Journal of Archaeological Science 47 (2014) 10–21

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Assessing life history from commingled assemblages: the biogeochemistry of inter-tooth variability in Bronze Age Arabia

Lesley A. Gregoricka*

Department of Sociology, Anthropology, & Social Work, University of South Alabama, HUMB 34, 5991 USA Drive North, Mobile, AL 36688, USA

A R T I C L E I N F O

Article history:
Received 2 November 2013
Received in revised form
11 February 2014
Accepted 5 April 2014
Available online xxx

Keywords:
Strontium isotopes
Oxygen isotopes
Inter-tooth sampling
Mobility
Life history
Commingling
Oman peninsula

A B S T R A C T

Stable isotopes represent a remarkable means of assessing the life histories of individuals in the archaeological record, primarily by taking advantage of multiple skeletal tissues that form and remodel throughout life. However, this methodological tool also has the potential to provide crucial information on the life histories of individuals represented only by commingled, fragmentary, and otherwise isolated human skeletal remains, particularly when more traditional methods of evaluation are not possible. In this study, a sequential analysis of radiogenic strontium ($^{87}Sr/^{86}Sr$) and stable oxygen ($\delta^{18}O$) isotopes of associated molars from the *in situ* mandibular or maxillary fragments of 19 commingled individuals from multiple Bronze Age tombs in the United Arab Emirates was undertaken in order to examine temporal changes in mobility at the level of the individual. The majority of individuals display little difference in inter-tooth isotope ratios, suggesting a general lack of residential mobility between early childhood and late adolescence, an unexpected result given abundant evidence (artifactual and written) for a population actively engaged in both regional and interregional trade in the third millennium BC. However, two individuals from the Emirate of Fujairah demonstrate disparate inter-tooth $^{87}Sr/^{86}Sr$ values – likely indicative of some migration event – which calls into question the supposed cultural isolation of the region during the second millennium BC.

1. Introduction

A recent bioarchaeological shift in emphasis from the population level to that of the individual – variously described as osteobiography (Mayes and Barber, 2008; Stodder and Palkovich, 2012) or life history (Barrett and Blakey, 2011; Zvelebil and Weber, 2013) – has introduced new perspectives into the interpretation of past lifestyles and behaviors. Increasingly refined methodological techniques have for the first time permitted a detailed assessment of individual life histories and the temporal shifts associated with particular periods of the life cycle, all of which can be utilized to form a more holistic and comprehensive understanding of past populations as a whole.

Radiogenic and stable isotopes incorporated into human skeletons during life represent a remarkable means of assessing the life histories of individuals in the archaeological record. Primarily by taking advantage of multiple skeletal tissues that form and remodel at different stages throughout life, bioarchaeologists have begun to rely more heavily on biogeochemical data as a way to elucidate not only changes in diet within the life course but also geographic origins in childhood and residential mobility later in life. In particular, intra-tooth sequential sampling has come to the forefront of archaeological chemistry as a means of improving our understanding of specific life histories. Previous studies have used intra-tooth stable isotope analysis of faunal enamel in an attempt to reconstruct seasonal migrations and changes in patterns of dietary intake (e.g., Balasse, 2003; Balasse et al., 2002; Bocherens et al., 2001; Britton et al., 2009; Fricke and O'Neil, 1996; Montgomery et al., 2010; Stevens et al., 2011; Weidemann et al., 1999). Far fewer applications to human enamel have been conducted (e.g., Holt, 2009; Lovell and Dawson, 2003; Sandberg et al., 2012; Wright, 2013), although as with faunal biogeochemical studies, the goal of more precisely identifying and understanding particular processes – including the process of weaning, developmental defects, and migration patterns – remains the same.

While these intra-tooth sampling methods have gained popularity over the past decade, especially because of their ability to minimize the destructive nature of isotope sampling for rare or small samples, a number of issues make the use of intra-tooth sampling and its associated technology problematic. First, studies

* Tel.: +1 989 307 9213; fax: +1 251 460 7925.
E-mail address: lgregoricka@southalabama.edu.

http://dx.doi.org/10.1016/j.jas.2014.04.004
0305-4403/

comparing $^{87}Sr/^{86}Sr$ enamel values derived from both solution-based MC-ICP-MS and laser ablation report conflicting measures of accuracy because of Ca–P–O isobaric interference; as the combined mass of calcium, phosphorus, and oxygen mimics that of ^{87}Sr, $^{87}Sr/^{86}Sr$ values are artificially inflated during laser ablation (Richards et al., 2008; Simonetti et al., 2008). Some (e.g., Copeland et al., 2010) have reported better accuracy and precision, suggesting that enamel matrix diagenesis may play a role in methodological differences in strontium values, while others point to analytical challenges in producing reliable $^{87}Sr/^{86}Sr$ ratios from regions with low strontium concentrations (~100–200 ppm) (Horstwood et al., 2008). This uncertainty makes it necessary to approach intra-tooth sampling using laser ablation analysis with caution.

Secondly, and most pertinently, establishing a definitive time resolution for specific growth increments of enamel is not yet fully understood due to the process of amelogenesis itself. After the formation of a preliminary enamel matrix during the secretory stage, the second phase of enamel formation – maturation – can be characterized by consecutive but irregular, multi-directional mineralization fronts that do not adhere to discrete, incremental units of growth (Balasse, 2002; Fisher and Fox, 1998; Hillson, 1996; Montgomery et al., 2010). Furthermore, the initiation and termination of mineralization, in addition to overall mineralization rate and intensity, can vary substantially between enamel layers (Sandberg et al., 2012; Suga, 1979; Suga et al., 1979). As a result, isotopic signatures derived from intra-tooth sampling procedures reflect attenuated values that are better presented as a product of long-term averaging than as exact gauges for short-term behavior (Balasse, 2002; Passey and Cerling, 2002). Consequently, while preliminary patterns reflecting seasonal changes, mobility, and dietary change have been tentatively identified (Balasse et al., 2002, 2005; Fricke and O'Neil, 1996; Kohn et al., 1998; Sharp and Cerling, 1998) and point to the potential of intra-tooth sampling, a single sample nevertheless represents months of enamel mineralization (Hoppe et al., 2004).

