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Investigating fluoride toxicity in a Middle Woodland population from west-central Illinois: A discussion of methods for evaluating the influence of environment and diet in paleopathological analyses

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ABSTRACT

Diet is a key factor in the health of individuals and of communities, both ancient and modern. In studies of ancient health, termed paleopathology, most paleodiet researchers have focused on estimates of the nutritional quality of diet across distinctive menus, comparatively evaluating quality of life across space and time. Health, however, can also be affected by environmental dietary factors, including toxic levels or deficiencies of trace elements and minerals. In this paper, we emphasize the importance of rigorous differential diagnosis in paleopathology and the multiplicity of factors that may influence an individual's response to environmental stressors. Our example develops from observations of pathology in remains from the Ray site, a 2000 year-old Middle Woodland cemetery from west-central Illinois. We had previously developed a differential diagnosis for an environmental condition, wherein an abundance of fluoride placed people at risk for poor health. Here we use this differential diagnosis, published in detail elsewhere, as an example to illustrate the importance of linking environmental, dietary, epidemiological, and physiological factors in developing a well-supported differential diagnosis. We also consider directions for future studies that link molecular biology, geo-chemical and isotopic analysis to knowledge of past fluoride toxicity.

1. Introduction

Evaluating health in ancient communities requires considering the synergistic relationship between diet and disease. Most studies of ancient disease-diet relationships have focused on menu reconstructions and inferred nutritional quality of the diet. The environment, however, may also affect health by introducing toxic or deficient levels of substances into the diet. For example, diets deficient in iodine commonly lead to goiter (Fuge, 2013). The impact of toxic levels of lead is also well known (Flora et al., 2012). This paper discusses a previously developed paleopathological analysis (Nelson et al., 2016) of a less well-known condition in paleopathology, fluorosis, wherein an environmental abundance may cause an increased ingestion of fluoride, ensuing poor health. In so doing, we first consider the significance of studying health in the past and then illustrate by example the importance of rigorous evidence-based differential diagnoses in paleopathology and follow with discussion of a variety of technological methods that may provide further information in the observed pathology.

Paleopathology is foundational in the study of ancient health. Through paleopathological analyses we not only gain evolutionary understanding of diseases, but we may also gain insights about the social construction of pathological conditions. Another important goal of paleopathology is providing information of relevance in today's world. For example, dietary reconstructions and environmental studies reveal the impact of resource exploitation on health, often illuminating environmental influences of disease. Through understanding environmental and social factors, preventative measures can be improved.

The study of disease in past populations requires the researcher to make several assumptions and to voice several caveats. Initially, we must make the uniformitarian assumption that disease processes and host responses in the past were similar to those today. This assumption is, of course, less justified as we move back in time to species with no living representatives. Paleopathological studies are also inherently limited by the fact that many diseases are simply invisible archaeologically, leaving no skeletal or desiccated tissue evidence. Further, researchers must appreciate the full spectrum of possible disease changes across sex and age groups, keeping in mind many canonical references (Aufderheide and Rodriguez-Martin, 1998; Ortner, 2003) typically present exemplar extreme cases to illustrate a given condition.

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Paleopathology is by definition an interdisciplinary endeavor, at its center uniting the biomedical and archaeological sciences. Though time consuming and often expensive, the application of new technological methods, such as next generation DNA approaches, may strengthen differential diagnoses. In addition, theories and contextual information drawn from archival sources brings the social sciences and humanities, writ large, to the study of ancient health (Buikstra and Cook, in prep).

To illustrate the significance of interdisciplinary paleopathology, we consider previously reported examples of skeletal fluorosis from the Ray Site, a Middle Woodland site dating 50BC–AD400, in Illinois (Nelson et al., 2016). Within this site we identified eight individuals who displayed a constellation of similar pathological changes. Though these changes were not so severe as those illustrated in standard paleopathology texts, we argued that our evidence was most consistent with a diagnosis of fluorosis. We also hypothesized that this condition is being overlooked in North American archaeological contexts due to the lack of rigorous differential diagnoses that consider environmental influences. Here we review this differential diagnosis and also discuss future directions for research.

2. The Ray Site: observations and differential diagnosis

The Ray Site (11Br-104) is a Middle Woodland (50 BC to AD 400) accretional cemetery located in west-central Illinois, near the confluence of the Illinois and La Moine Rivers (Fig. 1) (Flotow, 1983; Nelson et al., under review). Slightly more than 100 individuals had been buried along a steep ridge crest, with burials aligned northwest to southeast. While most had been interred in a linear pattern, there were four apparent clusters of three or more individuals and an isolated concentration of nine burials in the southeast area of the site (Fig. 2) (Flotow, 1983; Nelson et al., under review). The burials were excavated between 1975 and 1980 as part of a rescue excavation conducted by trained avocational archaeologists Mary and Glen Hanning (Flotow, 1983).

