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Technical Note

Anemia or scurvy: A pilot study on differential diagnosis of porous and hyperostotic lesions using differential cranial vault thickness in subadult humans

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ABSTRACT

Metabolic disorders, such as scurvy, manifested in human skeletal remains provide insight into health, nutrition, and environmental quality in past populations. Porous cranial vault lesions are often used to diagnose metabolic conditions in subadult remains, but overlapping gross lesion expressions have led to over-diagnosis of anemia and under-diagnosis of scurvy. Studies by Ortner and colleagues have suggested that specific porous cranial lesions are pathognomonic of scurvy, but additional diagnostic tools are necessary. In this technical report, we offer a preliminary assessment of cranial vault thickness (CVT) at the site of porous lesions (*sensu lato* porotic hyperostosis, cribra orbitalia) as a method for distinguishing between scurvy and anemia in subadult crania. Computed Tomography (CT) was used to measure CVT at various landmarks associated with porotic hyperostosis and cribra orbitalia, complemented by lesion scores, from scorbutic ($N=11$), anemic ($N=3$), and non-pathological ($N=28$) subadult crania used as a control group. Results indicate that CVT consistently distinguishes scorbutic from non-pathological individuals, while anemic individuals overlap with both – likely a function of small sample size in this study. Despite current limitations, CVT has the potential to be an objective diagnostic tool for distinguishing scurvy and expanding reconstructions of nutritional adequacy over the life course in past populations.

1. Introduction

Porous lesions on the cranial vault are among the most commonly reported skeletal lesions in the paleopathological record. These include porotic hyperostosis, which is characterized by areas of circumscribed porosity and pitting on the ectocranial vault, and cribra orbitalia, a morphologically similar lesion that occurs on the orbital roofs. Since the 1960s, these lesions have frequently been attributed to iron deficiency anemia. However, more recent scholarship and advancements in differential diagnosis within paleopathology suggests that iron-deficiency anemia has been over-diagnosed; porous lesions, including porotic hyperostosis and cribra orbitalia, may instead: (1) be related to other conditions, especially megaloblastic and hemolytic anemias, scurvy, and rickets, and; (2) that underlying and subtle differences in lesion etiology may be distinguished based on the morphology and distribution of lesions on the crania (Ortner and Ericksen, 1997; Ortner et al., 1999, 2001; Walker et al., 2009).

In an influential series of works, Ortner and colleagues (1997, 1999, 2001, 2003) proposed that scurvy, which at the time was infrequently diagnosed in archaeological skeletal samples, could be identified in subadults based on the presence of two specific lesions. These include porous and occasionally hypertrophic bilateral lesions on the greater wing of the sphenoid bone, often accompanied by cribra orbitalia, and porous and hyperostotic, non-hypertrophic vault lesions. While such specific diagnosis is not possible in all instances, this criterion has since been used to identify many cases of scurvy in the archaeological record (*sensu lato* Geber and Murphy, 2012; Mays, 2008). Zuckerman and colleagues (2007) further proposed that differential cranial vault thickness

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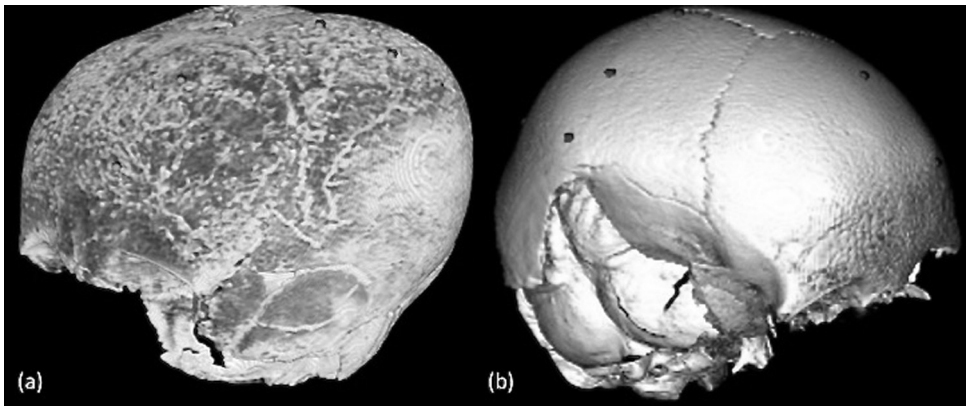

Fig. 1. Porous cranial lesions attributable to (a) scurvy and (b) anemia.

