The Paleodiet of the Iron Age Site of Pella in Jordan using Stable Carbon Isotope Analysis

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Abstract: *Stable carbon isotope ratios were determined from 25 samples of human dental enamel from the Iron Age IIA site of Pella in Jordan to reconstruct the paleodiet. The site is located hundreds of meters below sea level and enjoys warm winters but very dry and hot summers. The teeth enamels were treated with sodium hypochlorite to remove organic materials and acetic acid to remove carbonate residues; then digested with phosphoric acid at 90 °C. The collected CO2 gases were analyzed using a Finnegan mass spectrometer against PDB standards. The results indicate an average d13Cdiet of about -21.2 ‰, which is around C3 plant values after the application of 9.6% as an enrichment factor.*
Keywords: Paleodiet, Iron Age, Jordan, Stable Carbon Isotopes, Pella..

Introduction

Little is actually known about the Iron Age in Jordan especially from bioarchaeological point of view; studying the human skeletal remains within a cultural context. This can at least partly be attributed to the general lack of human skeletal remains from this period. While there is a number of important Iron Age funerary sites, such as Amman (Harding, 1951; Yassine, 1975; Abu Ghanimeh, 1984; Hadidi, 1987), Sahab (Ibrahim, 1972; Dajani, 1970), Tell Mazar (Ibrahim, 1977: 78), Dhiban (Stern, 2001), Jabal Hamrat Fidan (Levy et al., 1999) and Irbid (Dajani, 1964). Many, if not all of them, are characterized by very poor skeletal preservation conditions. This has seriously impeded the reconstruction of the inhabitants' paleobiology up to this point. The reconstructed way of life in these sites has many missing links and gaps, where the major one is the people themselves. The recovered faunal materials, especially the human remains, suffered a large degree of deterioration that hindered comprehensive and detailed reconstruction of the inhabitants' paleobiology.

Much of the archaeological studies that dealt with the human skeletal remains, in general, have focused on the relationships between man and environment (Tutken, 2002; Langlois et al., 2003; Hu et al., 2007), subsistence strategy (Landon, 2005; Krigbaum, 2003), economy (Wright, 2003) and social status (Le Huray and Schutkowski, 2005). All of these dimensions are interrelated with diet (Sullivan, 2005), which unfortunately is not elucidated for the Iron Age in Jordan yet. Pella, for example, is one of the Iron Age sites that revealed faunal remains with well-defined archaeological contexts and chronology. Therefore, it has the potential to investigate the paleodiet, which is the aim of this study, using stable carbon isotope analysis. This technique is a reliable method for reconstructing the past diet, which is the first application in the region for Iron Age sites. The method was previously applied on the Byzantine teeth from Waqqas in Jordan Valley very close to Pella (Al-Shorman and Al-Shiyab, 2004). This study considers the dimension of stable carbon isotopes as an indicator of C3 and C4 plant consumption in Pella and consequently the paleodiet.

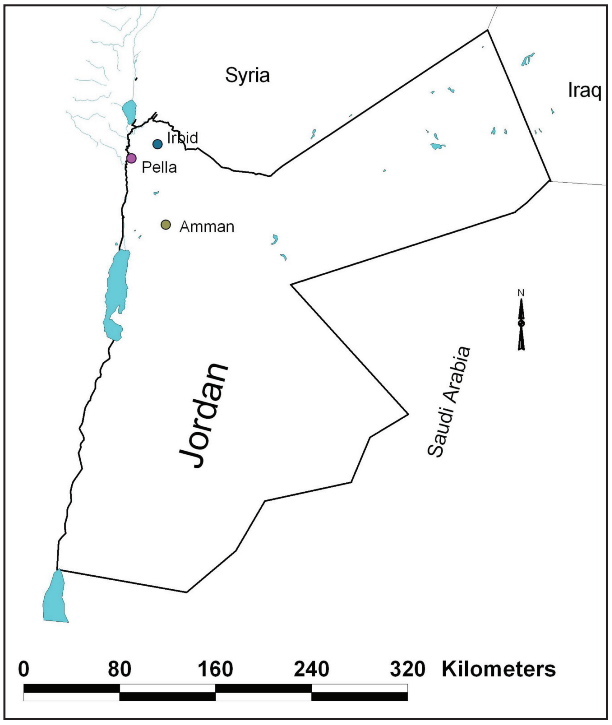

Fig. 1: Location map of the Pella archaeological site.