2.1. Observations

An inventory of the Ray Site burials records at least 117 individuals, including 30 adult males, 29 adult females, 37 juveniles, and 21 unassigned individuals (Nelson et al., under review). During an osteological review of the remains, we found eight individuals who displayed similar abnormal skeletal changes, which included osteosclerosis, ossification of ligamentous and tendinous attachments, and healed and healing fractures. Dental defects such as dental pitting and mottling were noted as per Dean's Index (Dean, 1936). The condition affected five males and three females with estimated ages-at-death above 20 years of age (Table 1). Males present a more extreme expression of the disease than females, with an increased presence of enthesophytes, osteophytes, fractures, and periosteal deposition. Most affected individuals were middle-aged to older adults (Table 1).

2.2. Differential diagnosis

The abnormal skeletal changes observed in these eight Ray Site individuals are overall relatively subtle in comparison with the extreme representations typical of clinical and paleopathological textbooks (Aufderheide and Rodriguez-Martin, 1998; Ortner, 2003; Mann and Hunt, 2013; Resnick and Niwayama, 1988). In our earlier publication, we detailed these skeletal changes and compared them to those typical of nine present-day conditions: ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis (DISH), hematogenous osteomyelitis, hypoparathyroidism, myositis ossificans (*fibrodysplasia ossificans progressiva*), osteopetrosis, treponemal infection, Paget's disease of bone, and skeletal fluorosis (Table 2). These diseases present skeletal changes most similar to those observed in our study sample, and were therefore the focus of our differential diagnosis.

The starting point for developing this matrix of clinically anticipated changes is the constellation of bony and dental abnormalities noted in the affected Ray Site individuals. These include dental pitting and mottling, dense periosteal deposition, calcification of ligamentous and tendinous attachments, and an increased prevalence of fractures. Although a given skeletal change is not pathognomonic for a single disease, considering the suite of skeletal changes and their distributions across skeletons allows us to narrow our focus. We recognize that individuals may have died in early or late stages of the disease, meaning that degrees of expression may vary significantly. As illustrated in Table 2, the condition most consistent with our observed changes is fluorosis. This result was then examined within the framework of epidemiological data and the environmental context.

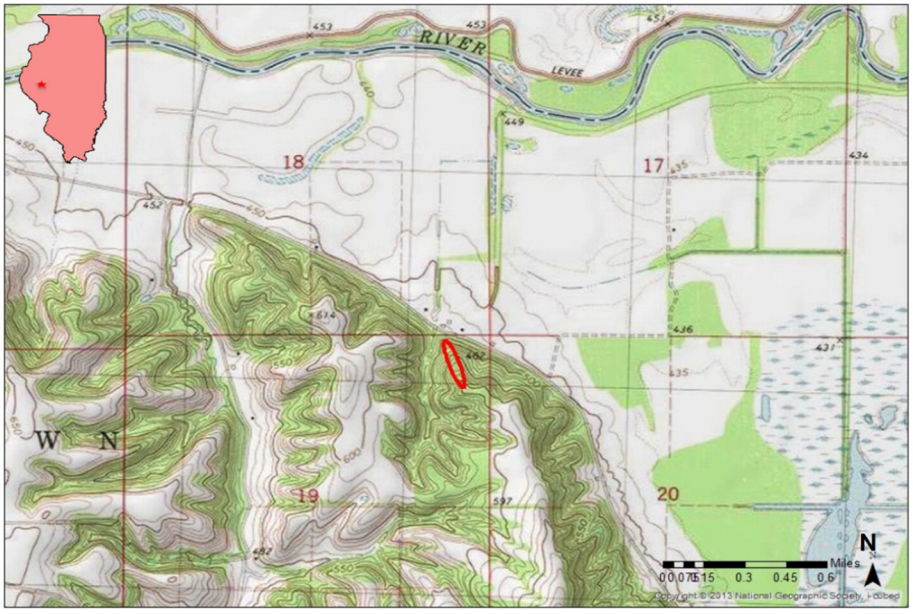

Fig. 1. Map of Ray Site location within Illinois. The La Moine Rive to the north, Illinois River (not shown) to the east of location. Ray site indicated with the red circle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Map taken from Nelson et al. (under review).

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