6.6 | 1/2 | 1/2 | 0/2 | 0/2 | 0/2 | 0/2 | 2/2 |
| M3 | 5/33 | 15.1 | 1/2 | ---- | 2/11 | 18.0 | 2/5 | 2/5 | 1/5 | 2/5 | 1/5 | 0/5 | 2/5 |
| ALL M | 10/138 | 7.2 | 1/14 | 7.1 | 6/50 | 12.0 | 5/10 | 4/10 | 1/10 | 3/10 | 2/10 | 2/10 | 3/10 |
| ALL DENT | 10/493 | 2.0 | 1/52 | 1.9 | 6/179 | 3.4 | 5/10 | 4/10 | 1/10 | 3/10 | 2/10 | 2/10 | 3/10 |
| **HOBBS** (female) | | | | | | | | | | | | | |
| I/C[1] | 0/38 | 0 | 0/8 | 0 | 0/22 | 0 | --- | --- | --- | --- | --- | --- | --- |
| PM | 3/30 | 10.0 | 1/12 | 8.0 | 2/16 | 12.5 | 0/3 | 3/3 | 0/3 | 3/3 | 0/3 | 0/3 | 0/3 |
| M1 | 2/16 | 12.5 | 2/4 | ---- | 0/7 | 0 | 1/2 | 1/2 | 0/2 | 2/2 | 0/2 | 0/2 | 0/2 |
| M2 | 1/21 | 4.8 | 1/4 | ---- | 0/15 | 0 | 1/1[4] | 1/1[4] | 0/1 | 1/1 | 0/1 | 0/1 | 0/1 |
| M3 | 1/17 | 5.9 | 1/2 | ---- | 0/6 | 0 | 1/1 | 0/1 | 0/1 | 1/1 | 0/1 | 0/1 | 0/1 |
| ALL M | 4/54 | 7.4 | 4/11 | 7.1 | 0/28 | 0 | 3/4 | 2/4 | 0/4 | 4/4 | 0/4 | 0/4 | 0/4 |
| ALL DENT | 7/110 | 6.4 | 5/31 | 16.1 | 2/66 | 3.0 | 3/7 | 5/7 | 0/7 | 7/7 | 0/7 | 0/7 | 0/7 |
| **GRAY FARM** | | | | | | | | | | | | | |
| I/C[1] | 4/48 | 8.3 | 3/12 | 25.0 | 1/21 | 4.8 | 0/4 | 1/4 | 3/4 | 3/4 | 1/4 | 0/4 | 0/4 |
| PM | 4/58 | 6.9 | 1/12 | 8.0 | 1/22 | 4.5 | 1/4 | 2/4 | 1/4 | 3/4 | 1/4 | 0/4 | 0/4 |
| M1 | 10/29 | 34.0 | 2/10 | 20.0 | 1/10 | 10.0 | 3/10 | 3/10 | 4/10 | 8/10 | 2/10 | 0/10 | 0/10 |
| M2 | 7/21 | 33.3 | 1/11 | 9.0 | 4/9 | 44.4 | 6/7 | 0/7 | 1/7 | 7/7 | 0/7 | 0/7 | 0/7 |
| M3 | 5/17 | 29.4 | 0/4 | 0 | 2/10 | 20.0 | 4/5 | 0/5 | 1/5 | 5/5 | 0/5 | 0/5 | 0/5 |
| ALL M | 22/67 | 3.3 | 3/25 | 12.0 | 7/29 | 24.1 | 14/22 | 3/22 | 6/22 | 20/22 | 2/22 | 0/22 | 0/22 |
| ALL DENT | 30/173 | 17.3 | 7/49 | 14.3 | 9/72 | 12.5 | 15/30 | 5/30 | 7/30 | 26/30 | 4/30 | 0/30 | 0/30 |

[1] Incisors and canines are pooled, [2] smooth surface, [3] pulp exposure, [4] teeth with more than one carious lesion

*Table 2. Intra- and inter- Kentucky Lake sample caries prevalence by tooth type*

| | Link/Slayden | Hobbs | Gray Farm |
|---|---|---|---|
| sex differences within samples | | | |
| I/C | ---- | ---- | 0.1250 |
| PM | ---- | 1.0000 | 1.0000 |
| M1 | ---- | ---- | 1.0000 |
| M2 | ---- | ---- | ---- |
| M3 | ---- | ---- | ---- |
| All M | 1.0000 | **0.0040** | 0.3095 |
| All Dent | 1.0000 | **0.0091** | 0.7904 |

| | Link/Slayden x Hobbs | Link/Slayden x Gray Farm | Hobbs x Gray Farm |
|---|---|---|---|
| caries in the total sample | | | |
| I/C | ----- | **0.0059** | 0.1264 |
| PM | **0.0119** | **0.0179** | 0.6787 |
| M1 | 0.3137 | **0.0009** | 0.1641 |
| M2 | 1.0000 | **0.0025** | **0.0448** |
| M3 | 0.6498 | 0.2768 | 0.1748 |
| All M | 1.0000 | **0.0001** | **0.0007** |
| All Dent | **0.0219** | **0.0001** | **0.0003** |
| | | | |
| sample comparisons by males | | | |
| I/C | ---- | 0.0602 | 0.2421 |
| PM | 0.3824 | 0.3824 | 1.0000 |
| M1 | **----** | **----** | ---- |
| M2 | **----** | **----** | ---- |
| M3 | **----** | ---- | ---- |
| All M | 0.1333 | 1.000 | 0.1665 |
| All Dent | **0.0254** | **0.0281** | 1.0000 |
| | | | |
| sample comparisons by females | | | |
| I/C | ---- | 0.2292 | 1.0000 |
| PM | 0.0582 | 0.2857 | 0.5619 |
| M1 | 1.0000 | 1.0000 | 1.0000 |
| M2 | ---- | **----** | **----** |
| M3 | ---- | 1.0000 | ---- |
| All M | 0.0825 | 0.2110 | **0.0104** |
| All Dent | 1.0000 | **0.0144** | **0.0577** |

sex differences. There is an under-enumeration of males by molar type within both the Link/Slayden and Hobbs samples and for the M3 in the Gray Farm sample (see Table 1), therefore the between sex comparisons are restricted. There are no carious teeth in the I/C and PM categories in the Link/Slayden sample but the collective molar and collective dentition tests (including I/C and PM) are not significantly different by sex (see Table 2). In the tests by tooth type in the Gray Farm comparisons, males and females are not significantly different. The Hobbs sample exhibits a statistically different higher prevalence for males in the total tooth sample (16% versus 3%), undoubtedly effected by the higher male prevalence in the (small) male collective molar sample (36.4% versus 0%). In the absence of definitive differences between the sexes in caries prevalence, the samples can be pooled for statistical testing.

*Caries prevalence compared to maize-intensive samples*
The total-sample comparisons of caries presence by tooth type of Link/Slayden with the Toqua, Citico, and Dallas samples generated statistically significant differences for all tests except the third molar (Table 3). In contrast, all the total sample compari-

*Table 3. Caries prevalence in the Kentucky Lake samples compared to maize-intensive samples*

| | TOQUA | | | CITICO | | | DALLAS | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total samples | | | Total samples | | | Total samples | | |
| | Link/ Slayden | Gray Farm | Hobbs | Link/ Slayden | Gray Farm | Hobbs | Link/ Slayden | Gray Farm | Hobbs |
| I/C | **0.0001** | 1.0000 | 0.1070 | **0.0001** | 0.0649 | 1.0000 | **0.0034** | 0.5195 | 0.2444 |
| PM | **0.0001** | 0.4999 | 1.0000 | **0.0001** | 0.4514 | 0.0575 | **0.0001** | 0.4816 | 1.0000 |
| M1 | **0.0001** | 0.6742 | 0.1587 | **0.0005** | 0.3728 | 0.3784 | **0.0001** | 1.0000 | 0.1499 |
| M2 | **0.0004** | 0.6059 | **0.0303** | **0.0003** | **0.0318** | 0.6086 | **0.0001** | 0.2352 | **0.0084** |
| M3 | 0.1273 | 1.0000 | **0.0425** | 0.3657 | 0.1267 | 0.5691 | 0.1780 | 1.0000 | **0.0449** |
| All M | **0.0001** | 0.4796 | 0.2811 | **0.0001** | **0.0015** | 0.2441 | **0.0001** | 0.7780 | **0.0001** |
| All Dent | **0.0001** | 0.5131 | **0.0058** | **0.0001** | **0.0030** | 0.7503 | **0.0001** | 1.0000 | **0.0017** |
| | male samples | | | male samples | | | male samples | | |
| I/C | 0.3833 | 0.1145 | ---- | 1.0000 | 1.0000 | ---- | 0.6043 | **0.0425** | ---- |
| PM | **0.0512** | 0.6982 | ---- | 0.2279 | 1.0000 | ---- | 0.1344 | 1.0000 | ---- |
| M1 | ---- | 0.4930 | ---- | ---- | 0.1947 | ---- | ---- | 0.2140 | ---- |
| M2 | ---- | 0.2900 | ---- | ---- | 1.0000 | ---- | ---- | 0.2757 | ---- |
| M3 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| All M | 0.1216 | 0.0995 | 0.5077 | 0.1980 | 0.4823 | 0.2163 | **0.0458** | 0.0938 | 0.7334 |
| All Dent | **0.0089** | 0.8434 | 1.0000 | **0.0090** | 0.5987 | 0.8300 | **0.0033** | 1.0000 | 1.0000 |
| | female samples | | | female samples | | | female samples | | |
| I/C | **0.0182** | 1.0000 | 0.3794 | **0.0004** | 0.1534 | 0.4900 | **0.0349** | 1.0000 | 0.6075 |
| PM | **0.0319** | 1.0000 | 0.6307 | **0.0001** | 0.5374 | 0.0559 | **0.0020** | 0.4783 | 1.0000 |
| M1 | 0.0782 | 0.7194 | ---- | **0.0526** | 0.0991 | ---- | **0.0160** | 0.0762 | ---- |
| M2 | 0.1137 | ---- | **0.0199** | 0.1903 | ---- | 0.2507 | **0.0034** | ---- | **0.0006** |
| M3 | 0.7201 | 0.7189 | ---- | 1.0000 | 0.3330 | ---- | 0.7089 | 0.7127 | ---- |
| All M | **0.0017** | 0.6690 | **0.0002** | **0.0219** | **0.0004** | 0.8287 | **0.0045** | 0.1448 | **0.0001** |
| All Dent | **0.0001** | 0.4142 | **0.0112** | **0.0001** | **0.0001** | 0.1247 | **0.0001** | 0.1925 | **0.0004** |

sons by tooth type of the Gray Farm sample were not significantly different (Table 4). The Late Woodland Hobbs sample was significantly different in the posterior teeth from two (Dallas and Toqua) of the three East Tennessee Mississippian samples.

The number of statistical tests in the male cohort between the Kentucky Lake samples and the maize-intensive samples were restricted because of poor sample sizes in the male cohort. However, the congruence of the collective Gray Farm sample with the collective maize-intensive samples is maintained in the male sample comparisons (see Table 3). The under-enumeration of males in the Hobbs and Link/Slayden samples limits the number of teeth available to test. However, the pooled male dentitions in Link/Slayden are significantly different from the Toqua, Citico, and Dallas samples. The few tests available for the Hobbs sample are not significantly different for any of the maize-intensive samples. With larger samples available for the females, more tests are possible. Missing only a test for M2, there are otherwise no female sample differences between Gray Farm and any of the maize-intensive samples. The absence of caries in the incisiform teeth and premolars in the Link/Slayden sample is significantly different from all the maize-intensive samples. The lower frequency of dental caries in the first molars of Link/Slayden is significantly different ($p = \leq 0.05$) from the Citico

*Table 4. Comparison of site samples by caries location and severity*

| | Link/Slayden x Hobbs | | | | Link/Slayden x Gray Farm | | | | Hobbs x Gray Farm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | occlusal | CEJ | ss[1] | | occlusal | CEJ | ss[1] | | occlusal | CEJ | ss[1] | |
| All M | 0.5804 | 1.000 | ---- | | 0.6993 | 0.1655 | 0.3871 | | 1.0000 | 0.5633 | ---- | |
| | s | m | l | p ex[2] | s | m | l | p ex[2] | s | m | l | p ex[2] |
| All M | 0.0699 | 1.0000 | 1.0000 | 0.5055 | **0.0010** | 0.5717 | 0.0907 | **0.0242** | 1.0000 | 1.000 | ---- | ---- |
| TOQUA | | | | | | | | | | | | |
| | Link/Slayden | | | | Gray Farm | | | | Hobbs | | | |
| | occlusal | CEJ | ss[1] | | occlusal | CEJ | ss[1] | | occlusal | CEJ | ss[1] | |
| All M | 0.4997 | 1.0000 | 0.6885 | | **0.0183** | **0.0092** | 0.5791 | | 0.1404 | 1.0000 | 0.5832 | |
| | s | m | l | p ex[2] | s | m | l | p ex[2] | s | m | l | p ex[2] |
| All M | 1.0000 | 1.0000 | 0.6183 | 1.0000 | **<0.0001** | 0.3754 | 0.1356 | **0.0003** | **0.0158** | 1.0000 | 1.0000 | 0.3033 |
| CITICO | | | | | | | | | | | | |
| | Link/Slayden | | | | Gray Farm | | | | Hobbs | | | |
| | occlusal | CEJ | ss[1] | | occlusal | CEJ | ss[1] | | occlusal | CEJ | ss[1] | |
| All M | 0.7558 | 0.2425 | 0.6933 | | 0.5004 | 0.5771 | 0.5997 | | 0.6303 | 0.2229 | 0.5765 | |
| | s | m | l | p ex[2] | s | m | l | p ex[2] | s | m | l | p ex[2] |
| All M | 0.0978 | 1.0000 | 0.3481 | 0.1185 | **0.0039** | 0.3779 | 0.1348 | 0.1348 | 0.1537 | 1.0000 | 1.0000 | 1.0000 |
| DALLAS | | | | | | | | | | | | |
| | Link/Slayden | | | | Gray Farm | | | | Hobbs | | | |
| | occlusal | CEJ | ss[1] | | occlusal | CEJ | ss[1] | | occlusal | CEJ | ss[1] | |
| All M | 0.5008 | 0.7239 | 1.0000 | | 1.0000 | 0.1213 | 0.1121 | | 1.0000 | 0.5906 | 1.0000 | |
| | s | m | l | p ex[2] | s | m | l | p ex[2] | s | m | l | p ex[2] |
| All M | 0.1823 | 1.0000 | 0.1737 | 0.4472 | **0.0029** | 0.3615 | 0.6030 | **0.0135** | 0.1383 | 1.0000 | 1.0000 | 0.5818 |

[1] smooth surface, [2] pulp exposure

and Dallas samples, but not for the Toqua sample (p = 0.07194). The caries prevalence for females in the Link/Slayden samples for M2 and M3 are only significantly different for M2 in the Dallas sample. However, the pooled molar sample indicates that the fewer carious teeth in the Link/Slayden sample is significantly different from all of the maize intensive samples.

