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Stable isotope indicators of provenance and demographics in 18th and 19th century North Americans

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ABSTRACT

Using stable isotopes to gain insight into individual life histories is a valuable tool for unidentified or incomplete remains lacking historic records. This study analyzed stable carbon, nitrogen, and oxygen isotopes from bones and teeth of 18th–19th century North Americans of known ancestry, social class, and region of origin in an effort to discern qualitative patterns and create a quantitative predictive model of demographic information. The $\delta^{13}C_{collagen}$, $\delta^{13}C_{structural\ carbonate}$, and $\delta^{18}O_{structural\ carbonate}$ values provide the most overall information for detecting demographic differences, with $\delta^{15}N_{collagen}$ and $\delta^{18}O_{phosphate}$ to a lesser degree. Region of origin was the most predictable demographic factor with 82% correct classifications based on a two-variable model using $\delta^{13}C_{collagen}$ and $\delta^{18}O_{meteoric\ water}$ calculated from $\delta^{18}O_{structural\ carbonate}$, which reflects the influence of dominant local vegetation types and local drinking water. Ancestry was correctly identified in 68% of cases using $\delta^{13}C_{collagen}$. Social class was less predictable with correct identification in 60% of cases based on $\delta^{13}C$, $\delta^{15}N$, and $\delta^{18}O$ values where the upper class was most distinguishable. Isotope patterns observed in ancestry and social class groups are linked to cultural food preferences and food availability. Certain sample sites, such as military burials and urban cemeteries, show a greater range of isotope values suggesting a variety of individual regional origins and cultural backgrounds. Burials of extreme upper or lower class individuals show greater isotopic homogeneity suggesting reliance on localized food sources or cultural preferences for particular dietary choices.

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1. Introduction

Archaeological, anthropological, and forensic studies rely upon basic demographic information such as ancestry, age, social class, and provenance to draw sociological conclusions and interpret the life history of deceased individuals. Morphometric analyses may fail to yield such information from poorly-preserved or incomplete remains and written historical records are often non-existent. This study examines stable carbon, nitrogen, and oxygen isotopes in bones and teeth as qualitative indicators and a quantitative methodology for input into the statistical prediction of demographic information. These isotopes are proxies for residence and dietary habits linked to ancestry or social class (Ambrose, 1993; Koch, 1998; Koch et al., 1994; MacFadden, 2000; Peterson and Fry, 1987). A large sample of North American archeological remains (18th–19th centuries) with known demographics is used as an exemplar for developing a predictive statistical isotope model for regional, ancestry, and social status combinations from remains of indeterminate origin.

1.1. Stable isotope theory and considerations

Bones and teeth consist of organic and mineral components that record isotopic information. Well-preserved bones and tooth dentin contain collagen, a durable protein with carbon and nitrogen isotopes incorporated largely from dietary protein (Ambrose and Norr, 1993; Froehle et al., 2010; Hedges, 2003; Jim et al., 2004; Krueger and Sullivan, 1984; Lee-Thorp et al., 1989; Tieszen and Fagre, 1993). Bone, tooth enamel, and tooth dentin contain phosphate ($-PO_4$) in the mineral hydroxyapatite and structural carbonate ($-CO_3$) substituting for $-PO_4$ and $-OH$ groups in hydroxyapatite, both of which incorporate oxygen isotopes from drinking water (Bryant and Froelich, 1995; Kohn, 1996; Luz and Kolodny, 1985). Structural carbonates also include carbon isotopes incorporated largely through blood dissolved carbonates that reflect carbohydrate and lipid dietary components (Hedges, 2003; Tieszen and Fagre, 1993; Zazzo et al., 2010). Bone collagen and hydroxyapatite remodel throughout life and capture a lifetime

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average of isotopic input (Fogel et al., 1997; Francillon-Vieillot et al., 1990; Katzenberg, 1993; Stenhouse and Baxter, 1979). Teeth remodel very little after formation and capture isotope values of diet and water input during the shorter span of tooth formation only (Carlson, 1990).

Isotope values are reported in standard delta notation:

$$\delta X = \left[\left(R_{\text{sample}} - R_{\text{standard}}\right) \Big/ \left(R_{\text{standard}}\right)\right] * 1000$$

where X represents the system of interest (i.e. ^{13}C, ^{15}N, ^{18}O), R represents a ratio (i.e. $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{18}O/^{16}O$), and units are per mil (‰). The standards are V-PDB, atmospheric air, or V-SMOW for C, N, or O, respectively. This study analyzes carbon and nitrogen isotopes of bone and tooth collagen ($\delta^{13}C_{\text{collagen}}$ and $\delta^{15}N_{\text{collagen}}$), oxygen isotopes in phosphates and structural carbonates ($\delta^{18}O_{\text{phosphate}}$ and $\delta^{18}O_{\text{structural carbonate}}$), and carbon isotopes of structural carbonates ($\delta^{13}C_{\text{structural carbonate}}$).

