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Using Oxygen and Carbon Isotopic Signatures in Order to Infer Climatic and Dietary Information in Roman Edessa, Greece

Dimitra-Ermioni Michael [1] and Elissavet Dotsika [1]

[1] Stable Isotope and Radiocarbon Unit, Institute of Nanoscience and Nanotechnology, NCSR " Demokritos", 15310 Ag. Paraskevi, Greece

e.dotsika@inn.demokritos.gr

Abstract Even though many isotopic studies have been conducted on ancient populations from Greece for the purpose of dietary reconstruction; mostly through carbon and nitrogen isotopic signals of bone collagen, less attention has been given to the utility of apatite signatures (oxygen and carbon) as dietary and palaeoenvironmental tools. Moreover, until recently the isotopic signal of tooth enamel for both the purposes of environmental and dietary reconstructions has been rarely assessed in ancient Greek societies. Therefore, the present study aims to provide with novel isotopic information regarding Edessa; a town in Northern Greece, during the Roman period. The current study primarily aims to explore the possible differentiation between the present climatic conditions in Edessa in relation to those occurring at the Roman period. Secondly, this study aims to reveal the significant utility of enamel isotopic signatures (carbon and oxygen) in palaeoenvironmental and palaeodietary studies regarding ancient human remains. The isotopic analyses have been conducted at the Stable Isotope and Radiocarbon Unit of INN, NCSR "Demokritos". The population of Roman Edessa (2nd-4th c. AD) consists of 22 individuals, providing with 19 bone samples and 16 enamel ones. The mean enamel oxygen value is at -7.7 ±1.1 ‰, the bone apatite mean oxygen value at -9.2 ±1.9 ‰, and finally the mean carbon enamel value is at -11.7 ±1.2 ‰. Oxygen values probably indicate that Edessa had a cooler climate during the Roman times in relation to present conditions, even though more research should be carried out in order to be more certain. In addition, the possible existence of non-local individuals has been revealed through the oxygen teeth enamel-bone apatite spacing. Finally, the carbon enamel signature has pointed out possible differentiations between the adult and the juvenile diet. Based on Edessa's findings, the stated study strongly encourages the enamel oxygen and carbon isotopic signals as palaeoclimatological and palaeodietary tools respectively.

1. Introduction

Oxygen isotope ratios of human skeletal and tooth remains have been used in order to reconstruct palaeoclimatic conditions, to assess infant feeding practices [1] and to study mobility patterns of ancient populations [2,3]. On the matter of fact oxygen isotopic signature from the inorganic part of bones and teeth principally reflects the isotopic composition of the ingested water [i.e. 4, 5, 6, and 7]. In addition, apart from the collagen component of the bone; which has been frequently used in order to explore the dietary habits of past societies, apatite signatures and in particular the enamel carbon signal can also offer important information regarding palaeodiet. In fact, when bone and tooth samples are both available from the same individual, it is possible to compare the dietary habits between different stages of the individual's lifetime.

Thus, the basic aims of the present study are: 1) to compare the climatic conditions of a past population; Roman Edessa (2nd-4th c. AD), in relation to present environmental conditions in the stated area, and 2) to infer dietary information from the enamel carbon signature in order to encourage the inclusion of the abovementioned isotope in palaeodietary investigations.

2. Oxygen and carbon isotopes in bone apatite and tooth enamel

The utility of oxygen isotopic signatures for the purpose of palaeoclimatic investigation lies on the fact that the ratio of ^{18}O to ^{16}O of meteoric precipitation, expressed as $\delta^{18}O$ per mill (‰), relative to the international standard (vSMOW) varies geographically by temperature, humidity, evaporation, distance to the sea, altitude and latitude. The oxygen isotopic values decrease in colder climates (cold season, high altitude and latitude, further inland), while in warmer conditions (coastal locations, warmer season, low altitude and latitude) they increase [i.e. 8, 9]. The $\delta^{18}O$ in mammal teeth and bones depends on the oxygen isotopic ratio of oxygen sources, such as the ingested meteoric water, oxygen from consumed food and atmospheric O_2. However, due to the fact that oxygen isotope values of atmospheric O_2 are fairly constant [10], primarily the consumption of liquid water and secondly food contribute mostly to $\delta^{18}O$ values of body water [11]. In addition, drinking water differs from that of precipitation by 0.3-0.8 ‰ [12].

Apart from $\delta^{13}C_{coll}$ and $\delta^{13}C_{ap}$ values, carbon enamel isotopic values also correlate very highly to $\delta^{13}C_{diet}$, as it has been pointed out by experimental feeding studies on pigs [13]. Thus, any of these values can be used in dietary reconstructions of ancient populations. Tooth enamel is formed during only a limited part of an organism's life, and hence the isotopic signature captured is that of the diet during the period of enamel formation [14]. In contrast, bone 'turns over'; therefore its isotopic signal integrates diet more of the individual's lifespan (for example carbon and nitrogen isotopes of bone collagen reflect the protein diet of the past 10-20 years of life) [15]. Concluding, using $\delta^{13}C_{en}$ in conjunction with $\delta^{13}C_{ap}$ and $\delta^{13}C_{coll}$ can reveal possible dietary differentiations between the adult and the childhood/adolescent diet.