(CVT) might be a useful tool for distinguishing between scurvy and anemia, particularly megaloblastic anemia[1] (Walker et al., 2009) in subadult crania. This pilot study presents the results of a preliminary examination of the utility of cranial vault thickness, combined with cranial lesion distribution and morphology, to identify scurvy. We hypothesize that CVT in specific locations will correspond with a diagnosis of either scurvy or anemia. More specifically, we predict that total CVT at specific locations will be greater in individuals with anemia than individuals with scurvy, reflecting hypertrophy that occurs in anemic vault lesions but not scorbutic vault lesions. Second, outer table thickness will be greater in individuals with scurvy than individuals with anemia, as scorbutic lesions are exclusively hyperostotic. To assess differential CVT, archaeologically derived subadult crania with previously established diagnoses of scurvy ($N = 11$) or anemia ($N = 3$) were examined. They were also compared to a sample of archaeologically derived non-pathological, subadult crania ($N = 28$) serving as a control group. Computed Tomography (CT) was used to collect CVT at various landmarks associated with the locations of porotic hyperostosis and cribra orbitalia, complemented by standardized scores for these lesions.

1.1. Scurvy

Scurvy is caused by a deficiency of ascorbic acid or vitamin C (see various papers, this issue). This deficiency leads to fragile capillaries and abnormal, chronic bleeding, which produces subperiosteal hematomas, especially in response to minor trauma (Jaffe, 1972). Bleeding stimulates an inflammatory response that produces lesions on the cranium (Fig. 1A) and postcranial skeleton (Ortner, 2003). Subadults tend to be particularly vulnerable to the effects of vitamin C deficiency because extensive synthesis of collagen is involved in the growth process. This also creates more opportunities for the formation of defective vessels. Also, the periosteum, particularly in the orbits, is less firmly attached in subadults than it is in adults, making it more susceptible to tearing and bleeding (Ma'luf et al., 2002).

1.2. Anemia

Anemia is a pathological deficiency in either red blood cells (RBCs) or the hemoglobin they contain. Anemia provokes a hierarchical response, with increased RBC production in hematopoietic marrow constituting the last and most biologically costly resort for maintaining homeostasis (Ross and Logan, 1969). In the vault, resultant diploïc expansion causes resorption of the outer table, leading to the presence of porotic hyperostosis (Fig. 1B). Walker and colleagues (2009) have proposed that most porotic hyperostosis in the New World archaeological record is due to megaloblastic anemia, which is most commonly caused by chronic dietary deficiencies and malabsorption of vitamin B_{12} or folic acid.[1]

2. Materials and methods

2.1. Skeletal sample

The crania evaluated here were recovered from various Native American archaeological sites (Table 1) and are curated at the Smithsonian Institution National Museum of Natural History. Individuals with scurvy were diagnosed by examination of macroscopic lesion morphology and distribution by the fourth author (following Ortner and Ericksen, 1997; Ortner et al., 1999, 2001); several of the individuals included in this study were published as pathognomonic cases of scurvy by Ortner and colleagues (1997, 1999, 2001, 2003). Anemia was diagnosed based on macroscopic lesion morphology and distribution by the fourth author, following Ortner (2003). Individuals from the same collections that lacked cranial and post-cranial pathologies were included as a non-pathological control sample. All were aged to birth to 16 years on the basis of dental eruption (Ubelaker, 1978) and long bone length, when long bones were available (Scheuer and Black, 2004). Baseline, age-dependent CVT was recorded for non-pathological control crania; pathological CVT was recorded for the crania with scurvy and anemia. Subsample sizes were greatly limited by the scarcity of complete available crania in the Smithsonian's collections with the necessary diagnoses and without antemortem or taphonomic cranial deformation.

2.2. Data collection

Crania were scanned on a Siemens Emotion scanner (slice: 0.5 mm, mAs 83; voxel: 0.375). Using Osirix 2.7.1, fuzzy landmarks were independently placed by the first and second authors on 3D CT surface reconstructions of each crania at locations where porotic hyperostosis and cribra orbitalia commonly occur (Table 2). Fuzzy landmarks are landmarks located repeatedly (ten times) on the apparent centroid of a non-single point but delineated biological feature (e.g., the parietal boss) (Valeri et al., 1998). The total cranial vault thickness (outer table, inner table, and diploë) and outer table

[1] Hemolytic anemia is caused by either intrinsic factors within the RBC, producing hereditary forms of the condition (e.g., thalassemia, sicklemia), or extrinsic factors, such as toxins or drug use (Schrier, 1995). As hereditary hyperplastic anemia was likely absent in the pre-Columbian New World (de Zulueta, 1994; Dunn, 1965) and extrinsic causes are unlikely in the selected samples, hemolytic anemia was ruled out as a cause of these lesions.

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