The site

The area of Pella (Tabqat Fahl) is about 100,000 m2; it is situated on the eastern edge of the north Jordan Valley (Fig. 1) and the Arabian desert. It served as a major commercial center during many periods of its history with trade connections with Cyprus, Rhodes, Egypt, Asia Minor, Palestine, Syria and North Africa (Hoekman-Sites, 2005). The site is located in a very fertile agricultural area with permanent water sources in the Wadi Jirm. Pella was first excavated by a team from the University of Sydney in 1978. Since then, the excavations have focused on both the main mound of Khirbet Fahl (the Tell) and the surrounding environs, including a number of distinct tomb fields. The site shows human occupation from the Neolithic to the Islamic period, some 8500 years of continuous occupation producing human skeletal and burial remains (Bourke 1997).

Excavations from the main Tell at Pella indicate that LBA Pella is characterized architecturally and culturally as a prosperous and wealthy city-state, operating under the influence (if not control) of the New Kingdom of Egypt. The transition from the Late Bronze to the Iron Age at Pella is marked by an extensive destruction across the site both in domestic and public areas, tentatively dated to the middle of the 12th Century BC. The succeeding settlement at Pella during the Iron I is considerably smaller and suggests a settlement operating with much reduced resources, although the recent excavation of a massive LBA/Iron Age temple on the Tell may force a re-evaluation of this picture of precipitous decline in the early Iron Age (Bourke and Hendrix, 2001).

Tomb 89

Besides the Late Bronze tombs, a large rock-cut tomb (Tomb 89) was excavated during the 1987 field season. Tomb 89 is a bipartite chamber tomb, and is one of the few tombs at Pella to be discovered intact (Potts et al., 1988). It produced a considerable sample of the Iron Age skeletal material excavated at Pella; more than 88 disarticulated individuals and approximately 45 individuals in comingled state yielding a total of about 133 individuals. The tomb contained many funerary objects, including a bronze belt and an iron dagger, a modeled ivory plaque, several scarabs, glass and semi precious beads, as well as a number of alabaster vessels. The skeletons were disarticulated and pushed to the back of the chamber indicating tomb reuse probably over generations. The tomb was most likely a family tomb because of the presence of sub-adults (infants and children) as well as the presence of common genetic traits among the skeletons (Hendrix, 2006). The tomb was dated to 1100-850 BC (Bourke, 1997).

Stable carbon Isotopes

Techniques of stable carbon isotopes of

human tooth enamel accurately reflect the stable carbon isotopic signature of the whole diet eaten by the person during the time of enamel formation (Tykot, 2005; Krigbaum, 2002; 2005), while collagen reflects the protein source (Thompson et al., 2005). The inorganic mineral phase of tooth enamel is hydroxyapatite (Ca10(PO4)6(OH)2) that is precipitated in equilibrium with body water, which is mostly comprised of ingested water (Longinelli, 1984; Luz etal., 1984). Enamel hydroxyapatite contains a small amount of structural carbonate substituting for phosphate and hydroxyl ions. Consequently, the δ 13C values of structural carbonate in biogenic apatite record carbon isotopic composition in diet.

Teeth are not susceptible to diagenesis compared to bone, which may affect the isotopic signature of diet (Wang and Cerling, 1994; Koch et al., 1999). Humans fractionate carbon during precipitation in tooth enamel and bone apatite with an enrichment factor of about +9.6‰ (DeNiro and Epstein, 1978). The average δ13C in C3 plants (trees, shrubs, and grasses from temperate regions that utilize a 3-carbon molecule during the initial stages of photosynthesis) is -26‰ and -12‰ in C4 plants (Tieszen, 1991), which are grasses that are originally native to hot, arid environments and utilize a 4-carbon molecule during the initial stages of photosynthesis (Tykot, 2004).

Materials and methods

The study comprised 11 premolars and 14 permanent molars and in a very good state of preservation conditions. Deciduous teeth were excluded because they usually form in the embryonic stage and thus their isotopic signature does not reveal the individual's diet. Analyses from the human skeletons from Tombs 89 indicate adult and sub-adult examples, with several skeletons recovered in articulation (Hendrix 2004). The remainders of the skeletons were excavated by bone element due to the disarticulated nature of the bones, from both ancient practices and taphonomic processes associated with the passage of time. Dentition from the skeletons is well preserved and the teeth (no. = 25) used in this study come from commingled isolated adult teeth from Tomb 89. The sampled teeth represent a maximum number of individuals of 25 and a minimum number of individuals of 10 as shown in table 1. There is no macro technique available to reliably sex isolated commingled teeth, yet preliminary results indicate that a higher percentage of females is present in Tomb 89 (Hendrix 2004).