Figure 1. Map of Greek Macedonia showing the location of Edessa

3. Results and discussion

For the needs of the present study, 19 long bone fragments (femoral) and 16 teeth (canines or 2nd molars) from 22 adults were analyzed. Edessa is a town in Greek Macedonia located 95.5 km northwest of Thessaloniki (figure 1). The isotopic analyses were conducted at the Stable Isotope and Radiocarbon Unit of the Institute of Nanoscience and Nanotechnology, of N.C.S.R Demokritos, in Athens, Greece. The protocol followed for the bioapatite extraction was according to [16]. Powdered bone samples (200mg) were soaked in 2-3% sodium hypochlorite (NaOC1) for 24 hours, to oxidize organic residues. Samples were then rinsed with distilled water, and treated with 1M acetic acid-Ca acetate buffer for 12 hours, in order to remove exogenous carbonate. The teeth samples underwent the procedure of cleaning and powdering before the analyses, following the trend of non-chemically treating tooth enamel [i.e. 17] The oxygen values (bone apatite and tooth enamel) are presented in figure 2. The enamel oxygen values range between -5.7‰ to -9.2‰, whereas the mean value is at -7.7 ±1.1 ‰. The apatite oxygen values on the other hand, range between -5.8‰ to 12.1‰ with a mean value at -9.2 ±1.9 ‰.