In general, the tests for Gray Farm reveal a similar pattern of caries prevalence compared to Toqua, Citico, and Dallas. In contrast, the Link/Slayden sample is significantly different from the same samples. The Late Woodland Hobbs sample, collectedly and segregated by sex, exhibits caries prevalence congruence with the Citico sample. Hobbs does have a lower case prevalence of caries in the posterior teeth when compared to the Toqua and Dallas samples.

*Caries in Kentucky Lake by location and lesion size*

Inter-sample comparisons are limited to the posterior teeth as Link/Slayden and Hobbs have no carious I/C dentition (see Table 4). The most common locations for carious lesions are the occlusal surfaces followed by the CEJ. Smooth surface caries, that is, those that occur buccolingually and mesiodistally are infrequent and most often occur in a buccal pit (e.g., see Figure 2b, c). There is no statistically significant difference among the Kentucky Lake sites for crown/CEJ location of carious lesions. Lesion size in the four carious molars from the Hobbs sample are all small and there are no cases of pulp exposure. The larger samples of Link/Slayden and Gray Farm (see Table 4) generated statistically significant differences in the prevalence of small diameter caries and pulp exposures. The trend is toward larger size carious lesions in the Link/

Slayden sample and smaller size caries in Gray Farm.

*Lesion size and location compared to maize-intensive samples*

The comparisons for location of carious lesions on the tooth appear to not distinguish a maize-intensive diet in any patterned way. Locations for Link/Slayden and Hobbs do not differ from the Toqua, Citico, or Dallas samples (see Table 4). Gray Farm distinguishes from Toqua by having more occlusal relative to CEJ dental caries. Lesion size also does seem to discriminate the maize-intensive diet; neither Link/Slayden nor Hobbs differ from Citico or Dallas. The Hobbs sample differs in the proportion of small lesions from Toqua, but the prevalence difference in the expression of small lesions in Hobbs is likely an issue of sample size (4/4, 100%). The almost exclusive expression of dental caries as small lesions and the absence of pulp exposures (see Table 1) does distinguish Gray Farm from all three maize-intensive samples, as well as Link/Slayden.

*Age-at-death differences in caries prevalence among Kentucky Lake samples*

The paucity of burials classified as mature (50+ years of age) meant that age-at-death comparisons are restricted to the young (< 35 years) and middle age (35-50 years) cohorts. There are no carious teeth in the young adult samples of Hobbs (0/21) and Link/Slayden (0/65). Whereas 12.5% of the dentition (9/72) in the Gray Farm sample are carious. The prevalence difference is statistically significant between Link/Slayden and Gray Farm (Table 5). All of the carious teeth identified for the Hobbs sample belonged to ageable adults and fall into the middle age-at-death category (7/57, 12.3%). Only four carious teeth are ageable in the Link/Slayden sample and reflect 8.7 percent (4/46) of the middle age cohort. Hobbs and Link/Slayden are not significantly different from each other (p=0.7506). The larger proportion of carious teeth in the Gray Farm sample (6/31, 19.3%) is not statistically different either from Link/Slayden or Hobbs (see Table 5).

Given that the preponderance of carious teeth are molars, the molar teeth are compared by age-at-death. In the young age-at-death category, the Link/Slayden absence of caries (0/27) is significantly different from the Gray Farm sample (7/37, 18.9%) (p=0.0125) but the small sample of molars in the Hobbs sample (0/7) was not significantly different from Gray Farm or Link/Slayden (see Table 5). In the middle age-at-death category, Link/Slayden (4/21, 19%), Hobbs (4/23, 17.4%), and Gray Farm (1/10, 10%) are not significantly different from each other (See Table 5).

*Table 5. Comparison of site samples by age at death*

| | Link/Slayden x Hobbs | | Link/Slayden x Gray Farm | | Hobbs x Gray Farm | |
|---|---|---|---|---|---|---|
| | young | middle | young | middle | young | middle |
| All teeth | ---- | 0.7506 | **0.0033** | 0.1891 | 0.2010 | 0.5304 |
| All molars | 1.0000 | 1.0000 | **0.0125** | 1.0000 | 0.3126 | 1.0000 |
| **TOQUA** | | | | | | |
| | Link/Slayden | | Gray Farm | | Hobbs | |
| | young | middle | young | middle | young | middle |
| All Teeth | **0.0096** | 0.0806 | 0.1830 | 1.0000 | 0.3989 | 0.2221 |
| All molars | **0.0174** | 0.2279 | 0.4490 | 0.1735 | 0.5988 | 0.1618 |
| **CITICO** | | | | | | |
| | Link/Slayden | | Gray Farm | | Hobbs | |
| | young | middle | young | middle | young | middle |
| All teeth | **0.0001** | 0.1582 | 0.8579 | 0.8078 | 0.0979 | 0.4638 |
| All molars | **0.0011** | 0.6095 | 0.8285 | 0.4614 | 0.2020 | 0.4610 |
| **DALLAS** | | | | | | |
| | Link/Slayden | | Gray Farm | | Hobbs | |
| | young | middle | young | middle | young | middle |
| All teeth | **<0.0001** | 0.2620 | 0.5971 | 0.6086 | **0.0561** | 0.6827 |
| All molars | **0.0002** | 0.7757 | 0.3989 | 0.4433 | 0.1073 | 0.5824 |

*Age-at-death differences in caries prevalence compared to maize-intensive samples*
Although Link/Slayden is a Middle Mississippian site sample, it has consistently statistically significant lower caries prevalence in the young age-at-death category compared to Toqua, Citico, and Dallas. Antithetically, Gray Farm is statistically similar to all three. Hobbs does not differ from Toqua, but does for Dallas, and for Citico at a lower level of statistical reliability (p = ≤0.10). All samples are similar in the middle age category (see Table 5).

*Age-at-death difference for size and location of caries*
The preponderance of carious molars in the ageable Kentucky Lake sample (n=17) are found on the occlusal surface (14/17). The absence of carious teeth in the young age-at-death category of Link/Slayden and Hobbs means that no comparisons could be made among the Kentucky Lake samples. In the middle age-at-death category, there are nine molars in the collective sample. The molars in Hobbs and Link/Slayden have the same proportion of occlusal to cervical caries: three-to-one; the Gray Farm site has a single molar with an occlusal carious lesion. There is a subtle difference between the molars of Hobbs and Link/Slayden in the middle age-at-death category. All four of the lesions on the molars in the Hobbs sample are small in size while two of the occlusal carious lesions in the Link/Slayden sample are medium-sized. Link/Slayden also exhibits the only ageable carious lesion (at the CEJ) with pulp exposure. The absence of a statistically valid sample in the Kentucky Lake samples negated comparisons with the maize-intensive samples.

**Discussion**
*The archaeological context*
The bioarchaeological co-association of the intensive cultivation of specific cariogenic carbohydrates with dental caries prevalence (i.e., number of carious teeth) greater than 10 percent is commonly reported world-wide (e.g., Caselitz, 1998; Karsten et al., 2015; Larsen, 1991, 2005; Lubell et al., 1994; Lukacs, 1992; Patterson, 1986; Šlaus et al., 2011; Temple and Larsen, 2007; Turner, 1979) as well as in the late prehistoric contiguous United States (e.g., Emerson et al., 2005; Larsen, 1981; Powell, 1985; Watson, 2005). The utility of dental caries to flag agricultural intensification and/or the cultivation of particular cariogenic carbohydrates is particularly critical in archaeological contexts where material culture is wanting. The Mississippian sites of the Kentucky Lake Reservoir are located in a cultural frontier between the Middle Cumberland Culture of the Nashville Basin and the various Mississippian period phases of the Mississippi River watershed located west of the West Tennessee Uplands (see Figure 1) (see Mainfort, 1996; Mainfort and Moore, 1998; Smith, 1990). The socioeconomic context of the Kentucky Lake Mississippian sites is poorly understood, as are the geographically adjacent late prehistoric cultures from the Mississippi River watershed of west Tennessee. The Mississippi River valley (MRV) archaeological contexts are frequently compromised by historic period development (e.g., cultivation, urbanization, transportation [railroad and highway construction]), major changes in the meander pattern of the Mississippi river, and, unfortunately, looting (Mainfort and Moore, 1998). To date, much of the late prehistoric MRV archaeological assessment centers on ceramic patterns and their geographic distributions. However, there is archaeobotanical evidence of maize at the Chucalissa site (40SY1) (AD 1250-1500) located in the south-western corner of the state of Tennessee near the present-day city of Memphis (Smith, 1990). The general paucity of bioarchaeological data in the Mississippi River Valley limits comparisons with the Kentucky Lake samples to all but the most well-known Middle-to-Late Mississippian period site of Chucalissa (McNutt et al., 2012). Dental caries data for Chucalissa are restricted to the number of carious teeth (271/1386, 19.6%) (Robinson, 1976), which compares favorably (p = 0.7465) with the Gray Farm site sample (30/173, 17.3%), and contrasts with Link/Sladen (p = 0.0001) and Hobbs (p = 0.0041).

Whether maize presence as a staple crop in the Mississippi River Valley influenced a diffusion toward, at least, Gray Farm, is problematic. There is scarce evidence of Mississippian occupation east of the Mississippi River floodplain in the West Tennessee Uplands (Mainfort, 1996; Smith, 1990) suggesting little or no cultural influence from the Mississippi River Valley. Indeed, according to the seminal archaeological overview of Mississippian sites in the Kentucky Lake Reservoir by Quentin Bass, Mississippianization was an *in situ* development rather than culture-bearing in-migration(s) of populations into the area (1985:93).

In contrast, the mortuary pattern of interment characterized by the lining of the grave pit with stone slabs (“stone box burials”) associated with the Middle Cumberland Culture (AD 1250-1450, Thruston phase) of the Nashville Basin (Figure 1) (Dowd, 2008; Ferguson, 1972) frequently occurs in Kentucky Lake Reservoir Mississippian sites (Bass, 1985; Wamsley, 2018). Relative to the present study, the mortuary pattern of the Gray Farm site includes stone boxes as well as secondary interments of charnel house burials, whereas the entirety of the mortuary treatment at Link/Slayden is stone box (Bass, 1985; Wamsley, 2018). Predictably, no stone box interments occur at the Late Woodland Hobbs site (Kuemin Drews, 2000; Wamsley, 2018). Unfortunately, no caries data are available from Middle Cumberland Culture sites.

The socioeconomic circumstance of the Kentucky Lake samples is temporally important, as no Late Mississippian occupation (i.e., AD 1400-1600) is evident (Bass, 1985). This pre-Columbian abandonment of the lower Tennessee River valley is part of a larger post-AD 1450 regional depopulation phenomenon centered in the lower Ohio River valley known as "the Vacant Quarter" (Cobb and Butler, 2002; Williams, 1990). The abandonment is not well understood (Cobb and Butler, 2002; Williams, 1990), but may very well co-associate with precipitation corollaries of major climate change (i.e., "Little Ice Age," circa AD 1400-1850) (e.g., Anderson, 2001; Meeks and Anderson, 2013; Stinchcomb et al., 2011).

*The maize-intensive patterns*

The frequency of carious teeth by tooth type and caries prevalence segregated by age-at-death in the Gray Farm sample compared to the unequivocal maize-intensive samples from East Tennessee (e.g., Chapman, 2014; Polhemus, 1987) strongly suggests that it reflects a maize-intensive subsistence strategy. The strategic location of the Gray Farm site straddling the Cumberland and Tennessee River Valleys (see Figure 1) may have eco-culturally influenced the adoption of maize as a primary cultigen. That is, the Gray Farm site is located downstream from the communities of the Middle Cumberland Culture who are archaeologically identified as maize intensive (e.g., Beahm, 2013; Crites, 1984).

A singularity of the Gray Farm dental caries pattern occurs in lesion size and location relative to the Link/Slayden sample as well as the three Late Mississippian sites (Table 4). Gray Farm has an over enumeration of small carious lesions and an under-representation of pulp exposures. A number of variables could explain this finding. It could suggest a qualitatively different cariogenic food consumption pattern. That is, processing and/or consumption of maize that limits the metabolic activity of the oral bacteria. Or, more likely, a biased dental sample relative to antemortem tooth loss. The proportion of molar teeth out of the total tooth sample available for study is consistent across the age-at-death categories for Hobbs (7/28, 33% versus 23/57, 40%) and Link/Slayden (27/67, 40.3% versus 19/44, 43.2%). However, in the young age-at-death category for Gray Farm, over 50 percent of the dental sample is composed of molars (37/71); in the middle age-at-death category, the proportion is reduced to a third (10/30). Given that neither Hobbs nor Link/Slayden register any carious lesions among the young adults, the retention of teeth with more advanced lesions in middle age is plausible. Whereas, cariogenesis initiated in (at least) early adulthood would inevitably progress to necrosis and tooth loss by middle age. A directed examination of antemortem tooth loss would corroborate this.

