CHEMICAL DIETARY RECONSTRUCTION OF GRECO-ROMAN MUMMIES AT EGYPT'S DAKHLEH OASIS

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Abstract

At the Greco-Roman site of Kellis (Dakhleh Oasis, western desert of Egypt), about 20 km east of modern Mut is a burial site (Kellis-1 tomb group). Ceramic and cartonnage styles date these tombs from the end of the second century B.C. to the third century A.D. (Schweitzer, 2002). In 1993 the authors of this article examined and sampled 15 mummified bodies found in the first 12 tombs and in 1998 examined an additional 34 mummies from tombs 16-21. The details of this field work were present at the Dakhleh Symposium held in Melbourne, Australia in August 2000 and published in the proceedings of that conference (Aufderheide et al., 2003). The mummification methods identified by these mummy studies have been published as a separate article (Aufderheide et al., 2004). Herein we present results of reconstruction of the Kellis residents' diet by use of stable isotope (δ¹³C and δ¹⁵N ratio) methodology and coprolite studies.

Most individual members of ancient populations spent a major fraction of their time in the acquisition and processing of food. Since the principal goal of archaeological studies is the reconstruction of the daily life of ancient populations, information about the diet they consumed is of central archaeological interest. Indirect evidence about ancient diets can be acquired by examination of residual food items (e.g., bones) in middens or other site areas, detection of regional flora and fauna fossils and similar observations. During the past several decades chemical methods that identify components unique to certain food classes have been developed, and these were applied to samples from our examined mummies. Additional information was derived from coprolite (dried feces) extracted from the mummies’ intestine, and also from review of the entries in the ancient Kellis Agricultural Account Book found at the site.

Key Words
Kellis, Dakhleh Oasis, diet, coprolite studies, dietary reconstruction, pinworm

BASIC PRINCIPLES OF CHEMICAL DIETARY RECONSTRUCTION

Absorption of dietary carbon atoms are incorporated into compounds (carbohydrates, proteins and lipids) that make up the body's tissues. This synthetic process is an enzymatic
one, carried out principally by the liver. Plant carbohydrate formation is also an enzymatic one, driven by light energy in the photosynthesis mechanism. Finally, the burning of these compounds by the body's metabolic processes for energy produces carbonate, part of which becomes incorporated in bone mineral. The ultimate sources of this carbon is the atmosphere where about 99% of the carbon atoms are present in the form of the isotope $^{12}\text{C}$ and about 1% as $^{13}\text{C}$. Chemical reactions tend to incorporate more of the lighter $^{12}\text{C}$ atoms than the heavier $^{13}\text{C}$ atoms. The degree of this relative rejection (discrimination) of the $^{13}\text{C}$ atoms varies among the different enzymes involved. Photosynthesis of plant sugars, for example, use one of two differing enzyme systems. While both discriminate against $^{13}\text{C}$, the extent to which they do so differs substantially.

The first step in sugar synthesis by one (Hatch-Slack) of these systems produces a 3-carbon-containing sugar (C3 plants) whose carbon has been quite depleted of $^{13}\text{C}$ atoms. The other (Calvin) generates a 4-carbon-containing sugar (C4 plants) containing significantly more $^{13}\text{C}$ atoms, but still proportionately less than the 1% $^{13}\text{C}$ atoms in the atmosphere (Marino & McElroy, 1991). The $^{13}\text{C}/^{12}\text{C}$ ratio in tissue can be measured by ion ratio mass spectrometry, the results of which are predictive of the quantity of C3 and C4 sources in the diet. The values are expressed as the degree (delta or $\delta^{13}\text{C}$) to which they differ from that in a carbonate standard ore (PeeDee Belemnite). Since both photosynthetic enzyme systems discriminate against $^{13}\text{C}$, the $\delta^{13}\text{C}$ values are always negative. Within the body synthetic enzyme systems will influence the ratio further. The difference between the $\delta^{13}\text{C}$ value of the food source and that of the body tissue into which the food source has been incorporated is termed the fractionation factor. Most C3 plants have $\delta^{13}\text{C}$ values that cluster in the -27‰ (parts per thousand or parts per mil: ppm) region while C4 plants average about -12‰ (Ambrose, 1993).

