Journal of Archaeological Science (1998) **25**, 293–301

Stable Carbon and Nitrogen Isotopes as Dietary Indicators of Ancient Nubian Populations (Northern Sudan)

P. Iacumin

Università di Trieste, Dipartimento di Scienze Geologische, Ambientali e Marine, Via E. Weiss 6, 34100 Trieste, Italy, and Université Pierre et Marie Curie, CNRS-UMR 162, Laboratoire de Biogéochimie Isotopique, 4 Place Jussieu, 75252 Paris, France

H. Bocherens

Université Pierre et Marie Curie, Laboratoire de Biogéochimie Isotopique, Paris, France

L. Chaix

Département d'Archéozoologie, Muséum d'Histoire Naturelle, Genève, Switzerland

A. Marioth

Université Pierre et Marie Curie, Laboratoire de Biogéochimie Isotopique, Paris, France

(*Received 13 June 1996, revised manuscript accepted 17 March 1997*)

Human skeletal remains coming principally from the Kerma necropolis were studied for the carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}C$) isotopic composition of skin and bone collagen to reconstruct the dietary regimens of these populations. The majority of samples belong to the Kerma cultural period that is subdivided into three phases: Ancient (4450–4000 BP), Middle (4000–3700 BP) and Classic (3700–3450 BP). A few additional samples, belonging to the Meroitic (2300 BP–AD 350) and Christian (AD 500–1400) periods, have been measured for comparison.

The isotopic compositions of fossil and recent mammal and freshwater fish bones from the same area were also taken into account along with a few fossil plants considered to be representative of the Nubian population's diet.

On average, the measured $\delta^{13}C$ and $\delta^{15}N$ values suggest a mixed dietary regimen including C_3 and C_4 plants (C_4 plants being more important during the Ancient Kerma period), proteins from caprine and cattle (cattle being more important during the Ancient Kerma period), and freshwater fish.

Keywords: STABLE ISOTOPES, NITROGEN, CARBON, KERMA, DIETARY REGIMEN.

Introduction

The main problem in reconstructing the dietary regimens of ancient populations is obtaining reliable information on the various items representing ordinary daily food. This information cannot be always obtained from food remains found in archaeological sites. Analysis of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios of bone collagen provide direct information about the average diet of an individual over the last 25–30 years of his life (Stenhouse & Baxter, 1979; Van der Merwe, 1982; DeNiro, 1987). The isotopic composition of human bone collagen generally deviates from dietary mean values by about +5‰ for carbon (Van der Merwe & Vogel, 1978) and 3–4‰ for nitrogen (Schoeninger & DeNiro, 1984). The isotopic composition of other tissues, such as skin, is similarly considered to deviate in relation to diet but, until now, it has not been extensively studied. However, its turnover rate is very fast, probably of the order of a few weeks to a few months, and the isotopic values are probably representative of the food eaten throughout a short time period before death (Tieszen *et al.*, 1983; Katzenberg & Krouse, 1989).

The samples analysed in this study come from the Kerma necropolis, sited approximately 6 km east of the Nile river in Northern Sudan. In this area the $\delta^{13}C$ of diet can vary because of the differences in the relative importance of C_3 and C_4 plants: the former

*Author for correspondence.

0305-4403/98/040293+09 $25.00/as970206

include wheat, barley and most fruits and vegetables, eaten now and in pre-historic and historic times, showing $\delta^{13}C$ values centred around -26 to $-28‰$ (Smith & Epstein, 1971; Vogel & Van der Merwe, 1978). C_4 plants show $\delta^{13}C$ values higher than those of C_3 plants, centred around -12 and $-14‰$ (Bender, 1971; Smith, Martin & Boutton, 1979). The plants of economic importance in Nubia are essentially C_3; however, C_4 plants such as sorghum and millet are known to have been grown at least from the Meroitic age (2300 BP) (Rowley-Conwy, 1989). Earlier evidence for the use of these plants in southern Egypt goes back to 8000 years BP (Wendorf *et al.*, 1992). Moreover, C_4 grass can be part of the diet of domestic herbivores, thus providing ^{13}C-enriched meat to humans.

Previous isotopic research on the Nubian population from the Meroitic to the Christian age (350 BC–AD 1400) indicated that C_3 plants were dominant in the diet ($\%C_4=10$–25) and that during the period AD 350–550 there was a significant increase in consumption of C_4 plants (White & Schwarcz, 1994). Multiple measurements carried out along the shafts of hair suggested seasonal differences in consumption of C_3 and C_4 plants (White, 1993). Several health and nutritional studies were also carried out on Nubian remains indicating secular changes in mortality, body stature and skeleton pathology probably linked to the dietary regimen (e.g. Van Gerven *et al.*, 1990).