*The Link/Slayden patterns*

The archaeological context of the Link/Slayden site sample indicates a Mississippianized settlement pattern of a multiple-mound aggregated village (Bass, 1985), but it is clear that the subsistence pattern is different from Gray Farm and the East Tennessee Late Mississippian sites. The congruence of many of the dental caries comparisons with the Late Woodland Hobbs site and significant difference of the Link/Slayden sample with the maize-intensive samples affirms this. Interpretively important, the pattern and prevalence of dental caries is not consistent with pre-agricultural data. The total tooth sample caries prevalence for three Late Archaic hunter-gatherer samples from this reservoir is 2.7 percent (93/3414) (Smith, 1982) and is significantly different from Hobbs ($p=0.0352$) and Link/Slayden ($p=0.0316$). The location of carious lesions on all teeth in the Archaic sample is almost exclusively at the CEJ (53/58, 91.4%), in contrast to Hobbs where half of all carious lesions are on the occlusal surface.

The congruence of Link/Slayden and Hobbs in caries prevalence as well as the similarity of certain caries frequencies of Hobbs with the maize-intensive samples is consistent with the history of plant domestication in the Kentucky Lake Reservoir area. That is, west-central Tennessee is part of the core area within which the Eastern Agricultural Complex developed that was well-established by the Late Woodland period (e.g., Smith, 2006, 2011; Smith and Yarnell, 2009). In particular, archaeobotanical data from sites upstream in the Duck River

Valley (Normandy Reservoir) indicate there was a shift in the Late Woodland from the ceremonial use of maize to dietary use (Cobb and Faulkner, 1978; Shea, 1977). However, an elevation in caries prevalence does not necessarily indicate a shifting reliance toward maize as high prevalence has been observed in Woodland contexts pre-dating the introduction of maize (e.g., Alfono-Durrity et al., 2014; Rose and Marks, 1985; Rose et al., 1991).

Although the location of Link/Slayden may be geographically remote relative to the core area of the maize-intensive MCC, it is more likely that the site sample is temporally earlier than Gray Farm. A recent assessment of the ceramics at the Slayden site suggests a primary occupation at the earlier end of the temporal spectrum (~ AD 1100-1200) (Lunn, 2013), implying that maize-intensive agriculture, and perhaps the primary occupation of Gray Farm, post-dated circa AD 1200 in the Kentucky Lake Reservoir area.

*Dental caries as an archaeological problem-solving tool.* The progressive nature of carious lesions ultimately results in tooth necrosis and exfoliation. The geometry and length of time particular teeth are in occlusion certainly affect pathogenesis and vulnerability. However, the process is not simply linear as many intrinsic (e.g., general health, hypoplastic defects, attrition, periodontal disease, pregnancy/lactation) and extrinsic (e.g., food processing, food preparation) factors are involved. In short, dental caries is not simply a proxy for the dietary reliance of one or another fermentable carbohydrate. However, as the Kentucky Lake samples illustrate, the complexities of cariogenesis can be modulated to address particular archaeological questions despite the analytical constraints imposed by poor preservation and small sample size. The results of the present study suggest that maize-intensive agriculture temporally occurred in the Middle Mississippian period (~ AD 1100-1350) of the Kentucky Lake Reservoir area of west-central Tennessee post-dating the primary occupation of the Link/Sladen sites (~ AD 1200). All Mississippian period occupation of west-central Tennessee terminated by ~ AD 1450.

**Endnotes**

[1] The research protocols of the osteoarchaeological samples currently curated by the Frank H. McClung Museum, inclusive of the samples in this study, are not eligible for any form of destructive analysis.

[2] In accordance with NAGPRA regulations, the osteoarchaeological samples currently curated by the Frank H. McClung Museum are no longer eligible for research purposes pending repatriation and reburial.

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# Age and Sex-Related Topography of Carious Lesions and Oral Conditions among Prehispanic Coastal Mayas

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**Keywords:** Oral health, caries topography, antemortem tooth loss, Maya, Prehispanic, Mexico

*ABSTRACT* **Objectives**: The objective is to assess topographic distribution of carious lesions on the crown and cement-enamel junction (CEJ) by sex and age class and relate it to food intake.
**Materials and methods**: Sixty-eight males and 45 females aged 15 years and older from the Prehispanic Classic period Maya site of Xcambó (AD 250-700) were selected and organized into 15-30 years, 31-45 years and 46+years age classes. Caries were scored on all permanent teeth based on their location on the crown, interstitial CEJ as well as buccal and lingual CEJ. Antemortem tooth loss (AMTL) was considered as present when the tooth socket was remodeled and the bone reabsorbed to such an extent that it no longer provided support for the tooth.
**Results**: Caries affected 14.6% of the permanent teeth in males and 27.7% in females. About half of all the lesions were located at the mesial and distal CEJ edge of the teeth (50% in males and 46.6% in females), while 12.9% and 17.1% (respectively for males and females) affected the buccal and lingual CEJ edge. Multiple carious lesions were found on 19.7% of teeth in males and 24.9% in females. Lastly, AMTL was recorded in 16.4% of sockets in males and in 27.4% in females. The overall frequencies of dental caries and AMTL increase with age at death, and differences by sex are statistically significant; on the contrary, interstitial CEJ, buccal and lingual CEJ and multiple carious lesions do not follow an age-related pattern of distribution, and do not show statistically significant differences between males and females when differences are analyzed using Chi-Squared test.
**Discussion and conclusions**: The coastal site of Xcambó shows one of the highest frequencies of dental caries in the region. The high socioeconomic status of the site suggests that carious lesions were not due to a diet based on maize, but that also sugary (honey and various fruits) and starchy foods were ingested on a daily basis. Cariogenic sticky foodstuff, which likely triggered dental caries progression at the buccal and lingual CEJ edges of the teeth, were ingested by all the members of the society regardless of sex and age.

Studies of carious lesions in Prehispanic Maya societies from the northern lowlands (i.e. the Peninsula of Yucatan, Mexico) have highlighted a marked heterogeneity in the frequency of such lesions (Cucina et al., 2011), regardless of the sites' geographical location. Significant access to non-cariogenic proteins of marine origins (fish and seafood), which characterize coastal sites, is not found to buffer the sites' settlers from the insurgence of carious lesions (Cucina et al., 2003, 2011; Seidemann & McKillop, 2008). Likewise, dental caries is not always an indicator of poor nutrition affecting mainly the fringes or commoner segments of the society (Cucina & Tiesler, 2003, 2007).

The present study focuses on the Maya site of Xcambó, which is dated to the Classic period (AD 250-700) and is located along the northern shores of the Yucatan peninsula (Mexico) (Figure 1). The site was an autonomous port of trade dedicated to the production and administration of marine salt, and its population was characterized by a relatively homogeneous and high socioeconomic level, though no true political elite lived there (Sierra Sosa et al., 2014).

Previous papers (Cucina et al., 2003, 2011) revealed that the human skeletal collection from Xcambó manifested among the highest frequencies of carious lesions in comparison with other inland and coastal sites from the region. Cucina et al. (2003, 2011) have already discussed the generic causes of Xcambó' s high frequency of dental caries, with the 2003 paper investigating the oral conditions in the site's different compounds. Given the site's economic wealth, and the large amount of fish and animal remains recovered, which suggests a diet

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with heavy animal protein consumption, the authors pointed to both lifestyle and daily habits, and to the access to cariogenic food like honey, as causative factors for carious lesions. According to their findings, and to the evidence that both males and females equally increased in carious lesion frequencies from an earlier time, access to such "exotic" types of food was granted to both sexes and was not gender related.

However, all these studies (see Cucina et al., 2011 for a list of comparative studies and related publications) focused on the overall frequency of carious lesions regardless of their topographic location on the crown or around the teeth cervical edges.

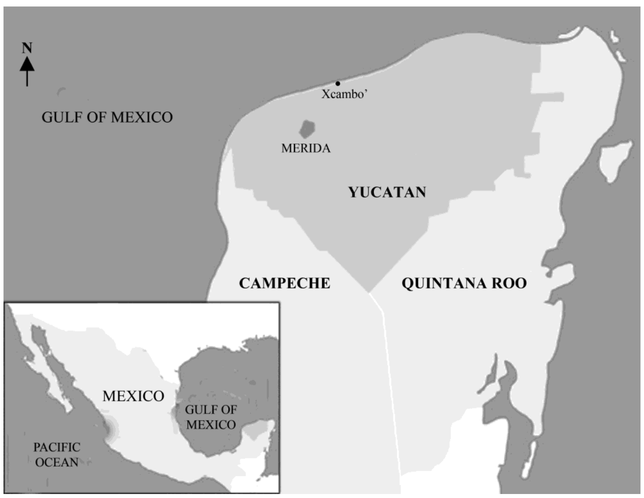


Figure 1. Geographical location of the site of Xcambó within the context of the northern Maya lowlands, Yucatan.

Topographic distribution of carious lesions is meant to be informative of the kind of food ingested, in particular for cervical caries that are considered indicative of a starchy diet and are found to affect mainly older individuals (Lanfranco & Eggers, 2010; Lingström et al., 2000). Based on these premises, the present study aims at investigating the topographic distribution of carious lesions by age and sex in the permanent dentitions of a selected sample from the Classic period Maya skeletal collection of Xcambó. The purpose of this study is to assess, and interpret it from a biocultural perspective, whether age and sex play a role in the onset of different kinds of carious lesions (i.e., crown vs cervical), or whether the qualitative (topographic) distribution of carious lesions is independent from the individuals' biovital parameters.

**Materials and Methods**

The skeletal sample was excavated between 1996 and 2000 by one of the authors (TSS, - National Institute of Anthropology and History, Yucatan Center) (Sierra Sosa, 1999; Sierra Sosa et al., 2014). The skeletal collection is currently housed at the Bioarchaeology and Histomorphology Laboratory, School of Anthropological Sciences, Autonomous University of Yucatan (UADY). For the present study, 113 individuals were selected. In order to avoid interobserver error, only individuals scored by the senior author were chosen. The final sample comprises 68 males and 45 females, and is composed of individuals for whom sex and an age at death of 15 years and older could be estimated. Individuals not scored by the senior author, without a clear sex determination, and whose age at death did not fit into the 15-30 years, 31-45 years and 46+ years age categories, were excluded from the present study. Every individual was assigned to one of three age categories by sex: 23, 30 and 15 individuals comprise the male sample by age classes, and 9, 12 and 24 individuals the female one. Biovital data were extrapolated from the skeletal collections' database of the Bioarchaeology and Histomorphology Laboratory (UADY). A total number of 1,915 permanent teeth and 2,437 sockets were studied.

All the available permanent teeth were scored for the presence of carious lesions, while tooth sockets were evaluated for antemortem tooth loss (AMTL). It must be stressed that the skeletal collection of Xcambó is characterized by a relatively low degree of occlusal wear. Therefore, attrition was not a limiting factor for scoring dental caries and its subsequent analysis.

Carious lesions were scored following a 0-4 scale, with grade zero indicating no lesions; grade 1 indicates that the lesion had affected only the enamel; grade 2 corresponds to the lesion that had penetrated into the dentine. Caries were scored as grade 3 when the lesion had penetrated into the pulpal chamber, and grade 4 indicated a cavity that had destroyed more than half of the crown (Cucina et al., 2003, 2011). Lesions were considered as present when they had penetrated into the dentine; therefore, caries affecting only the enamel were considered as absent (Hillson, 2001; Cucina et al., 2011). Carious lesions were scored according to their location on the crown and long the CEJ. When carious lesions had affected the exposed root, they were recorded as such, and included with CEJ or cervical lesions (Watt et al., 1997). For the purpose of this study, carious lesions affecting any side of the crown were considered all together; mesial and distal CEJ carious lesions, instead, were analyzed separately from those of the buccal and lingual CEJ. Multiple carious lesions have been counted regardless of their location on the crown or the CEJ. The frequencies of teeth presenting mesio-distal CEJ, bucco-lingual CEJ, as well as multiple carious lesions were calculated based on the number of carious teeth. In this case, mesio-distal CEJ and bucco-lingual CEJ are not mutually exclusive because some teeth did present both kinds of lesions at the same time.

The presence of AMTL was considered when the maxillary and mandibular bones were available for study, the tooth socket was remodeled, and the bone had reabsorbed to such an extent that it could not provide support to the tooth. The overall rate of AMTL was calculated on the exclusive basis of the total number of sockets available.

Comparative analyses were run using Chi-Squared statistical test. Sample size was large enough that it did not need Yate's correction or the use of Fisher's exact test.

**Results**

Table 1 lists the frequency of carious lesions for the anterior, posterior, and total dentition by sex and classes of age (see also Figure 2 for the graphical distribution by sex and age). Carious lesions are more frequent in the posterior dentition in comparison with the anterior teeth. In male individuals, lesions range from 13.2% in the 15-30 years age class, to 20.5% in the 46+ class, with a total value of 14.6%. Females, on the other hand, range from 17.3% in the younger class to 37.5% in the older, with a total frequency of 27.7%. Differences between sexes are statistically significant (Chi-Squared=48.17, 1 d.f., p=.000), as previously noted also by Cucina et al. (2011) in a Late Classic-only sample. As expected, frequencies of lesions increase with age for all the categories with the exception of the anterior teeth in the male sample, for which the highest frequency (7.7%) can be found in the younger age class.

The topographic distribution of carious lesions, whose frequency has been calculated out of the total number of teeth with carious lesions, is described in Table 2 and graphically represented in Figures 3 and 4. Mesio-distal cavities at the CEJ (Table 2 upper part, and Figure 3) tend to increase with age in both sexes, with the exception of the anterior teeth in the male segment of the collection. Overall, about half of all the carious lesions scored in the collection are located in between teeth long the CEJ edge of the crown. Differences by sex are not significant (Chi-Squared=0.4206, 1 d.f., p=.5166).