The $^{15}\text{N}/^{14}\text{N}$ of proteins is also expressed as $\delta^{15}\text{N}$, measured against that of atmospheric air whose $\delta^{15}\text{N}$ value is zero. Plant values can range from 0 to about +8‰ averaging about +4‰ but vary with the archaeological site. At every step of the food chain $\delta^{15}\text{N}$ is increased about +3‰ to 3.4‰ (Ambrose, 2000). Thus the long marine food chain can result in values as high as +30‰ in the larger fish or sea mammals such as sea lions.

**METHOD**

Full-thickness samples of cortical bone from the femur diaphysis was employed. After cleaning it was processed as described in Tieszen & Fagre (1993). In addition, braids from the hair of two mummies were separated at their junction with the scalp, washed and divided into 2 cm segments (about the length of scalp hair growth in two months). Each segment was tested separately for its $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ value.

**RESULTS AND DISCUSSION**

Results are listed in Table 1. The relatively low standard deviation (as well as the resulting values for the variance (C.V.) value reflect the fact that at Dakhleh the diet was common to most individual members. Experimental animal studies have indicated that the carbonate in bone mineral (apatite) is derived from plasma carbonate which, in turn, is the product of energy metabolism burning carbohydrates, lipids and even protein. Hence its value reflects all elements of the diet. Thus simply subtracting the fractionation factor (about
+9.4‰) from the bone mineral carbonate values will predict the δ¹³C value for the whole diet; i.e., Δ₁³C_{whole diet} = δ¹³C_{apatite} + (+9.4‰). The +9.4‰ fractionation factor we use here is that found in animals (Ambrose & Norr, 1993). The value for humans has not yet reached consensus, but may be as much as 1‰ or more positive. For the Dakhleh mummies, Δ₁³C_{whole diet} = -14.8 - (+9.4) = -24.2‰. Modern relevant C3 plants, including wheat, barley, beans and fruit from Nubia and the Nile Valley have been measured and found to have a mean value of about -26.5 ± 2.9 (S.D.) ‰ (White, 1992). However, decades of burning fossil fuels has diluted atmospheric δ¹³C values by about 1.5‰ (Marino & McElroy, 1991), and a step in the food chain enriches the δ¹³C by about 1.0‰. Corrections for these factors would lead us to expect that ancient C3 plants by Dakhleh had a value of about -25.0‰ and that a food chain step with such a diet would produce a value of about -24.0‰. Hence our measured value would indicate that the diet our studied individuals at Dakhleh would have been close to a pure C3 diet. This C3 "label" could have been acquired from eating an exclusively C3 plant diet, an exclusively meat diet of animals that eat only C3 plants or any proportion of each of these.

White (1993) has studied stable isotope ratios in Nubian mummy hair samples and found very distinct fluctuations between C3 and C4 values along the length of the hair relating to seasonality. She attributed this to the consumption of wheat and barley (C3 plants) throughout most of the year, but millet and sorghum (C4 plants) when these matured during the summer. While the small standard deviation values of our samples suggested little variation in the Dakhleh diet, we did measure δ¹³C values in two mummies whose braids were about 20 cm long. Growth of scalp hair is slightly in excess of 1 cm/month. The results of these were plotted and are displayed in Figure 1. As the standard deviation values had predicted, these δ¹³C values indicate an essentially monotonous diet over a 20-month interval.

But at Dakhleh we have additional sources of information about foods grown there during the Greco-Roman Period. These include the Kellis Agricultural Account Book (KAB), a codex consisting of eight "pages," each one of which is a wood board about 33 x 11 x 2.5 cm with perforations through which cords were threaded to keep them intact and in order. The Greek inscriptions on these pages apparently represent payment and expenditure records by an agricultural property manager (Bagnall, 1997). Its value in reference to diet reconstruction lies in the fact that the exchanges were made largely in the form of food items. It is interesting, therefore, that the cereal grains wheat (Triticum aestivum: bread wheat) and barley (Hordeum vulgare), both C3 plants, are among the most common; sorghum and millet (C4 plants) are never mentioned. Other items included fruits (figs and dates), wine (for which this oasis became well-known), vegetables including onions, turnips and radishes, olives and olive oil. All of these are consistent with a C3 diet. Although these entries reflect transactions, not ingestion, they at least document their availability at Kellis.