Another means of obtaining isotope values associated with specific periods of growth, development, and maturation instead lies with the bulk sampling of different teeth and bone with known formation and remodeling rates (Dupras and Tocheri, 2007). Unlike intra-tooth sampling, this method does not seek to pinpoint the exact timing (in weeks or months) of isotope incorporation into skeletal tissues, but instead takes a broader life history approach by comparing two or more extended periods (e.g., infancy, adolescence, adulthood) within the life cycle. While the utilization of numerous skeletal tissues to achieve such an evaluation supplies a wealth of information when more complete individual skeletons are present and well preserved, commingled skeletal material presents a challenge to even the most basic methods of evaluation (including age and sex estimation). Further, without direct association of skeletal elements, commingled remains do not traditionally lend themselves to extensive examinations of individual life histories.

Nevertheless, for millennia in the Near East, communal burial was a common form of disposing of the dead, and as a result, commingled collections are frequently represented in the archaeological record in the Levant (Al-Shorman, 2003, 2004; Amiran et al., 1986; Blau, 2006; Chesson, 1999; Haskins, 1988; Lev-Tov et al., 2003; Nagar et al., 1999; Ortner and Frolich, 2008; Sheridan, 1999; Ullinger et al., Early view), Arabia (Blau, 1998, 2001a, 2001b, 2007; Frifelt, 1991; Gregoricka, 2011, 2013a; Haerinck, 1991; Porter and Boutin, 2012; Potts, 1993), and Anatolia (Boz and Hager, 2014; Losch et al., 2006; Whitcher et al., 2009). Commingled collections can provide surprisingly abundant data on variables such as health, non-specific stress indicators, activity patterns, and diet, and as such, have the potential to provide crucial information on communities in the past (Adams and Byrd, 2008; Adams and Konigsberg, 2004; Osterholtz et al., 2014). Moreover, despite the commingled nature of these interments, mandibular and maxillary fragments commonly contain multiple *in situ* teeth from the same individual, permitting an appraisal of temporal change in the life course using isotopes incorporated into enamel hydroxyapatite.

Here, a sequential analysis of radiogenic strontium ($^{87}Sr/^{86}Sr$) and stable oxygen ($\delta^{18}O$) isotopes of consecutively forming molars from the *in situ* mandibular and maxillary fragments of 19 commingled individuals from multiple Bronze Age tombs in the United Arab Emirates was undertaken in order to examine temporal changes in mobility at the level of the individual in early life.

2. Mobility and mortuary traditions in Bronze Age Arabia

Considerable changes in funerary practices over the course of the third and second millennia BC – exhibited by differences in tomb placement, architecture, and membership – are inextricably linked to fluctuating patterns of mobility across the Arabian landscape. These mortuary traditions have customarily been classified as Umm an-Nar (ca. 2700–2000 BC) and Wadi Suq (ca. 2000–1300 BC), and are discussed in further detail below.

The commencement of the Umm an-Nar period brought with it widespread sedentism in response to the domestication of the date palm, instigating the nomadic pastoralists of the preceding Hafit (ca. 3100–2700 BC) period to seek out sources of fresh water to support oasis agriculture and permanent settlement (Mery and Tengberg, 2009; Potts, 1990). Villages constructed by Umm an-Nar communities were typically centered around large mud-brick fortress towers, which served to protect wells critical to the survival of crops grown in this arid environment (Blau, 1999; Potts, 2001, 2009). In addition to garden crops, domesticated herds and marine resources supplemented the varied diet of these third millennium populations (Al Tikriti, 1985; Aspinall, 1998; Potts, 1998; Uerpmann, 2001). Located in close proximity to these settlements, monumental circular tombs 4–14 m in diameter contained hundreds of commingled individuals representing approximately 200–300 years of use (Al Tikriti and Mery, 2000; McSweeney et al., 2008; Potts, 1997). The fine craftsmanship evident in the expertly-shaped ashlar façades of these tombs, coupled with their generally large size, speaks to the communal division of labor and hierarchical system of management required to construct such funerary structures (Cleuziou, 2007).

The fragmentary and commingled nature of human remains in Umm an-Nar tombs can be attributed to a number of factors affecting the postmortem environment, including natural taphonomic processes (e.g., water, rodent burrows), human disturbance from the looting of metals and stones in antiquity, and intentional mortuary practices (Blau, 2001a,b). In rare instances, one or more fully articulated individuals have been recovered, buried in a flexed position and variably laid on either their right or left sides (Benton, 1996; Blau, 2001a,b, 2001c; McSweeney et al., 2008). These individuals are consistently found at the lowest levels of the tomb's foundations and point to a funerary strategy consisting of an initial primary interment, with whole bodies placed into these graves until a need for space required that those already buried were pushed aside in order to make more room (Blau and Beech, 1999). Articulated limbs and other skeletal elements recovered from Umm an-Nar tombs lend credence to this interpretation (e.g., Mery et al., 2004; Schutkowski, 1988). In some cases, it appears that small fires were lit within the tomb to clear additional human debris, and in at least one instance, postmortem cut marks suggest deliberate disarticulation (Al Tikriti and Mery, 2000; McSweeney et al., 2008).

While interregional relations reemerged in the preceding Hafit period, it was the intensification of trade with the far-reaching city-