Location at the buccolingual edges of the CEJ (Table 2 lower half, and Figure 4) is less frequent that at the mesiodistal one. Their distribution by sexes and age classes ranges between 0% and 100%; the latter (100.0%) however, is the result of only four carious lesions. Overall frequencies total 12.9% in males and 17.1% in females; similar to the mesio-distal CEJ le-

*Table 1. Absolute values and percent frequencies of carious lesions in the anterior, posterior and total dentition by sex and age classes*

| | Anterior | | | Posterior | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| **Males** | Caries | Caries-free | % | Caries | Caries-free | % | Caries | Caries-free | % |
| 15-30 | 12 | 144 | 7.7% | 46 | 239 | 16.1% | 58 | 383 | 13.2% |
| 31-45 | 10 | 213 | 4.5% | 68 | 280 | 19.5% | 78 | 493 | 13.7% |
| 46+ | 4 | 63 | 6.0% | 38 | 100 | 27.5% | 42 | 163 | 20.5% |
| **Total** | **26** | **420** | **5.8%** | **152** | **619** | **19.7%** | **178** | **1039** | **14.6%** |
| **Females** | | | | | | | | | |
| 15-30 | 7 | 67 | 9.5% | 29 | 105 | 21.6% | 36 | 172 | 17.3% |
| 31-45 | 9 | 59 | 13.2% | 33 | 82 | 28.7% | 42 | 141 | 22.9% |
| 46+ | 42 | 101 | 29.4% | 73 | 91 | 44.5% | 115 | 192 | 37.5% |
| **Total** | **58** | **227** | **20.4%** | **135** | **278** | **32.7%** | **193** | **505** | **27.7%** |

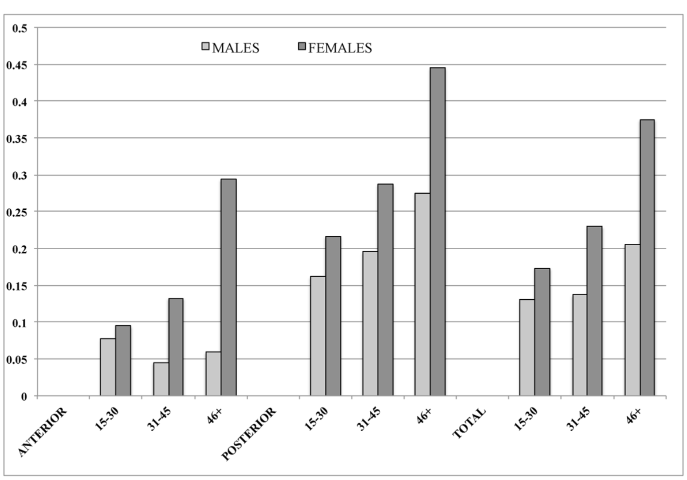


Figure 2. Frequency of carious lesions by sex and age-at-death for anterior, posterior, and total dentition.

*Table 2. Frequency of caries location at the mesio-distal and bucco-lingual CEJ edge for anterior, posterior and total number of teeth by sex and age classes*

| | Anterior | | | Posterior | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| **Male** | Carious teeth | M-D | % | Carious teeth | M-D | % | Carious teeth | M-D | % |
| 15-30 | 12 | 8 | 66.7% | 46 | 16 | 34.8% | 58 | 24 | 41.4% |
| 31-45 | 10 | 5 | 50.0% | 68 | 32 | 47.1% | 78 | 37 | 47.4% |
| 46+ | 4 | 1 | 25.0% | 38 | 27 | 71.1% | 42 | 28 | 66.7% |
| **TOT** | **26** | **14** | **53.8%** | **152** | **75** | **49.3%** | **178** | **89** | **50.0%** |
| **Female** | | | | | | | | | |
| 15-30 | 7 | 2 | 28.6% | 29 | 7 | 24.1% | 36 | 9 | 25.0% |
| 31-45 | 9 | 3 | 33.3% | 33 | 14 | 42.4% | 42 | 17 | 40.5% |
| 46+ | 42 | 27 | 64.3% | 73 | 37 | 50.7% | 115 | 64 | 55.7% |
| **TOT** | **58** | **32** | **55.2%** | **135** | **58** | **43.0%** | **193** | **90** | **46.6%** |
| **Male** | Carious teeth | B-L | % | Carious teeth | B-L | % | Carious teeth | B-L | % |
| 15-30 | 12 | 0 | 0.0% | 46 | 3 | 6.5% | 58 | 3 | 5.2% |
| 31-45 | 10 | 3 | 30.0% | 68 | 6 | 8.8% | 78 | 9 | 11.5% |
| 46+ | 4 | 4 | 100.0% | 38 | 7 | 18.4% | 42 | 11 | 26.2% |
| **TOT** | **26** | **7** | **26.9%** | **152** | **16** | **10.5%** | **178** | **23** | **12.9%** |
| **Female** | | | | | | | | | |
| 15-30 | 7 | 1 | 14.3% | 29 | 7 | 24.1% | 36 | 8 | 22.2% |
| 31-45 | 9 | 1 | 11.1% | 33 | 4 | 12.1% | 42 | 5 | 11.9% |
| 46+ | 42 | 7 | 16.7% | 73 | 13 | 17.8% | 115 | 20 | 17.4% |
| **TOT** | **58** | **9** | **15.5%** | **135** | **24** | **17.8%** | **193** | **33** | **17.1%** |

sions, difference by sex is not statistically significant (Chi-Squared=1.2607, 1 d.f., p=.2615). In general, buccolingual CEJ carious lesions tend to increase with age, with the exception of the female younger age class, which shows higher frequencies in comparison with the two other age classes.

Table 3 and Figure 5 present the absolute values and percent frequencies of multiple caries within the total number of carious lesions, by sex and age classes. Similarl to the overall frequency of lesions, also for multiple caries females present higher frequencies (ranging between 24.4% and 25.9%) than their male counterpart (ranging between 19.2% and 19.7%). In this case, however, differences between sexes are not statistically significant (Chi-Squared=1.4459, 1 d.f., p=.229).

Multiple lesions do not follow the same patterns by age and location as the overall rate of dental caries. In fact, the age class that appears to be most often affected by more than one lesion in a single tooth is the 31-45 years, both for males and females. Also, the category of posterior teeth, which is the one that is more often affected by dental caries, does not always present higher frequencies of multiple lesions. To the same extent as the pattern by age class, also in this case the lack of a clear pattern applies for males and females, and the difference between sexes is not significant (Chi-Squared=1.4459, 1 d.f., p=.229).

Last, AMTL is presented in Table 4 and Figure 6. Similar to dental caries frequency, AMTL also increases with age in both sexes, and the difference between males and females is statistically significant (Chi-Squared=42.1579, 1 d.f., p=.000). The most noticeable increase occurs in the female oldest group, which shows a total frequency of 42.1% in comparison with the 16.1% calculated among females 31-45 years of age. An increase in males, instead, is not as noticeable as in their female counterpart.

## Discussion

The sample used in this study is slightly different from the ones previously published by Cucina and colleagues (2003, 2011), for it includes a younger age cohort of individuals between 15 and 20 years of age (Cucina et al., 2003, 2011 started from age 20 and older), and only used sexed individuals whose age could be assigned to one of the three age classes. Nonetheless, overall frequencies are very similar between the studies. As expected, the overall frequency of carious

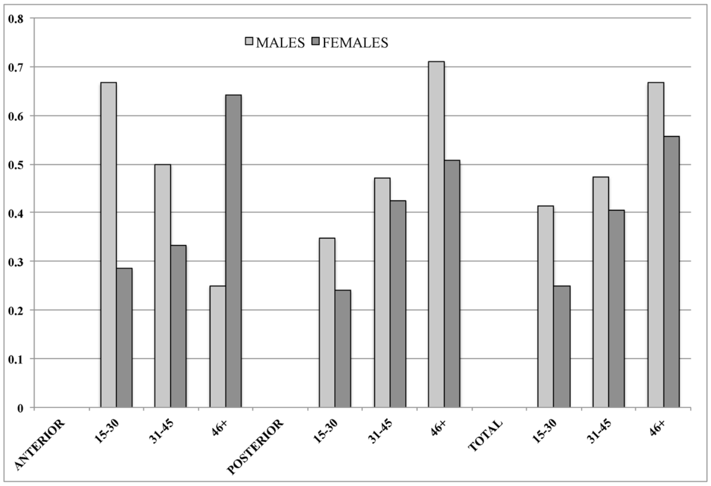


Figure 3. Frequency of mesial and distal CEJ carious lesions by sex and age-at-death for anterior, posterior and total dentition.

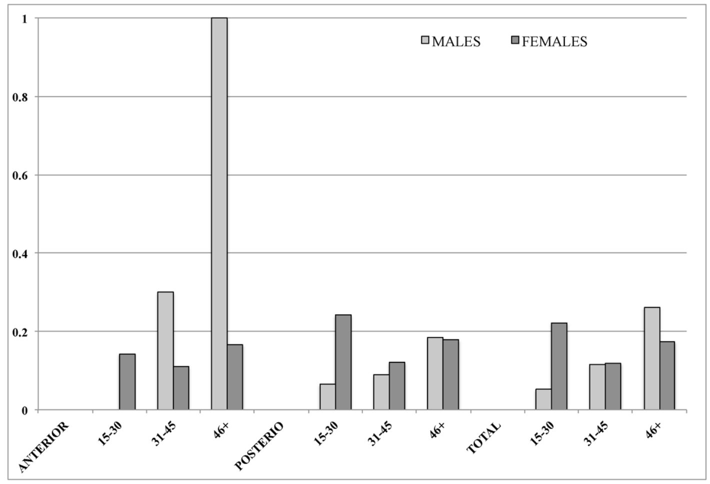


Figure 4. Frequency of buccal and lingual CEJ carious lesions by sex and age-at-death for anterior, posterior and total dentition.

*Table 3. Frequency of multiple caries in the anterior, posterior and total dentition by sex and age classes*

| | Anterior | | | Posterior | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| **Male** | Carious teeth | Multiple | % | Carious teeth | Multiple | % | Carious teeth | Multiple | % |
| 15-30 | 12 | 3 | 25.0% | 46 | 8 | 17.4% | 58 | 11 | 19.0% |
| 31-45 | 10 | 1 | 10.0% | 68 | 15 | 22.1% | 78 | 16 | 20.5% |
| 46+ | 4 | 1 | 25.0% | 38 | 7 | 18.4% | 42 | 8 | 19.0% |
| **Total** | **26** | **5** | **19.2%** | **152** | **30** | **19.7%** | **178** | **35** | **19.7%** |
| **Female** | | | | | | | | | |
| 15-30 | 7 | 0 | 0.0% | 29 | 4 | 13.8% | 36 | 4 | 11.1% |
| 31-45 | 9 | 2 | 22.2% | 33 | 12 | 36.4% | 42 | 14 | 33.3% |
| 46+ | 42 | 13 | 31.0% | 73 | 17 | 23.3% | 115 | 30 | 26.1% |
| **Total** | **58** | **15** | **25.9%** | **135** | **33** | **24.4%** | **193** | **48** | **24.9%** |

*Table 4. Frequency of AMTL for anterior, posterior and total number of open and remodeled sockets by sex and age classes*

| | Anterior | | | Posterior | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| **Male** | AMTL | TOTAL | % | AMTL | TOTAL | % | AMTL | TOTAL | % |
| 15-30 | 9 | 208 | 4.3% | 39 | 336 | 11.6% | 48 | 544 | 8.8% |
| 31-45 | 34 | 190 | 17.9% | 70 | 429 | 16.3% | 104 | 619 | 16.8% |
| 46+ | 34 | 151 | 22.5% | 66 | 219 | 30.1% | 100 | 370 | 27.0% |
| **TOT** | **77** | **549** | **14.0%** | **175** | **984** | **17.8%** | **252** | **1533** | **16.4%** |
| **Female** | | | | | | | | | |
| 15-30 | 4 | 68 | 5.9% | 12 | 128 | 9.4% | 16 | 196 | 8.2% |
| 31-45 | 12 | 101 | 11.9% | 29 | 153 | 19.0% | 41 | 254 | 16.1% |
| 46+ | 36 | 123 | 29.3% | 155 | 331 | 46.8% | 191 | 454 | 42.1% |
| **TOT** | **52** | **292** | **17.8%** | **196** | **612** | **32.0%** | **248** | **904** | **27.4%** |

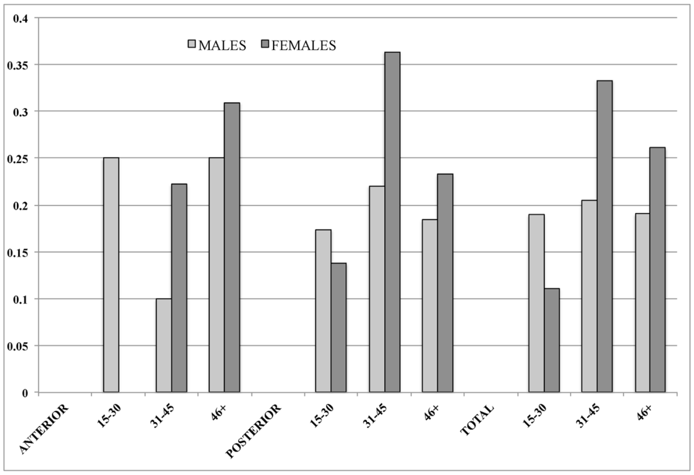


Figure 5. Frequency of multiple caries by sex and age-at-death for anterior, posterior and total dentition.