The $\delta^{15}N$ of collagen varies principally with the trophic level: such an effect may be used, at least from a theoretical point of view, to determine the degree of dietary meat dependency. However, at a given trophic level, the $\delta^{15}N$ values vary also as a result of differences in the $\delta^{15}N$ of the primary source of nitrogen for the plants at the base of the food chain, which may vary according to ecological parameters (Mariotti *et al.*, 1980; Rodière *et al.*, 1996). Climate may affect the $\delta^{15}N$ of plants and soil: a decrease in the total amount of precipitation and/or relative humidity causes a $\delta^{15}N$ enrichment (Cheng, Bremmer & Edwards, 1964; Heaton, 1987). The $\delta^{15}N$ of animals may also vary widely with the amount of rainfall (Heaton *et al.*, 1986): herbivores have higher $\delta^{15}N$ values in areas with less than 400 mm of rain per annum (Sealy *et al.*, 1987). This is due, at least partially, to the regulation of urea excretion in response to water stress (Ambrose & DeNiro, 1986; 1987).

A recent isotopic study on Egyptian human skeletal remains from the Nile Valley ranging in age from about 7000 BP to AD 200 suggested a mixed diet including C_3 plants plus animal resources (both freshwater fish and animals feeding on C_3 plants) (Iacumin *et al.*, 1996). Among the 37 human samples measured for that study only one yielded $\delta^{13}C$ and $\delta^{15}N$ values very different from all the others, suggesting a diet based, at least partially, on C_4 plants or meat of C_4-plant eating animals. This individual probably spent most of his life in a different country and died in Egypt shortly after his arrival.

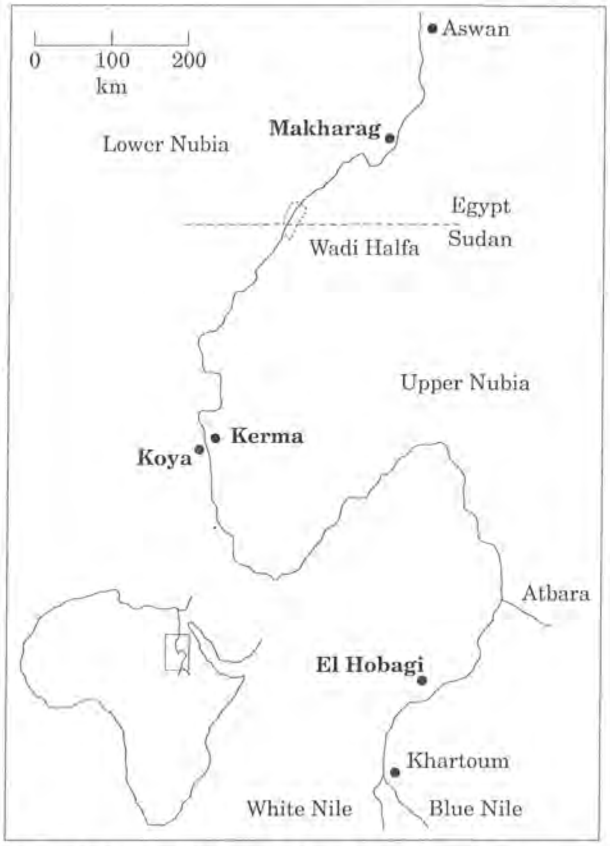

Figure 1. Map of Northern Sudan showing the collection sites.

The present study was carried out to compare these results with the data obtained from the Egyptian remains and to obtain information about the dietary habits of the population of Kerma during different time periods.

Material and Archaeological Information

The studied samples consist of 22 individuals principally coming from the necropolis close to the ancient town of Kerma (Sudan) about 600 km north of Khartoum (Figure 1). The beginning of the Kerma culture may be referred to about 4500 BP, almost contemporaneous with the Old Empire in Egypt. It developed for about 1 millennium until the Egyptian conquest in *c.* 3450 BP. The Kerma civilization has been divided into three cultural phases: Ancient Kerma (AK, 4450–4000 BP), Middle Kerma (MK, 4000–3700 BP) and Classic Kerma (CK, 3700–3450 BP). The temporal boundaries of these three cultural periods are described in Tables 1 and 2 on the basis of differences in human burial traditions (Chaix, 1986; Bonnet, 1990; Simon, Kramer & Susini, 1990).