In addition to the KAB, numerous seeds have been identified in excavation soils from this site. These include cereal grains (bread wheat [Triticum aestivum], two-rowed barley [Hordeum vulgare ssp. Disticum] and six-rowed barley [Hordeum vulgare ssp. vulgare], dates, grapes, apricots, pomegranates, peaches, squash, beans and olives) (Thanheiser, 1999). All these are C3 plants. Grape seeds (Vitis vinifera) recovered from human (mummy) coprolites provide some direct evidence of ingestion (Horne, 2002--see below). Thanheiser
et al. (2002) note that hazelnuts, pistachio and walnuts were imported into Egypt and their distribution reached Kellis, and suggested that this remote site may not only have supplied its own botanical needs, but also used its surplus (olive oil, wine, wheat) to develop active trade activity. Though all this only indicates the site population “menu,” not ingestion, it is nevertheless an impressive record.

Faunal skeletal elements found at Kellis indicate that the majority (77%) were those of pigs, cows, goats and chickens, supplemented by rabbits, dogs, ducks, geese, gerbils, ostrich, mice and camel (Churcher, 2002). This author also notes that the presence of Nile fish and oyster shells reflect trade with the Nile valley while marine snails at Kellis indicate more distant trade. Except for the latter, the plants and seeds consumed by most of these animals would have provided a C3 label. These remains also contribute to the “menu” list.

Apatite and collagen have different fractionation factors for $\delta^{13}$C. That of apatite, as noted above, is constant at about +9.4‰ in animals. The value in humans has not yet reached a consensus but may be as much as 1.0‰ higher. This is useful to estimate whole diet $\delta^{13}$C value. That of collagen, however, is variable, depending on other dietary factors. However, in a monoisotopic diet in which the protein component and the whole diet $\delta^{13}$C values are identical, the fractionation factor for $\delta^{13}$C in collagen is +5‰. Thus, under such circumstances the difference between the collagen and the apatite $\delta^{13}$C values is 4.4. Larger differences imply that the $\delta^{13}$C of the dietary protein is more enriched in $^{13}$C atoms in relation to the whole diet and vice versa (Ambrose et al., 1997). In our Dakhleh study the difference in $\delta^{13}$C values between that of collagen and apatite was only 4.9, so close to 4.4 that this implies most of the protein carbon atoms' $\delta^{13}$C values were quite close to that of the whole diet.

Schwarz et al. (1999) list the $\delta^{15}$N values of ancient animal remains at the Kellis site. That of cows, donkeys, pig and goat had $\delta^{15}$N of +13.2‰; chickens and eggs had values of about 16.0‰. Since $\delta^{15}$N has a trophic step value of +3‰, ingestion of such meat would result in collagen values of about $\delta^{15}$N +16.2‰ for most animal meat and up to +19.0‰ for chickens. Since most of these animals would have ingested C3 plants, their meat would have a $\delta^{13}$C label of C3 plants (about -24.0‰). Barley would have contributed a $\delta^{15}$N label of about +17.2‰ in human collagen and wheat about +19.0‰. The mean measured value of $\delta^{15}$N in the Dakhleh mummies was 18.4‰. Thus, except for chickens and their eggs, wheat would have made a more major contribution than did animal meat to the human $\delta^{15}$N measured value. If the Kellis Account Book records reflect the Kellis population's diet, this would be consistent with a predominately plant source for dietary protein.