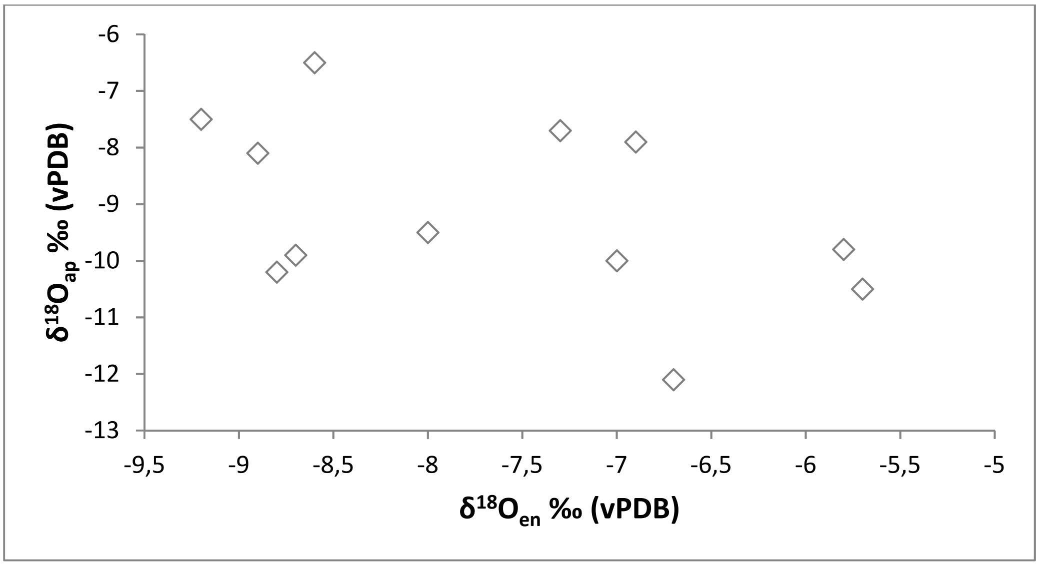

Figure 2. Oxygen enamel isotope values vs. bone apatite values

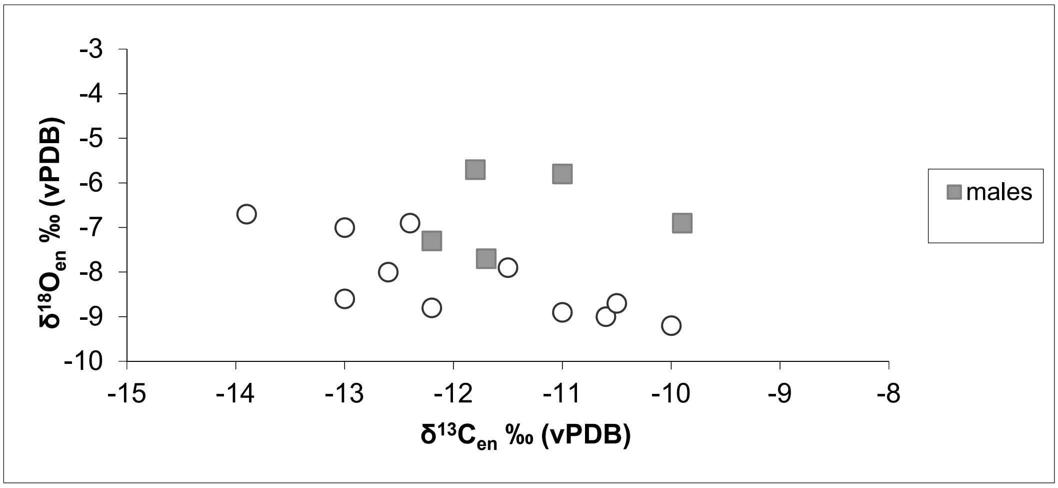

Figure 3. Carbon enamel isotope values vs. oxygen enamel values in relation to sex

Edessa's distance to the sea is at 320 meters. The mean annual precipitation rate is at 500mm; however it exceeds 750mm in regions of higher altitude (mountainous areas). The oxygen isotopic signature for spring waters in Edessa varies from -6.9 to -7.3‰ [8]. The mean maximum temperature in winter is between 8-10 ºC, whereas the minimum between -1 to -0.5 ºC. In the summer, the mean maximum temperature is at 28 ºC, while the minimum between 10-13 ºC. Therefore, the mean annual temperature for Edessa is approximately at 12 ºC. As mentioned above, the $\delta^{18}O_{ap}$ is highly correlated to the $\delta^{18}O_w$ of drinking water [5, 18], and therefore based on the relationship between apatite phosphate and carbonate, formed by [19], we derive that $\delta^{18}O_w = 1.53\ \delta^{18}O_{ap}$ (PDB)-0.14 [20]. When performing the stated equation for our samples (both enamel and bone apatite), it seems that $\delta^{18}O_w$ (spring waters) during the Roman period were more negative in relation to present conditions, thus reflecting that Edessa was colder. However, more research needs to be carried out in order to be certain and specify the exact range of oxygen isotopic signals in the past. For example teeth from present Edessa, derived from local individuals who drink tap water (local water) should be collected, in order to compare with a greater detail the climatic conditions of the past in relation to those of the present period. In addition, when comparing the enamel oxygen signatures with the bone apatite ones, significant differentiations are noted for at least 4 individuals. E/T36NN (male; 20-35 years old), E/T27B (male; 20-35 years old), E/T25 (female, 36-50 years old) and E/T26 (female, 36-50 years old), display oxygen enamel-apatite spacing of 4.8δ, 4δ, 3δ and 5.4δ respectively. In addition, the enamel oxygen values for the stated individuals are more positive in relation to their bone apatite ones, possibly reflecting that during their earlier years they lived in warmer places in relation to Edessa.
The mean carbon enamel value is at -11.7 ±1.2‰. According to [21], a diet comprised of 100% terrestrial sources would lead to a mean value at -12.2 ‰. Therefore, our carbon values; which are clustered mainly between -10 to -14 ‰ (figure 3) basically suggest a more C_3 terrestrial based diet (i.e. cereals, fruits, vegetables, terrestrial animals). Interestingly, according to the collagen and apatite bone samples which reflect the adult diet of the stated population, there is evidence of significant consumption of C_4 sources (i.e. millet), and to a lesser extent some freshwater intake [22]. According to literary sources, in both the Greek and Roman society, childhood was considered distinct from adulthood, and it has been commented by many ancient writers that children required a discrete diet from adults [23, 24, 25]. In particular, according to Galen juveniles in the ancient Greco-Roman world should primarily be fed on cereals, before being gradually introduced to other food sources [26; p. 267]. Therefore, a possible difference could be suggested between the juvenile and adult diet, albeit other possibilities should also be taken into consideration [22]. Moreover, the enamel carbon signature; similarly to the other carbon proxies ($\delta^{13}C_{ap}$ and $\delta^{13}C_{coll}$), does not suggest any significant dietary differences between the two sexes; hence further supporting the absence of gender differentiations [22]. All in all, the enamel carbon signature has revealed important information regarding the diet of the said population.

4. Conclusions

Concluding, oxygen results deriving from enamel and bone apatite samples, possibly point out that during the Roman period Edessa faced colder climatic conditions in relation to present day. However, more research should be conducted in order to clarify the climatic conditions with a higher precision. Furthermore, enamel carbon fingerprinting revealed the dietary habits of the said population during their childhood years, suggesting a possible differentiation between the childhood/juvenile and the adult diet. Therefore, apart from carbon collagen and apatite signatures, carbon enamel signal can also offer important information regarding the dietary patterns of ancient civilities, and even point out possible dietary shifts during the lifetime of past individuals. Hence, as enamel carbon signature is a valuable isotopic tool, we strongly encourage its inclusion in palaeodietary studies.

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