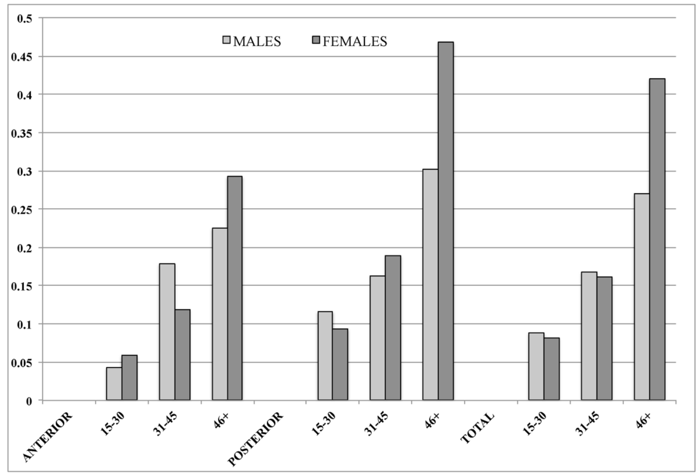


Figure 6. Frequency of antemortem tooth loss (AMTL) by sex and age-at-death for anterior, posterior and total dentition.

lesions, regardless of the location on the crown or CEJ, increases with age (Hillson, 1996). Within sexes, the most noticeable and statistically significant increase occurs between the 31-45 and 46+ age classes, both for males and females; such increase, however, is much more extreme in the female group (respectively, Chi-Squared=11.083, 1 d.f., p=.000871 for females , and Chi-Squared=5.379, 1 d.f., p=.020 for males).

Differences between sexes, instead, reach significant levels in the 31-45 years age class (Chi-Squared=8.9387, 1 d.f., p=.002792), and highly significant levels in the 46+ years age class (Chi-Squared=16.6523, 1 d.f., p=.0000450) (the Chi-Squared difference between males and females in the younger age group is 1.9707, p=.1603). The fact that females manifest higher frequencies than males in each age class is a phenomenon that has been thoroughly discussed in the literature, and that rests on physiological/hormonal differences between sexes as well as differential access to resources and daily habits (see Larsen et al., 1991; Lukacs, 1996, 2008; Lukacs &Largaespada, 2006). In a recent study on carious lesions in two modern samples from northern Yucatan (Vega & Cucina, 2014), females manifested statistically significant higher rates of caries already in the 15-19 year age class. Similarly Cucina and colleagues (2011) stated that differences between sexes were more marked in the younger age groups (starting at age 20 years), though no values of statistical significance were reported. In the present study, instead, differences between the younger age group by sex does not reach the significance thresholds (though females still manifest more carious lesions than males). It is possible that adding to the present study the individuals aged 15 to 20 years, whose amount of carious lesions tend to be lower because of the younger age, might have contributed to more balanced values between sexes dropping the difference below significance.

Differently from the quantitative amount of dental caries, results indicate no differences between sexes for multiple caries, for interstitial caries at the CEJ, and for lingual and buccal caries at the CEJ. Moreover, it is important to stress that none of the above variables presents differences between anterior and posterior teeth, clearly indicating the way teeth are affected in terms of topography and multiple carious lesions does not follow the same anterior vs posterior pattern that characterizes the overall frequency of carious lesions.

Interstitial dental caries at the CEJ (mesial and distal CEJ) is commonly generated by plaque that forms in between teeth, and proliferates in the presence of a diet rich in gelatinized maize and starches (Lanfranco & Eggers, 2010). Experimental animal models suggest that sucrose, maltose, fructose, simple starches or starches in combination with sucrose stimulate the production of cervical lesions, smooth surface lesions or both (Frostell et al., 1967; Lingström et al., 2000). They are also associated with regular consumption of alcohol, low salivary secretion (xerostomy) and high concentration of salivary lactobacilli (Badet & Thebaud, 2008; Beck, 1990; Brown et al., 1986). Age and mechanical factors like cervical calculus and periodontal bone reabsorption represent additional elements favoring the insurgence of cervical lesions (Banting, 2001; Otani et al., 2009). Liebe-Harkort (2012) found exceptionally high rates of dental caries in an Iron Age population from Sweden. Lesions were most common in the cervical region, which the author interpreted as probably related to a dietary pattern where starchy and sticky food tended to accumulate around the neck of the teeth.

At Xcambó, such lesions are very frequent and affect about half of the carious teeth recorded in both sexes, following a pattern that increases with age. On the contrary, these lesions do not differentiate between anterior and posterior dentition, which can be explained with the fact that, by accumulating in between teeth, plaque finds a hospitable environment regardless of the morphology of the crown above the cervical part of the tooth.

Buccal and lingual caries at the CEJ edge, and root caries, instead, were detected in 12.9% and 17.1% of the males' and females' carious teeth respectively. In males, anterior teeth present higher frequencies than the posterior teeth, while frequency distribution is more evenly balanced in females. As expected, such figures are much lower than mesial and cervical caries at the CEJ, because the buccal and lingual sides are less suitable for plaque to deposit and can be more easily cleaned by tongue and salivary autolysis. Nonetheless, their presence stresses the hypothesis of intake of sticky and cariogenic food.

Last, multiple carious lesions affect slightly less than one out of five teeth in males (19.2%) and one out of four teeth in females (24.9%), which indicates that, despite the considerable amount of lesions recorded, the majority of teeth were attacked only by one cariogenic event. Little information is available in the literature with regard to the pattern and meaning of multiple carious lesions in human populations. Watt et al. (1997) only reported an "average number of surfaces affected by caries per carious tooth" (1997: 617), without specifying the frequency of multiple caries, as well as the possible reasons behind such evidence.

Frequency of carious lesions at Xcambó is one of the highest found among the Prehispanic skeletal collections from the Yucatan peninsula (Cucina et al., 2011). Only the coastal site of Wild Cane Cay, Belize (Seidemann & McKillop, 2008) shows higher frequencies than those recorded at Xcambó. According to the authors, the heavy reliance of the Wild Cane Cay inhabitants on tree crops like *Orbignya cohune*, *Acrocomia mexicana* and *Bactris major*, which are soft foods that presumably adhere to the teeth, could account for the high caries rate; this would be exacerbated by the low amount of dental wear. The authors, however, do not report the sample composition by age and sex, so it is difficult to make detailed comparisons, even though the impressive 36.2% of teeth affected by carious lesions remains the highest among the Prehispanic Maya sites reported in the literature (Saul & Saul, 1997; Glassman & Garber, 1999; Magennis, 1999; Whittington, 1999; Cucina & Tiesler, 2003; Cucina et al., 2003, 2011; Marquez & Hernández, 2007).

In the case of Xcambó, the high frequency of dental caries encountered in the female subgroup might also be due to the elevated number of women aged 46+ years in the sample; with 24 individuals, it represents more than 50% of the whole female sample (N=45). Nonetheless, if the three age classes were represented by the same number of individuals, the overall frequency would drop to about 24.5% (instead of the 27.7%), a figure that still remains one of the highest frequencies in the Maya realm. Antemortem tooth loss does not seem to account for differences between sexes, since the frequencies of teeth lost in life (16.4% in males and 27.4% in females) match very close the rates of carious lesions.

The topographic distribution of carious lesions opens a new window on the biocultural and dietary habits of these people. In particular, it is worthy to note the similarity in distribution of lesion by sex and location (anterior and posterior teeth), and in some cases, also by age. Cervical lesions at Xcambó are observed in the youngest age cohort analyzed here, and bucco-lingual CEJ carious lesions are even more frequent in younger females than in older females. Cervical caries have been associated with older ages, mainly as the result of periodontal bone reabsorption (Faine et al., 1992; Lanfranco & Eggers, 2010). Although age is definitely a conditioning factor, the presence of cervical caries (both M-D and B-L) in the younger age class indicates that it was not a problem limited mostly to older people, but that affected every segment of the society, as also noted by O'Sullivan et al. (1993) in prehistoric British children.

As mentioned above, CEJ carious lesions in general and bucco-lingual CEJ lesions in particular, are associated with the ingestion of cariogenic starchy and, more so, sticky food (Frostell et al., 1967; Lanfranco & Eggers, 2010; Lingström et al., 2000). No data on tartar phytoliths, which could help shed light on the kind of plants ingested, exist yet for the skeletal collection of Xcambó. However, iconographic, epigraphic and historical information report the extensive use of maize-based *atole* beverages to which cocoa, honey and different varieties of fruits were added (Fernandez Souza, 2019). *Yutal kakaw* (fruity cacao), cacao with honey, sweet cacao were often ingested (Beliaev et al., 2009). *Capulin* (a cherry-like small fruit) is reported in several Classic period Maya sites (Lentz, 1999). Fernandez Souza (2019) reports of tamales (see also Taube, 1989) dressed with many different ingredients, many of which were sugar-based like fruits and *camote* (sweet potato), and an extended use of honey to sweeten different recipes and to make a marmalade of sorts. Natural plants also exist that might have entered the local peoples' diet, as for example the *Batis maritima* (Saltwort/Beachwort) (Marcone, 2003), which is typical of marshy coastland in the Yucatan peninsula (Lonard et al., 2011); its succulent leaves and seeds are nutritious, starchy, and relatively (but not highly) rich in sugars.

Although the basic nutritional intake consisted of marine and terrestrial animal proteins, as well as maize, beans and squash (Fernandez Souza, 2019), all the other kinds of foodstuff mentioned above represented important contributions to the daily intake. We must remember, however, that while the whole population commonly ingested fruits, honey and tamales, other ingredients (like cacao) were oftentimes limited to the society's wealthier class (Cucina et al., 2011). In this perspective, the elevated socio-economic status of the population of Xcambó (Sierra Sosa et al., 2014), in particular during the Late Classic, permitted them to access also this kind of foodstuff. The picture that emerges based on the kind of foodstuff and food recipes is that the bucco-lingual CEJ lesions might have been triggered also by the ingestion of sugary sticky fruits and not just by starchy ones. Sucrose and fructose, in fact, are more cariogenic than starches, because they enhance the streptococci's acidic (and cariogenic) activity (Lingström et al., 2000).

Nonetheless, dental caries is the result of a very complex interaction of different intrinsic (pH, salivation, dental plaque) and extrinsic (type of food, timing of food consumption and food preparation) parameters, so a simplistic association between starches and caries must be taken with caution (Lingström et al., 2000). In particular, timing of food consumption is a parameter that likely played a role in the insurgence of carious lesions in this population. Frequent intake of cariogenic food exposes the individuals to a more intense activity by the oral bacteria (Larsen et al., 1991; Vega & Cucina, 2014); the site's administrative tasks undertaken by the local people, in particular the male segment, likely exposed them to more frequent ingestion of cariogenic alcoholic and non-alcoholic beverages and food, increasing risks of insurgence of carious lesions, as already proposed by Cucina et al. (2011).

## Conclusions

In conclusion, dental caries rates at the Classic period site of Xcambó were among the highest in the Yucatan peninsula, regardless of the geographical (coastal or inland) location. The frequency increases with age and is more common in females than males. However, a more detailed distribution of lesions on the crown and cervical edges of the teeth shows patterns not always related to age and sex. The presence of lesions long the buccal and lingual CEJ edges suggests frequent intake of sticky cariogenic food in this population. The way food was prepared, with honey and fruits oftentimes added to different recipes, and the timing of ingestion seemingly exposed this population to increased risks of developing carious lesions already by a young age. A more detailed topographic analysis of carious lesions in other coastal and inland human archaeological settings from the region, each one within its own biocultural context, will allow a clearer picture of the effects of diet and daily habits on the oral conditions of the inhabitants of the peninsula in Prehispanic times.

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# The Medieval Transylvanian Oral Condition: A Case Study in Interpretation and Standardization

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*ABSTRACT* Interpretation of dental 'health' in archaeologically derived skeletal assemblages is challenging due to the lack of patient histories, clearly understood pathological processes, broad etiologies, and cultural perceptions of health. Furthermore, the language used in description of pathological conditions of the oral cavity condition is not consistent across researchers thereby resulting in challenging cross-site comparison. Standardization of terms and description is necessary as proposed by Pilloud and Fancher (2018). This paper demonstrates the challenges associated with cross-site comparisons through an attempt to place medieval Transylvanian Székely peoples' oral condition within a larger medieval cultural and biological framework. To do this, first, a review of medieval perceptions of dental health and treatment is provided. Next, a total of 90 individuals recovered from two medieval Székely cemeteries were analyzed for pathological conditions of the oral cavity. The results of the analysis were then compared to other medieval skeletal assemblages reporting on dental 'health'. Results show that conditions of the medieval oral cavity cannot be generalized and comparisons are further complicated by a lack of standardization in description and reporting thus supporting this volume's call for standardization. Results also show that conditions of the oral cavity are specific to time and place even between the two Transylvania sites discussed.

Health, as a descriptive term, is commonly used in the bioarchaeological literature to indicate evidence of pathological modification on the skeleton. However, the World Health Organization includes mental and social factors, in addition to bodily disease states, as important to an assessment of health (WHO, 1999). Reitsema and McIlvaine (2014) have added that a majority of pathological modifications observable in skeletal and dental tissues could have been caused by a myriad of conditions. Within the more focused parameters of oral health, the lack of patient histories, clinical records, and environmental living conditions has resulted in inconsistent application of terminology, understanding of disease etiologies, and recording of observations in bioarchaeological contexts (Pilloud & Fancher 2019, this volume). What this means is that to understand the 'health' of a population, one must consider physical, mental, and social factors without access to patient histories, clearly understood etiologies, or standardized definitions among researchers. Bioarchaeologists are suited to address this challenge through the application of a multifaceted approach that pieces together cultural and biological information. Combined with the use of standardized language, communication between researchers can be improved and interpretations more accurately compared across sites. This paper examines pathological conditions of the oral cavity among medieval Transylvanian Székely communities as a case study to apply the vocabulary and definitions discussed by Pilloud and Fancher (2019) and to demonstrate the challenges of comparison between sites. Furthermore, it contributes to the paucity of information available on archaeologically derived skeletal collections from Eastern Europe.