Carbon isotopes indicate the plant type consumed by an individual. Two photosynthetic pathways common to most plants, C3 (dicots, most trees, shrubs, few grasses, and wheat) and C4 (specific grasses and sedges including corn), produce distinct isotope ranges with the former depleted in ^{13}C (Heaton, 1999; O'Leary, 1988; Smith and Epstein, 1971). Given the fractionation of ~2–5‰ between plants and bone collagen (Balasse et al., 1999; Hedges, 2003; Koch, 1998; Roth and Hobson, 2000; van der Merwe, 1982), humans consuming a strict C3 diet exhibit $\delta^{13}C_{\text{collagen}}$ values of ~-22 to −18‰, while those consuming a strict C4 diet (largely corn-based) exhibit values of ~−11 to −7‰. Given the fractionation of ~12–15‰ between diet and bone structural carbonate in large mammals (Hedges, 2003; Koch, 1998; Kohn and Cerling, 2002; Passey et al., 2005; Zazzo et al., 2010), a strict C3 diet exhibits $\delta^{13}C_{\text{structural carbonate}}$ values of ~−13 to −9‰, while a strict C4 diet exhibits values of ~−1 to +3‰. Most human isotope values fall within these endpoints as people typically consume a mix of plant types and livestock/game with mixed feed. Given that isotopically enriched C4 grasses and corn crops were more common in warmer southern regions, the difference between C3- and C4-based diets translates to the difference between a primarily northern versus southern diet, respectively, for North Americans. Southerners should have enriched $\delta^{13}C$ values since both wild and domesticated animals consume local plants, and corn itself was a staple in southern diets (Pace, 1993). Northern diets, European-style diets of immigrants, or European-style diets consumed as a cultural preference would include less corn and produce $\delta^{13}C$ values in the C3 range.

Nitrogen isotopes reflect trophic position and amount of meat in the diet. Mammals, including humans, fractionate nitrogen between diet and bone collagen, producing a ~3–4‰ stepwise enrichment with trophic level (Bocherens and Drucker, 2003; DeNiro and Epstein, 1981; Minagawa and Wada, 1984; Post, 2002; Schoeninger and DeNiro, 1984; Sutoh et al., 1987). Archaeological North Americans exhibits $\delta^{15}N_{\text{collagen}}$ values of ~+8 to +14‰ indicating a high position in the trophic structure and significant carnivory (Fogel et al., 1997; Katzenberg, 1993; Katzenberg et al., 2000; Raynor and Kennett, 2008; Ubelaker and Owsley, 2003). In a time period when ancestry and social class are intimately linked, it is hypothesized that lower classes and African Americans had less access to meat and relied on less expensive, readily available grains, resulting in depleted $\delta^{15}N_{\text{collagen}}$.

Oxygen isotopes in precipitation and meteoric drinking water have clear regional patterns in North America with enriched values in warmer lower latitudes and depleted values in cooler higher latitudes (Bowen and Wilkinson, 2002; Dutton et al., 2005; Kendall and Coplen, 2001). The $\delta^{18}O$ of local meteoric drinking water correlates with mammalian body water and $\delta^{18}O_{\text{phosphate}}$ with subtle variations in fractionation according to species and climatic variables (Bryant and Froelich, 1995; D'Angela and Longinelli, 1990; Daux et al., 2008; Kohn, 1996; Levinson et al., 1987; Longinelli, 1984; Luz and Kolodny, 1985; Luz et al., 1984). Observed $\delta^{18}O_{\text{phosphate}}$ and $\delta^{18}O_{\text{structural carbonate}}$ therefore serve as a proxy for region of origin with northerners showing more depleted $\delta^{18}O$ values than southerners.

Inherent in the use of any isotope system for investigating demographic information is the assumption that sampled individuals relied upon a fairly local diet and remained regionally stationary. Immigration, imported foods, or extensive cross-regional migrations due to cultural influences or military service could produce a biased indication of provenance. For this reason, archaeological remains from the 18th–19th centuries represent an initial test case insofar as these people were more likely to adhere to these assumptions.

2. Methods and materials

2.1. Samples

Sample localities consist of twelve 18^{th}–19^{th} century North American burial sites (Table 1). Remains were procured through associations with state and federal agencies, universities, contract archaeology programs, and local administrators of churches and cemeteries. All individuals were evaluated by the Smithsonian's National Museum of Natural History Division of Physical Anthropology. All individuals included in this study were adults. Ancestry classifications and sex were assigned based on osteological criteria. Region of origin and social class were assigned based on site locations and historical records.

2.2. Chemical extraction

Solid bone chunks and tooth dentin were isolated for collagen extraction using a rotary tool or bone saw. Bone, tooth dentin, and tooth enamel were powdered for phosphate and structural carbonate analyses using a mortar and pestle.

Collagen was extracted from bones and tooth dentin according to modified methods of Longin (1971). Solid bone and dentin pieces (~200–500 mg) were sonicated in water to remove sediments and labile salts, and demineralized in 0.6 M HCl at 4 °C for 24 h increments (acid replaced daily) until reaction ceased. Samples were rinsed to neutrality before soaking in 0.125 M NaOH for 24 h to remove humic and fulvic acid contaminants. Remaining crude extract was reacted in 0.03 M HCl at 95 °C for 18 h to separate soluble and insoluble phases of collagen. The resulting supernatant was lyophilized to isolate purified collagen extract.

Structural carbonate was extracted from bones, tooth dentin, and tooth enamel by modified methods of Bryant et al. (1996). Approximately 20 mg of powdered material was soaked in 2–3% sodium hypochlorite to remove organic components. Samples were rinsed and soaked in 1 M acetic acid solution buffered with 1 M calcium acetate (pH ~4.5) for 4 h to remove secondary carbonate phases. Samples were rinsed to neutrality and dried (60 °C).

Phosphate was isolated from bones, tooth dentin, and tooth enamel using the method of Dettman et al. (2001). Approximately 20 mg of powdered material was soaked in 2 M hydrofluoric acid for 24 h to liberate phosphate ions. The resulting supernatant was isolated, diluted, and neutralized with 20% ammonium hydroxide. Insoluble silver phosphate was precipitated by addition of 2 M silver nitrate, then rinsed and dried (60 °C).