A word needs to be said about the distinctly elevated nitrogen levels in these samples. The mean $\delta^{15}$N value for the Dakhleh mummies was +18.4 ± 0.95‰. Coastal populations consuming marine fish and sea mammals often present such high values. However, high $\delta^{15}$N values have been found also in hyperarid deserts like the Sahara. Schwarz et al. (1999) recently have addressed this question. Their database in that article included the values found in these Kellis mummies. In addition, they demonstrated $\delta^{15}$N values of +12‰ to +16‰ in different animals (cow, donkey, pig, chickens) and even some higher values for some of the grains and fruits noted above. Explanations for the oft-reported elevated $\delta^{15}$N values in humans and animals in desert areas have suggested that the excretion of $\delta^{15}$N -
reduced urea, with intrarenal urea recycling would be expected to increase body tissue $\delta^{15}N$ values in arid regions, the $+3\%o$ value for $\delta^{15}N$ trophic level resulting from the renal recycling. Animal experiments failed to confirm that proposed mechanism (Ambrose, 2000). Schwarcz et al. (1999) also point out that the $\delta^{15}N$ values found in Dakhleh animals are greater than can be explained physiologically. They suggest that the high $\delta^{15}N$ Sahara soil values may result at least partly from loss of $^{15}N$-depleted ammonia gas formed in soils by bacterial action. In any event, they noted that at sites reported to date, soil $\delta^{15}N$ is inversely proportional to mean annual rainfall levels. At Dakhleh the values found in plants and animals are high enough to suggest that much of the high human values was derived, ultimately, from the suggested high soil values, though some minor inconsistencies remain. The high $\delta^{15}N$ levels of both plants and terrestrial meat at Dakhleh frustrate clear differentiation between these two protein sources. Using the few reference values available (Schwarcz et al., 1999) we can conclude that most of the dietary protein probably was derived from plants.

Finally the $\delta^{13}C$ difference in values between that of collagen and that of apatite is called “spacing.” The spacing value for a carnivore is usually about 2 to 4‰ while that for an herbivore is commonly 5 to 7‰. The mechanism for these differences is controversial, but can be pragmatically useful. That value for the Kellis mummies is $4.92 \pm 0.64$. This is consistent with a principally C3 vegetal diet supplemented to only a minor degree with meat from a C3-eating terrestrial animal.

**COPROLITE STUDIES**

About one gram of coprolite (dried feces) material obtained by dissection from each of six of these mummies (No. 13, 101, 102, 103, 106 and 126) was rehydrated and examined microscopically. Many broken, undigested fragments of botanical fibers were identified, but no small animal bones were found. This is consistent with the biochemical isotope patterns. Numerous seeds were also noted, about half of which were grape seeds (Vitis vinifera). In addition coprolites of mummies 13 and 106 were found to contain ova of Enterobius vermicularis (pinworm) (Figure 2). To our knowledge, pinworms have not been reported previously in either ancient or modern Egypt. A detailed report of this finding and its significance has been published separately (Horne, 2002).

**SUMMARY OF CHEMICAL RECONSTRUCTION FINDINGS**

The chemical studies of the Dakhleh mummies indicate they survived almost entirely by consumption of C3 foods. This was derived principally from an intake of C3 plants such as wheat, barley and fruits. The protein dietary component had a value similar to that of the whole diet. Most of the protein probably was derived from these plants. The high $\delta^{15}N$ values of both plants and animals, probably reflecting high local soil $\delta^{15}N$ values, were most likely responsible for most of the similar increased $\delta^{15}N$ values in the humans. The fact that humans had a mean elevation of $\delta^{15}N$ values about $+3\%o$ higher than plant and animal values suggests that the increment represents a trophic step fractionation due to ingestion of protein from plants or from C3-eating meat sources such as chickens and their eggs. These findings are consistent with the “menu” items represented by faunal (Churcher, 2002) and floral (Thanheiser, 2002) remains found at Kellis, with the items recorded in the Kellis Agricultural
Account Book and with the microscopic findings in the coprolite examinations. Hair braid studies indicate that in contrast to later Nubian practices in the Nile Valley, millet and sorghum were not among Dakhleh grain crops.

REFERENCES


Table 1

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Site</th>
<th>Value (%)</th>
<th>± S.D.</th>
<th>C.V. (%)</th>
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Caption: Stable isotope ratios of carbon and nitrogen in Dakhleh mummies.

Legend: S.D. = one standard deviation; C.V. = coefficient of variation.