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**Condition of the oral cavity: Medieval cultural perspective**

Human skeletal remains hold important information about the social and biological context in which a specific person navigated. Interpretation of that individual's lived experience begins with understanding the cultural context of the time. For the medieval individuals discussed here, an understanding of medieval medical practices is useful.

Healthcare in the middle ages was predominately influenced by Hippocrates's 5th century B.C. humoural theory. In his treatise, *The Nature of Man*, Hippocrates stated that the body was composed of humours, or body fluids, specifically, blood, yellow and black bile, and phlegm. These humours corresponded with different conditions and seasons: blood, hot and wet, predominates in spring; yellow bile, hot and dry, in summer; black bile, cold and dry, in autumn; and phlegm, cold and wet, in winter (Jouanna, 2012). It was thought that every person had a different make-up of humours; even organ systems within people had different humoural constructions and poor health resulted when the humours were out of balance. The noted Greek physician, Galen, later supported and expanded Hippocrates' work, which gave it the sustainable success that carried it into the Enlightenment (Jouanna, 2012; King, 2013). Multiple other interpretations branched off Hippocrates' original idea but the vocabulary and general understanding of the humours remained prevalent in medieval understandings of health and medicine (Jouanna, 2012; King, 2013).

The broadly applied humoral theory extended into dentistry (Anderson, 2004; Bifulco et al., 2016). The Medical School of Salerno, Italy was one of the most influential medical resources of the medieval period. In addition to general medicine, they paid attention to dentistry and domestic oral hygiene. Trotula De Ruggiero, a person of somewhat mythic status associated with the Salerno school, is credited with writing the first treatise on oral hygiene (Bifulco et al., 2016). She advocated deep dental cleaning and brushing, mouthwash, chewing of herbs for daily cleaning and pleasant breath, as well as remedies for gingivitis, halitosis, and tooth whitening. Many of the ingredients she suggested are still used today in cosmetic and hygiene products (Bifulco et al., 2016). Though these practices are largely unobservable in skeletal remains, they indicate that medieval people were interested in oral care in addition to more visible and serious modifications.

Conditions of the oral cavity observable in the archaeological record include general tooth decay, dental caries, periapical lesions, and tooth loss. Toothache, which could have several etiologies, the most treated problem in medieval dental medicine, was managed with everything from fumigations to oaths (Anderson, 2004; Bifulco et al. 2016). J. Platearius, a doctor in the Salerno school, wrote that dental pain was specifically a result of imbalanced warm and cold humours from the brain or stomach (cited in Bilfulco et al., 2016). Additionally, some of the doctors at Salerno believed tooth decay was caused by odontalgic worms that caused pain with their movements, an idea that dates to Sumerian texts from 5,000 B.C. Gilbertus Anglicus (c.AD 1240) also agreed that tooth worms caused dental pain and required balancing the humours (cited in Anderson, 2004). Dental caries and fistulae were treated with herbal concoctions placed as a paste within the cavity of the tooth (Anderson, 2004) or by cauterizing the rotten dental pulp and sealing it with wax, which essentially destroyed the pulp chamber nerve supply (Bifulco et al., 2016).

Dental care was limited to non-invasive treatment (Anderson, 2004). Dental extraction was rarely cited in the Salerno documents because it was not a practice of physicians but rather "charlatans who practiced their profession in the streets and in open-air markets, and replacing the tooth with a tiny piece of wood or an iron bolt" (Bifulco et al., 2016:2). The 'charlatans' were barber surgeons and willing to do surgery, unlike doctors. They often learned their skill through performing surgery on the war wounded or as an apprentice; though, many had no formal education, and most were illiterate. Eventually surgery became a formalized profession and barbers were not allowed to provide surgical intervention except in cases of tooth extraction and blood-letting (Pelling, 1998). Access to barber surgeons was regulated by the Catholic Church and not accessible to females (Lopez et al., 2012). Those who could not access or afford a barber surgeon depended on prayer or pilgrimage as a means for a cure (Anderson, 2004). Medieval peoples understood that small infections of any type could become fatal if not attended to and took all available treatment precautions (Pelling, 1998).

In terms of actual oral heath, it is unknown what medieval peoples perceived as unhealthy. Literature related to oral 'health' during the medieval period is often derived from skeletal assemblages and the interpretations of modern researchers. That is the problem with the casual use of the word 'health'. It is temporally and socially complicated to define. At best, researchers must anecdotally pull information from various types of knowing (images, educational documents, song, and folklore) to try to understand an ancient perspective. In the case of the medieval oral condition, dental medicine and hygiene made important advancements during the medieval period and from that, we argue, that we can infer that the numerous treatments for dental pain and dental hygiene resulted from medieval concern for oral care.

**Condition of the oral cavity: Medieval bioarchaeological perspective**
Information derived from research on skeletal assemblages provides a data-driven perspective to complement the less direct information available from cultural sources like the examples discussed above. The bioarchaeological literature often reports on types and frequencies of dental modifications with reference to the social factors that might have impacted the results. These findings are then used to make an assessment about the dental, or overall, 'health' of the population represented by the skeletal assemblage. For instance, Lopez and colleagues (2012) reviewed the diverse factors that contribute to various conditions of the oral cavity covering explanations from clinical processes, gendered access to dental care, consumption of cariogenic foodstuffs, and culture-specific food preparation techniques. They demonstrated through a comprehensive literature review that generalizations about etiologies cannot be made and that the interpretations must be heavily context dependent. Lopez et al. (2012) investigated sex-differences in oral health from two medieval sites in Spain and concluded that there were no sex-based differences in dental health. These findings mirror similar contexts in France (Esclassan et al., 2009) and Croatia (Šlaus et al., 2011). However Lopez et al. (2012) note that when compared to the modern age individuals (late 18th century), sex-based differences were evident.

Belecastro and colleagues (2007) investigated diet changes and health decline in response to large social and economic changes after the fall of the Roman Empire. The dentition of two temporally contiguous sites (Roman Imperial to Early Medieval) in central Italy were investigated to make inferences about dietary practices across time. They concluded that overall protein consumption reduced after the decline of the Roman Empire and that the medieval diet consisting of higher carbohydrate intake led to an increase in dental wear, periapical lesions, and calculus. The lack of increased dental caries was thought to be due to the increased level of wear resulting from a harder and more fibrous diet, which required longer and stronger mastication. As the complicated morphology of the tooth wore away, there would be less opportunity for carious lesions to form; an interpretation supported by dental data from other medieval sites (Caglar et al. 2007; Chazel et al. 2005; Esclassan et al. 2009). Belecastro and colleagues (2007) also coupled dental data with pathological skeletal markers and evidence of infectious disease to conclude that while diet did not appear to change in significant ways, health conditions present during the Roman Imperial era continued and then worsened.

The inverse relationship of high dental wear and low dental carious lesions was not found at other medieval sites investigating changes in dental data between medieval sites and other time periods (e.g, Šlaus et al., 2011; Srejić, 2001), which demonstrates the variability in the medieval oral condition. Another example is demonstrated through frequency of carious lesions. Low levels of carious lesions and dental wear were reported for a medieval coastal site in Croatia (Novak et al., 2012). Rapid urbanization of the site during the Late Medieval period led to an increase in infectious disease indicators and overall reduction of health (Novak et al., 2012). Conversely, high levels of carious lesions and dental wear were present in two medieval, cemeteries from Serbia (Srejić, 2001). The cause of the high frequency was interpreted to be a result of food processing and poor oral hygiene.

Overall, there does not appear to be a general status of oral condition across the medieval period and conditions are highly specific to geographic, temporal, and social contexts. Interpretations of 'health' range from multiple lines of evidence as discussed above to more limited interpretations about diet and comparison to other medieval sites (e.g, Caglar et al., 2007; Chazel et al., 2005; Srejić, 2001). Each author managed challenges associated with limited historical data, limited comparative sites, and a general lack of standardized recording and reporting methods. These were some of the hurdles faced when placing the Transylvania case study sites into various comparative categories.

**Biocultural Context**
For the last seven years, our work has focused on documenting the lives of medieval and early modern Transylvanian Hungarians (Bethard et al., 2019; Molnár, 2001). The study area encompasses a

region of Eastern Transylvanian located inside the Carpathian Basin. It is currently home to over 600,000 people and called the Székelyföld by the ethnic Hungarian inhabitants who have lived there for nearly 1,000 years.

In this study, two historically Hungarian Transylvanian cemeteries located 18.5km apart in Harghita County, Romania were analyzed (Figure 1). The Papdomb archaeological site in Văleni (Hungarian: Patakfalva), Romania designates the ruins of a medieval church and its associated burial grounds. The second archaeological site is a medieval cemetery located on the grounds of the Catholic Church in Bradeşti (Hungarian: Fenyéd), Romania. Though inhabitants of both villages are identified as Romanian citizens today, the whole of Transylvania was not incorporated into the current political boundary of Romania until the conclusion of World War I. For the last millennium, the inhabitants of both Văleni and Bradeşti have identified as Hungarian, more specifically, as Székely. For clarity of discussion, the sites will be referred to via their official archaeological site designators; Papdomb and Fenyéd.

Excavation of the Patakfalva cemetery site began in 2014 as a salvage project per the request of the villagers. A collaboration between the inhabitants of Patakfalva, the Haáz Rezső Múzeum in nearby Odorheiu Secuiesc, and ArchaeoTek-Canada, LLC was created to excavate and analyze the remains. The Papdomb site was used repeatedly for several hundred years as indicated by historic records, temporally specific artifacts like coins, and evidence of burials truncated by later burials (Figure 2). In general, people were interred in a supine, extended position with their heads to the west, feet to the east. Body arrangement, soil stains left by decomposition, and remnants of coffin wood suggest that most individuals were buried in a coffin or a shroud. Overall preservation of skeletal remains, including infants, was good.

The Fenyéd cemetery was used repeatedly for several hundred years, primarily during the 11th and 12th centuries. Salvage excavations were conducted in 2013 due to erosion that exposed the medieval cemetery and a total of 54 burials were removed (Figure 3) (Nyárádi, 2013).

Historical information about the medieval period in Transylvania can be hard to find. Much of the research about the area is not published in English and does not show up in a standard literature search. Additionally, the history of the area is highly contentious in terms of which peoples invaded, owned, and occupied the landscape, as such sources can be heavily biased toward a singular perspective with conflicting information between sides (Lendvai, 2004). Archaeological evidence has been used as a more reliable indicator of the area's history (Ţiplic 2006). However, even this method is complicated due to outside influences directing the interpretation of sites as a part of a pre-1990 Romanian research agenda (Cosma & Gudea, 2002 cited in Ţiplic, 2006).

Archaeological and historical evidence demonstrates that starting in the 9th century the Carpathian Basin was an area of extensive biological and

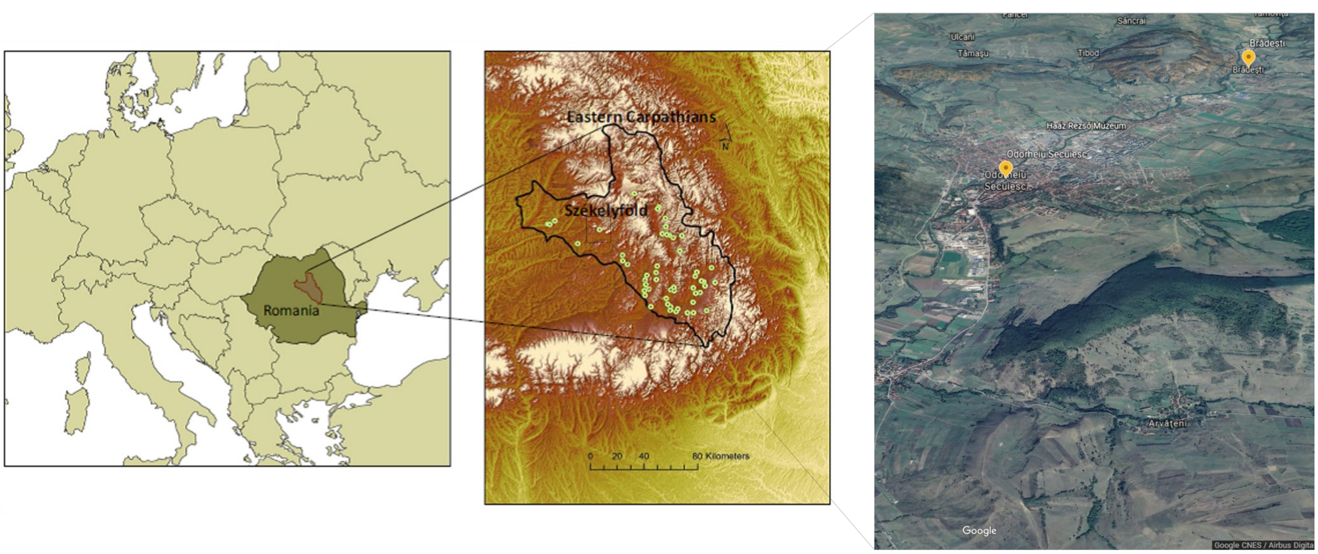


Figure 1. Tri-part map successively focusing on the location of the two cemeteries. Map modified from Molnár et al. (2015).