Tooth preparation and analysis were followed after Wright and Schwarcz (1998). The tooth crown was first cleaned with distilled water and dried at room temperature for 24 hours. Dentine was physically removed using a diamond pit. Enamel was finely ground using a mortar and a pestle. The sample powder was

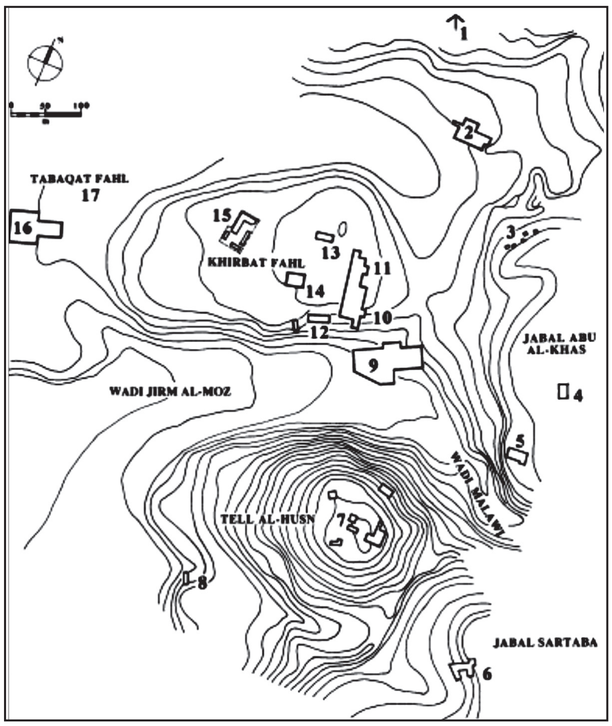

Fig. 2: A contour map of the Pella archaeological site.

soaked in 1.5% sodium hypochlorite (NaCLO) for 24 hours to digest organic residues, and then rinsed with distilled water four times. Carbonate minerals were removed by adding 0.1 M acetic acid (C2H4O2) to the sample for 24 hours; then rinsed with distilled water four times. The samples were dried using a freeze-drying machine for 3 days. The dry powder was then reacted in a sealed vessel with phosphoric acid (H3PO4) at 90°C. The resulting CO2 was collected in glass fingers that were used for the run in the Finnegan Mass Spectrometer at the Stable Isotope Lab/University of Arkansas. The results are reported relative to (PDB) isotopic reference standard. Reproducibility of this procedure was 0.2‰. The value of $\delta^{13}C$ was calculated using the following formula:

$$\delta\ ^{13}\text{C}\ (‰) = \left(\frac{^{13}C\,/\,^{12}C_{\ sample}}{^{13}C\,/\,^{12}C_{\ std}} - 1\right)\times 1000$$

Results and discussion

Although the Pella region has a dominating C3 ecosystem, a few C4 plants currently exist such as maze and may have contributed to the consumed diet. The hot climate in the Jordan Valley provides a suitable environment for the cultivation of C4 plants, which again does not exclude the possibility of C4 plants contribution to diet in the past. The $\delta^{13}C$ values of teeth enamel are reported in table 1, reflecting the signature of both C3 and C4 plants contribution to diet.

We hypothesized that there is no statistically significant difference (at $\alpha = 0.05$) between the results of $\delta^{13}C$ in premolars and the results of $\delta^{13}C$ in molars.

H_0: $\mu\ \delta^{13}C_{premolars} = \mu\ \delta^{13}C_{molars}$

H_1: $\mu\ \delta^{13}C_{premolars} \neq \mu\ \delta^{13}C_{molars}$

These hypotheses were tested using the single factor Analysis of Variance (ANOVA). The

Table 1: The results and descriptive statistics of d 13Cenamel.

Sample No.	δ13C ‰	Tooth type
5001	-12.02	1st Upper Premolar
5002	-11.38	2nd Upper Premolar
5003	-12.34	2nd Upper Molar
5004	-12.06	2nd Upper Premolar
5005	-12.00	2nd Upper Molar
5006	-10.59	2nd Upper Molar
5007	-12.04	2nd Upper Molar
5008	-12.03	2nd Upper Molar
5009	-11.58	2nd Upper Molar
5010	-11.49	2nd Upper Molar
5011	-11.85	2nd Upper Molar
5012	-12.03	3rd Upper Molar
5013	-11.82	1st Upper Premolar
5014	-10.90	1st Upper Premolar
5015	-11.14	1st Upper Premolar
5016	-11.56	3rd Lower Molar
5017	-12.67	2nd Lower Molar
5018	-11.35	2nd Upper Molar
5019	-11.85	2nd Lower Molar
5020	-11.87	1st Lower Premolar
5021	-11.94	1st Lower Premolar
5022	-11.64	2nd Lower Premolar
5023	-11.85	1st Lower Premolar
5024	-12.02	1st Lower Premolar
5025	-11.75	2nd Upper Molar
Mean	-11.75	-
Standard Deviation	0.44	-

results below show that the probability value (P = 0.58) is larger than 0.05, which means accepting the null hypothesis. Therefore, the results of $\delta^{13}C$ in both molars and premolars are consistent. Wright and Schwarcz (1998) stressed that the analysis of multiple teeth from the same individual may reveal dietary shifts caused by weaning, but in the teeth of Pella it seems that this is not the case, where all of the sampled teeth have almost the same isotopic signature. On the other hand, the enamel in premolars, second permanent molars, and third

Table 2: ANOVA single factor results.