Three samples from the Meroitic period (2300 BP–AD 350), one from Kerma (sample n. 91) and two from El Hobagi and two samples from the Christian period (500–1400), one sample from Makharag and one from

Table 1. Elemental and isotopic composition of human bones

N. tomb	Cultural period	Collagen %	%C col.	%N col.	C/N	$\delta^{13}C$	$\delta^{15}N$
Kerma							
44 (m)	AK	5·2	41·2	14·3	3·4	−14·2	12·6
45 (m)	AK	4·5	42·9	13·8	3·6	−16·1	11·8
50 (f)	AK	0·4	40·4	13·6	3·5	−17·6	12·2
67 (f)	AK	15·1	26·6	7·4	**4·2**	−27·3	5·5
193/a (m)	AK	2·9	21·7	7·1	3·6	−16·8	13·3
193/b (f)	AK	9·2	36·2	12·5	3·4	−17·2	11·2
116 (f)	MK	5·1	42·8	9·9	**5·0**	−20·7	12·2
187 (m)	MK	9·3	40·0	11·1	**4·2**	−20·1	12·6
189 (m)	MK	12·5	35·6	12·1	3·4	−20·6	12·1
171/1 (f)	MK	9·8	39·8	13·5	3·4	−20·4	12·4
171/2 (m)	MK	3·5	38·8	10	**4·5**	−20·3	12·4
188/a (m)	MK	13·6	39·9	13·2	3·5	−18·6	13·4
188/b (f)	MK	1·8	32·4	9·3	**4·1**	−22·6	9·1
188/c (m)	MK	2·1	35·4	10·3	**4·0**	−22·3	9·7
190 (m)	MK	2·4	32·8	10·8	3·5	−19·2	14·4
185 (f)	CK	14·4	33·8	11·2	3·5	−23·0	10·5
186 (f)	CK	6·9	40·7	14·7	3·2	−17·6	13·6
91	Mer.	0·2	39·4	6·8	**6·8**	−20·4	21·8
El Hobagi							
1 (m)	Mer.	0	0	0			
2 (m)	Mer.	0·3	33·6	6·1	**6·4**	−7·8	23·4
Makharag							
6	Christ.	0·2	0	0			
Koya							
3 (m)	Christ.	20·6	45·4	15·5	3·4	−13·3	12·1

The bold numbers refer to samples with C/N ratio >3·6 (see text for explanation). m=male; f=female; AK=Ancient Kerma (4450–4000 BP); MK=Middle Kerma (4000–3700 BP); CK=Classic Kerma (3700–3450 BP); Mer.=Meroitic Period 2300 BP–AD 350); Christ.=Christian Period (AD 500–1400). In particular sample 91 from Kerma dates back to the 1st century BC, sample 3 from Koya dates back to the beginning of the Middle Age.

Koya (10 km south-west of Kerma) belonging to the Christian period (AD 500–1400) were also analysed for comparison (Figure 1). Both cultural periods belong to the intensive agricultural phase of Nubian history.

The analysed samples are bones, represented mainly by fragments of phalanges and ribs, and fragments of skin recovered from the same bone sample (Table 1).

As reference samples we measured 18 fossil remains of animals found in the human burials of the necropolis, represented by bones, coprolites and keratin horn sheaths (Table 2); five fossil bones from the ancient town of Kerma and 12 bones of modern mammals from the Kerma area; bones of freshwater fish from Lake Nasser, a turtle plate from El Rooda and, finally, three samples of fossil plants from the town and necropolis of Kerma.

Radiocarbon ages were performed on skin and bone samples from eight of the studied tombs. However, the ^{14}C ages do not always correlate with the cultural periods of the tombs. In this preliminary paper we take into account only the reference to cultural periods while waiting for further radiocarbon ages and for their better correlation within the archaeological framework.

The modern environment in this area is desertic, except for the section along the Nile river which provides the only source of water, and is characterized by a rainfall of less than 50 mm per year. Recent palynological analyses carried out on sheep and goat coprolites from the tombs (Taylor, unpublished report) suggest that arid environmental conditions existed 4000 years ago: pollen of Urticaceae and Graminaceae was dominant along with several species of acacia, jujube and Cyperaceae.

The osteological material found in the town is poorly preserved due to the strong wind erosion and the variation of the Nile water level that periodically flooded this area. On the contrary, the human and animal material excavated from the necropolis is in a very good state of preservation: the desertic area not involved in flooding events allowed a process of natural mummification by desiccation of organic remains, and this made it possible to study peculiar samples such as skin, coprolites, leather as well as plant remains.