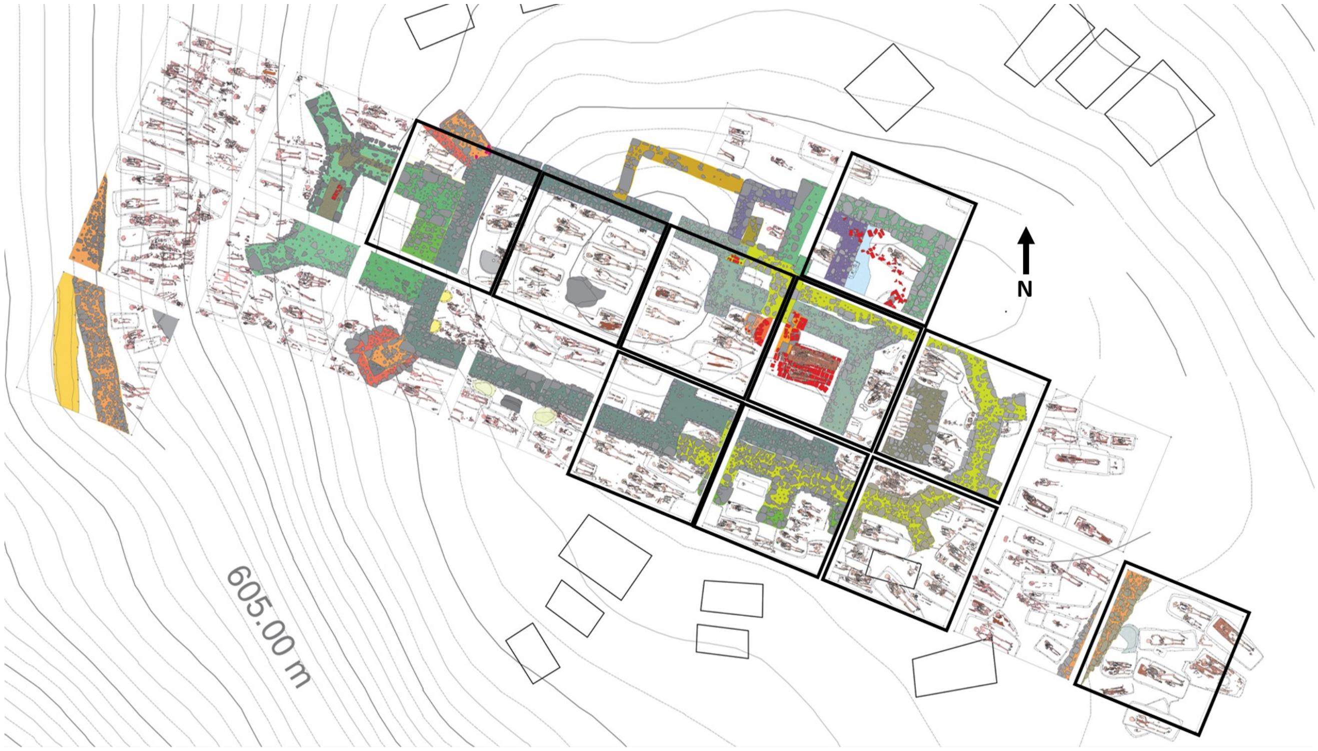


Figure 2. Burial plan map of Papdomb site with 2014 and 2015 trenches outlined.

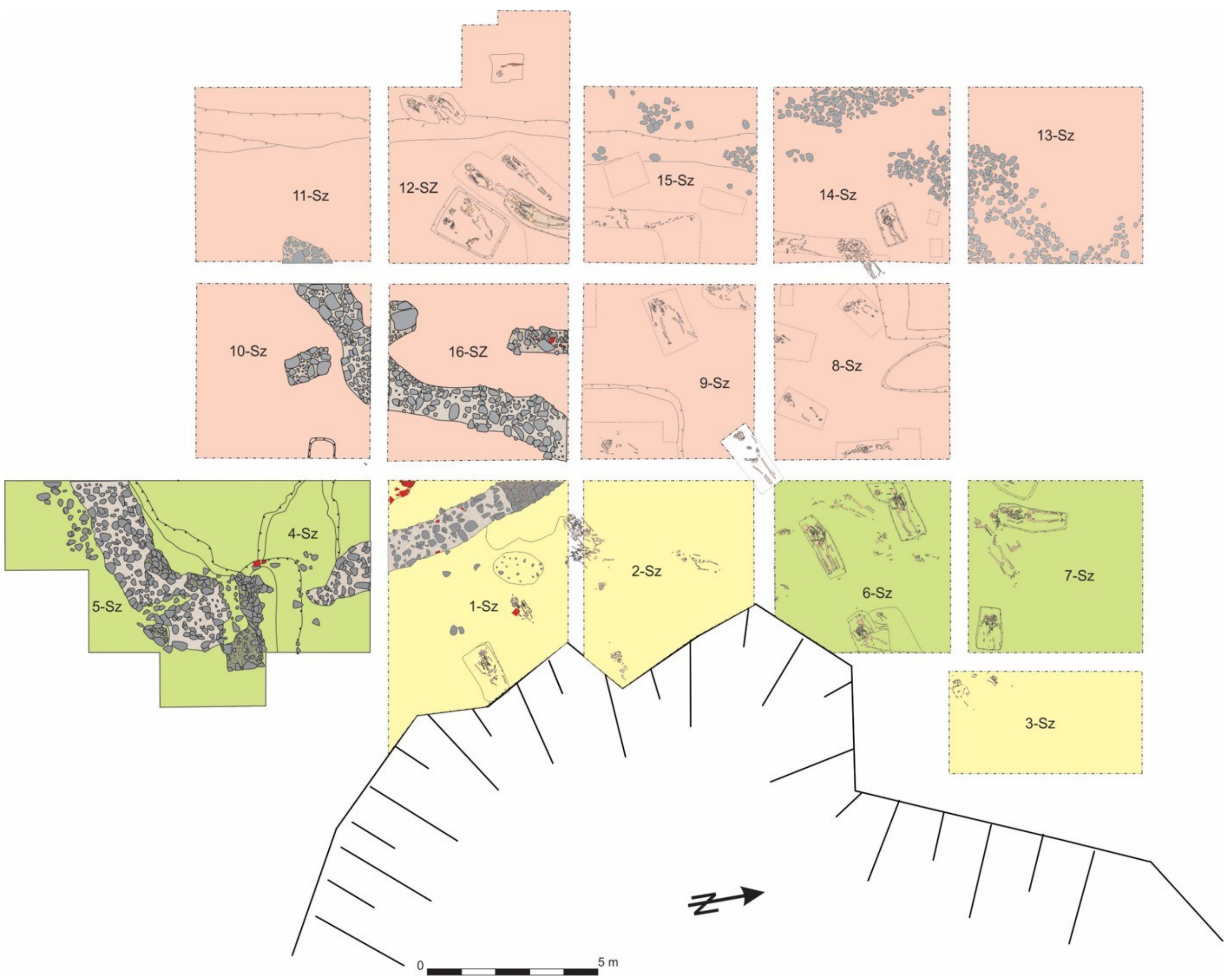


Figure 3. Burial plan map of Fenyéd site burials.

cultural movement from various groups including Slavs, Croatians, Bulgarians, Avars, Franks, Bijelo-Brdo and the first Hungarians (Lendvai, 2004; Ţiplic, 2006). Over the subsequent centuries, populations increased and decreased as a result of political and religious influences, especially from the Tatar invasion of the early 13th century. The medieval population size for Transylvania as a region has been estimated around 250,000 people with 100-200 people in an average-sized village. Mountainous villages, such as the ones in our case study, may have been smaller with difficult to estimate population sizes (Ţiplic, 2006).

The effects of large-scale social changes on small villages in Transylvania are unknown. This information could be gleaned from cemetery data (Ţiplic, 2006), but there has been limited published skeletal research on sites from the Carpathian Basin. Although the Bijelo-Brdo culture predates the two sites discussed herein, Bijelo-Brdo cultural elements are present in Transylvania and associated with early Hungarian sites (10th-11th century). Vodanovic and colleagues (2005) report on frequency and location of tooth loss and dental carious lesions from the Bijelo-Brdo archaeological site near Osijek, Croatia. They found that carious dental lesions and antemortem tooth loss increased with age. Antemortem tooth loss was 11.9% among older individuals and 6.7% for all individuals examined. They also found that 46.9% of individuals had at least one carious lesion with 1.8% of younger individuals having at least one carious lesion and 14% of older individuals having at least one carious lesion. Causes for the pattern of dental modification observed were vaguely attributed to diet and lifespan but no direct evidence for antemortem tooth loss or carious dental lesions was provided. In reference to food, Peschel and colleagues (2017) examined the diet of 12th to 19th century Transylvanians excavated from the Bögöz Reformed Church in Mugeni (Hungarian: Bögöz), Romania. They found that people were consuming animals fed from native grasses (pigs, sheep, and cows) as well as broomcorn or foxtail millet. They also reported that individuals from the earlier centuries ate less meat and fish.

It is unclear to what degree the Transylvanian villagers participated in available dental or other medical treatments during the medieval period. Westernization in the Székelyföld was visible as early as the 12th century as seen through the presence of a distinct style of hairpin found in association with burials at multiple cemeteries. This finding suggests that mountainous communities might not have been as isolated as assumed (Nyárádi & Gáll, 2015; Ţiplic, 2006). In terms of dental care and status, members of the noble family from the area were interred at the Papdomb site and do not show any direct evidence of dental treatment. Nor do their teeth appear to have less pathological dental modification than others in the Papdomb cemetery as evidenced by the presence of periapical lesions, carious lesions, and antemortem tooth loss including one edentulous individual.

To further investigate how the oral condition of the two Transylvanian cemetery assemblages compared to other medieval sites, we chose to place the two sites within the broader context of the medieval period in Europe. In doing so, we came across the research challenges described in this paper.

**Methods and Materials**

One of the goals of this paper is to report on pathological conditions of the oral cavity among medieval Transylvanian Székely communities as a case study to apply the vocabulary and definitions discussed by Pilloud and Fancher (2019) and to demonstrate the challenges of comparison between sites.

Skeletal assemblages from two cemeteries located 18.5km apart in Harghita County, Romania were analyzed. All the burials excavated between 2014 and 2015 have been analyzed and comprise the sample of this study. These graves are from trenches within the walls of the church; within the churchyard, and outside the yard wall (see Figure 2) providing a sample of individuals across the site. A total of 218 burials were removed during the two seasons of excavation (Nyárádi, 2014; Zejdlik, 2015).

All dental elements were sorted and identified by dental arcade, tooth type, and side. Buikstra and Ubleker (1994) and the Arizona State Museum systems were utilized to document dental carious lesions, periodontal recession, antemortem tooth loss, and periapical lesions. Antemortem tooth loss and periapical lesions were not always scorable due to poor preservation of maxillary and mandibular bone.

To acquire data from comparable medieval sites and to test the utility of a standardized language and definitions as called for by Pilloud and Fancher (2019), a literature review was conducted to synthesize data related to conditions of the oral cavity from medieval sites across Europe. Müeller and Hussein's 2017 meta-analysis of dental conditions was used as a model as it provided an extensive overview of the literature reporting on 'dental health' from sites between 3,000 BC and the 20th century. We modified their table by extracting only adults from medieval sites and by removing data on postmortem tooth loss, periodontal disease, and linear enamel hypoplasia. The choice to focus on adults was made to simplify the table; adults were more frequently examined than non-adults. Adults were considered individuals aged 16 years and older. Post-mortem tooth loss was removed from our analysis because it did not provide useful information regarding the condition of the oral cavity. Periodontal disease was removed because only two of the 21 references reviewed reported on it.

The resulting table (Table 1) consists of 21 references reporting on conditions of the oral cavity from medieval peoples across Europe. The 21 references include the two case study cemeteries discussed below. It should be noted that some references report on multiple sites. When possible, the site demographics were broken into male and female. Each dental condition was reported per total available teeth.

Without a set glossary of terms and definitions, one cannot be confident what is being compared. Pilloud and Fancher (2019) have provided recommendations on etiology, skeletal representation, and caution when examining various dental diseases or conditions. In most of the literature cited in Table 1, the authors did not describe etiologies. Instead, emphasis was placed on the physical evidence being observed and the criteria used to assess it. However, in a few cases, such as DeWitte and Bekvalac (2010) and Lopez et al. (2012) a clear and descriptive presentation of conditions and potential etiologies of the oral cavity are presented. A summary of Pilloud and Fancher's (2019) recommendations specifically related to the conditions identified in this paper and reduced to application in observation is provided below:

> *Antemortem tooth loss*: Assessment of this condition should be used cautiously because it has many causes. Investigators should preference a large gap in the dental arcade with evidence of reactive bone. They should also be aware of potential dental agenesis and impaction. If uncertain, antemortem tooth loss should not be recorded.

> *Carious dental lesions*: It is important to differentiate between carious lesions as the physical, dental hard tissue destruction of tooth enamel and, dental caries as the disease process of bacterial fermentation of consumed carbohydrates. The two terms should be used separately.

> *Periapical lesions*: This is a general term to describe a disturbance of the skeletal tissue around the apex of the tooth that may be related to a granuloma, cyst, or an abscess. The general term of 'periapical lesion' is preferred as the specific etiology can be difficult to diagnose without a soft tissue biopsy or a definitive patient history.

**Results**

A review of the 21 references in Table 1 revealed a range of definitions and etiologies associated with the conditions described. Diagnostic criteria for antemortem tooth loss was reported in a range of ways. In some cases, the criteria to define antemortem tooth loss was not defined (e.g., Lingström & Borrman, 1999; Slaus et al., 1997; Srejić, 2001). In the most simplistic descriptions, it was differentiated from postmortem tooth loss in which there was evidence of an alveolar socket (e.g., Caglar et al., 2007; Esclassan et al., 2009; Vodanović, 2005). Others described antemortem tooth loss as evidenced by alveolar resorption or remodeling (e.g., Chazel et al., 2005; Lopez et al., 2012; Meinl et al., 2010; Novak, 2015; Slaus et al., 2010; Stránská, 2015). Studies did not consider agenesis or impaction as a potential explanation for a lack of tooth presence.