Source of variation	SS	df	MS	F	P-value	F critical
Between groups	0.06	1.00	0.06	0.31	0.58	4.28
Within groups	4.64	23.00	0.20			
Total	4.71	24.00				

molars (sampled teeth) usually start to initiate at the age of about 2 years, 2.5 years, and 7years respectively (Hillson, 1996), and thus minimizing the possibility of precipitation of water from breast feeding milk into enamel.

The fractionation factor (α) of stable carbon isotopes was calculated using 9.6‰ as the enrichment factor (ε) after the formula of Craig (1954) below:

$\alpha = 1 + \varepsilon$

$\alpha = 1 + 0.0096$

$\alpha = 1.0096$

The mean $\delta^{13}C$ value of diet is estimated using the following calculations:

$$\delta^{13}C_{enamel} = \left(\frac{R\left({}^{13}C/{}^{12}C\right)_{enamel}}{R_{std}} - 1 \right) 10^3 = {}^{-}11.75\ ‰,$$

which is the average value in table 1 above.

$$\frac{R_{enamel}}{R_{std}} - 1 = -0.01175$$

$$\frac{R_{enamel}}{R_{std}} = 0.99825$$

$$\frac{R_{diet}}{R_{std}} = \frac{R_{enamel}/R_{std}}{\alpha}$$

α is the fractionation factor.

$$\alpha = \frac{R_{enamel}/R_{std}}{R_{diet}/R_{std}}$$

$$1.0096 = \frac{0.99825}{R_{diet}/R_{std}}$$

$$\frac{R_{diet}}{R_{std}} = \frac{0.99825}{1.0096} = 0.9788$$

$$\delta\ {}^{13}C_{diet} = 0.9788 - 1 = {}^{-}0.0212 = {}^{-}21.2\ ‰$$

The value of -21.2‰ is the average $\delta^{13}C_{diet}$ of the consumed whole diet in Pella during the Iron Age II A, which is around the C_3 plant value. However, around 1200 BC, the north Jordanian landscape changed considerably; many of the Iron Age sites (Lamprichs and Kafafi 2000; Lamprichs and Bastert 2004) changed their function to domestic and farming activities like wheat and barley cultivation. The obtained $\delta^{13}C_{diet}$ is close to the values of grains particularly wheat, -23.7‰ (Smith and Epstein, 1971), which would have been successful in the presence of ample amounts of rainfall and/or irrigation. The Iron Age I/II was a relatively wet period compared to the Late Bronze Age and the proceeding classical period for the same site based on measurements of the Dead Sea levels (Frumkin et al., 1991), which consequently may have enhanced a successful agriculture in the Jordan Valley. As stable carbon isotopes from tooth enamel reflect the whole diet consumed by the individuals, the value of -21.2‰ shows that the people were mainly getting their food from a C_3 ecosystem.

Conclusions

The stable carbon isotopes from human tooth enamel reflect the whole diet and ecosystem but not the source like animal protein, wild plants or cultivated plants. Consequently stable carbon isotope analysis on collagen is needed as it reflects the protein source of the consumed diet. Further samples and further tombs of different time periods are needed to establish intra-population dietary differences on a chronological order. The people of Pella during the Iron Age I/II probably lived in a favorable climate condition that enhanced farming; a subsistence strategy that might have sustained the local community of Pella taking into consideration its fertile and expanded landscape. Further insights into the successive occupations at Pella may clarify the past human adaptation in the ever changing climate.

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ملخص: تم تحديد نسب نظائر الكربون المستقرة ل ٢٥ عينة من ميناء الأسنان البشرية من العصر الحديدي في الموقع الاثري بيلا في الأردن لإعادة بناء الغذاء القديم. الموقع يقع مئات الامتار تحت سطح البحر ويتمتع بجو دافيء شتاءا وحار وجاف صيفا .عولج ميناء الأسنان بهيبوكلوريت الصوديوم لإزالة المواد العضوية وحمض الخليك لإزالة بقايا الكربونات ثم استوعبت العينات مع حامض الفوسفوريك على درجة حرارة مقدارها ٩٠ مئوية. تم تحليل غاز ثاني اكسيد الكربون الناتج من التفاعل لمعرفة نسب نظائر الكربون باستخدام جهاز طيف الكتلة حيث وجد ان متوسط $\delta^{13}C_{diet}$ يساوي -٢١,٢ ‰ وهو حول القيم الخاصة بنباتات C_3 وذلك بعد تطبيق معامل الاثراء ٩,٦٪ رياضيا.

Note

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