The animal remains (food refuse) found in the town show cattle to be predominant during the period known as Ancient Kerma. During the Classic Kerma period the frequency of sheep and goat bones definitely increases compared to cattle bones in the present day (Chaix, 1993*a*,*b*).

The cereal remains found in the tombs and the ovens and bread mould found in the town also suggest a

Table 2. Elemental and isotopic composition of animal remains

N. tomb	Type	Cultural period	Collagen %	%C col.	%N col.	C/N	$\delta^{13}C$	$\delta^{15}N$
Kerma Necropolis								
67	Dog bone (male)	AK	1·1	28·7	6·6	5·1	−21·8	12·3
77/1	Sheep coprolite	AK		39·7	7·1	6·5	−23·6	15·6
85/1	Sheep coprolite	AK		29	5·1	6·6	−19·8	25·1
89/3	Goat coprolite	AK		35·1	4·4	9·3	−23·1	16·4
193	Sheep bone (male)	AK	0·4	32·1	7·6	5·0	−14·5	12·5
116	Lamb bone (male)	MK	18·0	24·4	5·6	5·1	−28·4	1·6
116	Coprolite	MK		49·5	2·9	19·9	−25·9	13·8
185/1	Lamb bone (male)	MK	2·1	28·5	9·1	3·7	−17·8	8·6
185/3	Cattle bone	MK	1·7	16·4	3·7	5·2	−13·2	16·5
186	Goat bone (male)	MK	3·0	28·8	8·7	3·9	−22·7	6·7
186	Sheep bone (male)	MK	2·3	24·3	6·6	4·3	−26·9	3·5
189/9	Sheep bone (male)	MK	0·4	41·5	13·8	3·5	−15·9	6·0
190/3	Sheep bone (male)	MK	0·2	24·5	8·8	3·3	−17·7	5·2
190/7	Sheep bone (male)	MK	0·4	39·7	11·8	3·9	−19·3	9·7
156	Cattle horn (keratin)	CK		41·6	14·7	3·3	−11·0	11·2
171	Goat bone	CK	2·6	25·1	7·1	4·1	−25·2	5·8
171	Caprine bone	CK	0	—	—	—	—	—
175	Cattle horn (keratin)	CK		44·7	14·9	3·5	−14·3	12·7
Ancient town of Kerma								
	Donkey bone	KM	0·3	—	—	—	—	—
	Sheep bone	KM	0·1	8·1	2·2	4·3	—	—
	Freshwater fish bone	KM	1·0	—	—	—	—	—
	Freshwater fish bone	KM	0	—	—	—	—	—
	Turtle bone (*Trionyx*)	KM	7·0	42·7	15·3	3·3	−15·3	8·6
Recent animals								
El Rooda	Turtle carapace (*Trionyx*)			43·1	14·9	3·4	−19·9	8·3
Lake Nasser	Fish bone (*Clarias* sp.)		18·2	41·9	14·9	3·3	−18·2	12·1
Lake Nasser	Fish bone (*Tilapia* sp.		20·1	37·6	13·6	3·2	−17·0	11·6
Lake Nasser	Fish bone (*Hydrocyon* sp.)		14·2	41·4	15·2	3·2	−18·4	12·1
Kerma	Dog bone (male)		12·5	44·2	14·2	3·6	−16·6	10·1
Kerma	Dog bone (male)		13·0	43·5	15·4	3·3	−15·6	8·7
Kerma	Cattle bone		12·8				−14·3	7·9
Kerma	Cattle bone		9·2	43·2	16·6	3·0	−14·8	7·2
Kerma	Sheep bone		17·3				−16·4	5·7
Kerma	Goat bone (male)		12·6				−18·9	6·1
Kerma	Donkey bone		14·4				−12·0	4·4
Kerma	Donkey bone		18·9	44·2	16·8	3·1	−12·7	4·0

AK = Ancient Kerma (4450–4000 BP); MK = Middle Kerma (4000–3700 BP); CK = Classic Kerma (3700–3450 BP).

well-developed agriculture during the Kerma civilization (Chaix & Grant, 1993).