Carious dental lesion criteria were also described in numerous ways. Most authors used the term caries and did not distinguish between the process and the physical manifestation. The majority of the studies identified carious lesions as 'caries' and diagnosed them based on an enamel defect, specifically a pit that could be probed, and made the point to note that discoloration or a sticky lesion was not considered a carious dental lesion (e.g., Belcastro et al., 2007; Meinl et al., 2010; Novak, 2015; Stránská, 2015). Some authors also used radiographic imaging in addition to macroscopic observation to identify carious lesions (e.g., Chazel et al., 2005).

Most papers did not record periapical lesions. Those that did referred to them as abscesses. Diagnostic criteria in the papers described the presence of a perforating fistula as necessary for a diagnosis (e.g., Belcastro et al., 2007; Šlaus et al., 2010). Only Novak (2015) included the description of a sinus present in the alveolus at the apex of the tooth in addition to a perforating fistula as a diagnostic criterion.

Several challenges were identified in the attempt to establish a bioarchaeological context useful for comparison to the Transylvanian Székely case studies, namely the lack of standardization,

*Table 1. Summary data on conditions of the oral cavity from medieval archaeological sites*

| Location/ Time period | Individuals N (male/female/ indeterminate) | Analyzed teeth N total teeth/ N alveolar presence | Antemortem tooth loss N (%) | Carious dental lesions per tooth N (%male/ % female) | Periapical lesions per tooth N (%male/ % female | Reference |
|---|---|---|---|---|---|---|
| Ireland (rural) 400 -1000 AD | 167(85/82/-) | 3233 | ND (9.7%) | 98(2.5%/3.6%) | 85 2.3% | Novak 2015 |
| Italy (rural), 700 AD | 88 (45/40/3) | 1754/ND | ND (14%) | 263 (15%/ 15%) | 4.5% | Belcastro et al. 2007 |
| Austria (urban), 700–800 AD | 136 (64/72/-) | 2215/3649 | 869 (24%) | 331 (15%) | ND | Meinl et al. 2010 |
| Czech Republic (rural) 800-1100AD | 241 (-/-/-) | 1006/1011 | 0 | 6 (0.06%) | ND | Stránská et al. 2015 |
| Czech Republic (urban) 800-1100AD | 487 (-/-/-) | 1538/2699 | 0 | 18 (0.012%) | ND | Stránská et al. 2015 |
| Croatia (rural) 700-1100 AD | 151(59/38/-) | 2707/ND | 21.7% | 318(11.1%/12.6%) | 196 5.1% | Šlaus et al. 2010 |
| Croatia (urban) AD 1100- 1400 | 107(63/44/-) | 643/1378 | ND- data combined with abscesses | 62 (11%/7.6%) | ND- data combined with antemortem tooth loss | Novak et al. 2012 |
| Croatia (rural), 10 –11th century | 81 (-/-/-) | 923/ 1414 | 99/7% all | 92/ 10% | ND | Vodanović et al. 2005 |
| France (urban), 11 –15th | 107 (-/-/-) | 1183/3424 | 342 (10%) | 107 (9%) | ND | Chazel et al. 2005 |
| France (rural), 12 –14th | 58 (29/29/-) | 1395/1822 | 121 (7%) | 250 (22%/ 14%) | ND | Esclassan et al. 2009 |
| Scotland (rural), 1240–1440 | 561 (-/-/-) | 9991/ND | 7% all | 709/ 7% | ND | Watt et al. 1997 |
| Papdomb, Romania (rural) 14th -15th | 60 (34/21/5) | 1074 /ND | ND | 12.4% | 16 (1.4%) | Current study |
| Fenyéd-Bradesti, Romania (rural) 11 – 12th | 32 (-/-/-) | 569/ND | ND | 24.44% | 1 (0.2%) | Blevens and Adams 2017 |
| England (urban), AD 1350-1538 | 190 (-/-/-) | ND | ND | 484 (premolars and molars only) 27.3% | ND | DeWitte & Bekvalac 2010 |
| Turkey (urban,) 13th | 52(-/-/-) | 261/ND | 51 (6.9%) | 8 (15.38%) | ND | Caglar et al. 2007 |
| Spain (rural), 15th | 240 (123/117/-) | 1015/1254 | 239 (19%) | 48 (5%/ 4%) | ND | Lopez et al. 2012 |
| Scotland (urban), 13–16th | 52 (-/-/-) | 984/1246 | 60/ 4% all ages | 54/ 5% | ND | Kerr et al. 1988 |
| Serbia (rural), 14–16th | 369 (-/-/-) | 1680/2874 | 299 (10%) | 149 (9%) | 24 (1.4%) | Srejic 2001 |
| Finland (urban, poor people), 15–16th | 294 (-/-/-) | 4581/ 5803 Deciduous 600/600 | 622/11% all ages | 731/16% | ND | Varrela 1991 |
| Scotland (urban), medieval | 74 (-/-/-) | 1614/ 1958 Pre 255/ 279 | 156/8% all ages | 134/8% 5/7% | ND | Kerr et al. 1990 |
| Sweden (urban), 1621–1640 | 63 (-/-/-) | 936/1997 Pre 13/48 | 55/3% all ages | 106/11% | ND | Lingström and Borrman 1999 |
| Croatia (rural), 14 –17th | 68 (35/33/-) | 765/ND | ND | 72 (9%) | ND | Šlaus et al. 1997 |
| France (urban), 16 –17th | 109 (-/-/-) | 1267/3488 | 519 (15%) | 236 (19%) | ND | Chazel et al. 2005 |

*ND= no data or not specified

which made overall construction of Table 1 complicated. There were various forms of missing data and different reporting styles especially in terms of demographics. Additionally, the lack of standardization in description of conditions of the oral cavity suggests that while there was a general understanding of processes and analytical methods, there were certainly areas of concern regarding recorded data.

The data from Table 1 was distilled into descriptive statistics per condition. The numbers provided by each reference were broken down into the minimum percentage of the condition expressed, the maximum, and the mean. Not all references investigated all of the conditions reported in Table 1. The N column provides the number of references out of 21 that reported the condition. The results of the Transylvanian analysis were added to the bottom of the table to highlight how the Transylvanian cases fit into the general data on the medieval oral condition.

Of the 21 references reviewed in Table 1, 18 reported on antemortem tooth loss. Antemortem tooth loss occurred at variables rates across medieval sites with 0% reported for sites in the Czech Republic (Stránská et al., 2015) and 24% reported for a site in Austria (Meinl et al., 2010). The average number of total teeth lost antemortem across the sites recoded in Table 1 was 10.4%. Antemortem tooth loss was not recorded for the Papdomb or Fenyéd individuals for taphonomic and preservation reasons

Information regarding carious dental lesions from the two Transylvanian sites was examined against the descriptive statistics provided in Table 2. All of the 21 references reviewed in Table 1 reported on carious lesion prevalence. Like antemortem tooth loss, dental carious lesions were reported at variables rates across medieval sites with 0.6% reported for sites in the Czech Republic (Stránská et al., 2015) and 27.3% reported for a St. Mary Graces cemetery site in England (DeWitte & Bekvalac, 2010). The average total teeth with carious lesions across the sites recoded in Table 1 was 10.3%. Interestingly, the numbers for antemortem tooth loss and carious dental lesions across the sites are very similar. Also in both cases, the sites from the Czech Republic have the lowest numbers. When the two Transylvanian sites were compared to descriptive statistics in Table 2, the Papdomb site (12.4%) was just above the overall mean (10.3). However, the Fenyéd site (24.4%) was high. It was the second highest reported after the St. Mary Graces cemetery (27.3%). Both Transylvanian sites are higher than the Bijelo-Brdo culture site (7%) to which they are most culturally similar.

Reporting of periapical lesions was limited. Of the 21 references in Table 1 only 6, including the two case studies, provided data. The lowest reported prevalence was the Fenyéd site case study (0.2%) and the highest (5.1%) reported was an aggregation of three, Early Medieval villages in Croatia (Šlaus et al. 2010). The Papdomb site had a frequency of 1.4%, which was the second lowest rate.

## Discussion

The Fenyéd site had the second highest frequency of carious dental lesions among all 21 references reviewed and the lowest frequency of periapical lesions. The Papdomb site was slightly above average for frequency of carious lesions and had the second lowest frequency of periapical lesions. The two cemeteries were 18km away from each other and were used at the same time. Both were in rural Transylvania in a hilly area of the Carpathian Basin. They were, and remain, small villages with similar people, similar occupations, and similar access to resources. The two skeletal populations demonstrate very limited evidence of trauma or pathological indicators minus the expected occurrences of osteoarthritis and other common degenerative modifications in older individuals. All things considered, it had been assumed that the two sites would have had similar conditions of the oral cavity. It is possible that sample size, 32 adults from Fenyéd versus 60 adults from Papdomb, could have impacted the results. Regardless, the difference suggests that other factors were present and point in a direction of further investigation.

## Conclusions

Health is a vague term that encompasses physical, emotional, mental, and social factors. To adequately study health requires patient histories and a better understanding of etiological factors. It is difficult to interpret in the bioarchaeological record. It is limited by the inherent attributes of archaeological skeletal assemblages. However, as bioarchaeologists we are tasked with finding ways to overcome those challenges in investigation and interpretation to best represent the people we are speaking about.

Situating interpretation within the social and cultural context of a specific time and place is important even if it is indirect and acquired through less utilized means of knowing, such as images and folklore. This has become apparent in our research among the Székely of Transylvania whose own origin story is unknown and has written itself out of lore and legend (Lemdvai, 2004). Next, applying bioarchaeological data at various scales provided different perspectives on the variability across time and place even though it all fell under the classification of 'medieval.' Specifically, this study demonstrated that the oral cavity was variable across medieval Europe even in cases with similar contexts such as transitions from Late Antiquity to the Early Medieval period, sites in Croatia and Romania with similar cultural periods, or two rural, Székely, Transylvanian villages. Finally, further complicating the situation was a lack of standardization in descriptions and reporting, which underscores the call of Pilloud and Fancher (2019) to standardize terminology and further understand the etiology of processes that affect the oral cavity; hopefully, leading to improvements in data reporting. We will never know what ancient individuals experienced or perceived in terms of their dental health but we can be more responsible in the way we discuss it.

*Table 2: Descriptive statistics of the data reported in Table 1 with the Transylvanian sites highlighted for comparison*

| | **Antemortem Tooth Loss (n= 18)** | **Carious Dental Lesions (n=21)** | **Periapical lesions (n=6)** |
|---|---|---|---|
| **Min** | 0% | 0.6% | 0.2% |
| **Max** | 24% | 27.3% | 5.1% |
| **Average** | 10.4% | 10.3% | 3.3% |
| **Papdomb** | ND | 12.4% | 1.4% |
| **Fenyéd** | ND | 24.44% | 0.2% |

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# EDITOR'S NOTE ON SPECIAL EDITION ON ORAL HEALTH

This special edition of Dental Anthropology is based on a symposium from the 2018 American Association of Physical Anthropologists annual meeting entitled, *Reevaluating the Meaning of 'Oral Health' in Bioarchaeology* that I co-chaired with James P. Fancher. The goal of this symposium was to begin a dialogue on how oral health is defined and evaluated in a bioarchaeological context. Invited participants explored definitions and interpretations of this term within their own work. Out of the initial discussion at this symposium, presentations were turned into the manuscripts presented here. The volume begins with an outline of various conditions that are traditionally used in studies of oral health. The articles that follow explore traditional markers of oral health, predominately focused on periodontal disease and dental caries. Interpretations are then nuanced within a biocultural context using the archaeological record and what is known abut the etiology and progression of these conditions.

The resulting volume is a thoughtful evaluation of how oral health can be studied in bioarchaeology. The hope is that discussions will continue and further questions will be raised about bioarchaeological research and its limitations. With particular attention to terminology, the limits of diagnoses, the integration of clinical literature, and the development of advanced methods of study.

Thanks to the many authors who contributed to this volume and those who contributed to the initial symposium. Their work, discussions, and contributions to this journal are appreciated and will serve to grow the study of pathological conditions of the oral cavity and contribute to a better understanding of oral heath in the past.

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# LETTER OF OBITUARY:
*Grant Townsend*

Dear friends and colleagues,

It is with sadness that I write to inform you of the passing of Professor Grant Townsend on May 25th, after battling illness over the last 12 months. Many of you will know Grant from his involvement in the Dental Anthropology Association, and from his attendance at ISDM and AAPA meetings over the last 40 years. Many of you will also have known him as a collaborator, co-author, supervisor, mentor and friend.

It's difficult to sum up the depth and breadth of Grant's contributions to the field of dental anthropology in a few short paragraphs, but some of his key achievements include holding the Chair of Dental Science at the University of Adelaide for over 20 years; work on the collection and analysis of a seminal longitudinal data set from the Yuendumu people of central Australia, with Murray Barrett and Tas Brown; initiating a series of longitudinal Australian twin cohorts to quantify the role of genes and the environment in the development of various morphological features; publishing over 200 peer-reviewed articles, as well as numerous books and book chapters; and sitting on the editorial boards of many distinguished journals, including Dental Anthropology from 1997-2002.

Some of the many awards Grant received during his career included the Medaille de la ville de Paris for contributions to research in the field of dental anthropology; the IADR(ANZ) Alan Docking Science Award for outstanding scientific achievement in the field of dental research, and the IADR Distinguished Scientist Award for Craniofacial Biology Research in recognition of outstanding contributions to research over a significant period of time.

A great collaborator, Grant spent time in many research centres internationally over the course of his career, including sabbaticals in Finland and the United Kingdom, and visits throughout South-East Asia and the United States. During these times he developed long-standing friendships with other members of our community, many of whom would later go on to spend time in the Murray Barrett Research Laboratory in Adelaide working on the collections Grant curated.

Grant's enthusiasm for dental anthropology never waned, and he continued to work on projects arising from the longitudinal cohorts up until early this year, many of which remain ongoing. Grant will be missed by his extended research family at the Craniofacial Biology Research Group in Adelaide, and by those he worked with around the world.

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# Dental Anthropology

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## Research Articles



## Commentaries



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