Methods

A preliminary check of the presence of extractable organic matter was carried out by measuring the nitrogen content (weight %) of the total bone with a CHN elemental analyser. Thereafter, chunks of about 1 g of bone were demineralized in a 0·5 M EDTA-buffered solution at about 25°C, pH 7·2 (Tuross, Fogel & Hare, 1988). The collagen obtained was repeatedly washed with distilled water and freeze-dried. Collagen and other organic material (skin, coprolite, keratin horn and plant remains) were analysed for the isotopic composition of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) by means of an EA-IRMS elemental analyser on line with a VG Optima mass spectrometer, which also allowed the calculation of C and N content and of C/N ratios. The overall precision of analyses was ±0·1‰ for $\delta^{13}C$ and ±0·2‰ for $\delta^{15}N$. The stable isotope composition is reported as δ values in per ml:

$$\delta = \left(\frac{\text{Rsample}}{\text{Rstandard}} - 1 \right) \times 1000$$

where $R = {}^{13}C/{}^{12}C$ for $\delta^{13}C$ values and ${}^{15}N/{}^{14}N$ for $\delta^{15}N$ values. The standard for reporting carbon measurements is PDB-1 (a fossil marine carbonate of biogenic origin) and for nitrogen measurements is atmospheric nitrogen.

Results and Discussion

Preservation of collagen

The burial state of bones may result in diagenetic processes acting to solubilize and remove collagen or to contaminate it causing erroneous isotopic results. A method of checking the degree of preservation of bone

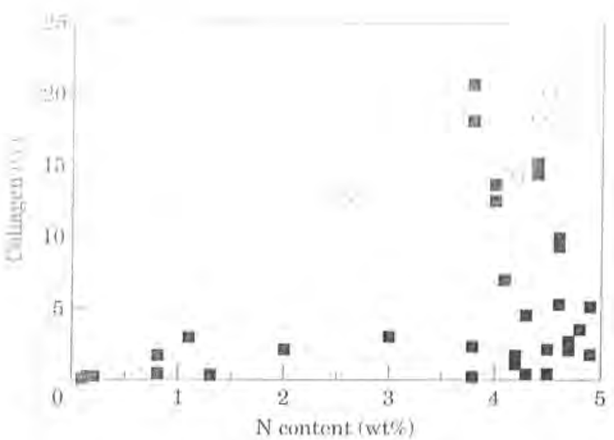

Figure 2. Percentage of collagen (wt% in whole bone) versus N content (wt% in whole bone) of fossil (human and animal, ■) and recent (animal, ○) bone samples.

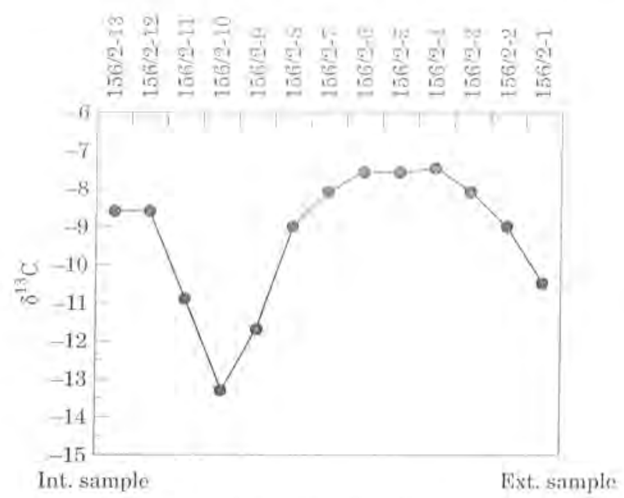

Figure 3. Keratin $\delta^{13}C$ values measured through a section perpendicular to the growth direction of the cattle horn (2·5 mm total thickness).

collagen is to measure its carbon and nitrogen content (wt%) and calculate its carbon/nitrogen ratio (C/N) which, for a well-preserved sample, should range from 2·9 to 3·6 (DeNiro, 1985). In the case of samples of modern bone collagen the wt% of C should be about 40–47%, while the wt% of N should be about 12–15%; well-preserved collagen from fossil or sub-fossil material should not yield C and N contents lower than 13% and 5% respectively (Ambrose, 1990, 1993). As reported in Table 1, several human samples show C/N ratios slightly higher than 3·6 along with a low N content but without an apparent correlation with the collagen yield or age. The situation is definitely worse when animal bones are considered (Table 2): only two male sheep (samples 189/9 and 190/3) have a good C/N ratio. In this case too, no relationship with collagen yield is apparent. The samples collected in the town had no measurable collagen, probably because of their bad state of preservation.

When the percentage of collagen (wt% of whole bone) is compared with the bone nitrogen content (around 4–5% in a fresh bone) samples with high %N show highly variable percentages of collagen, ranging from 0 to about 20·0% (Figure 2). Even when collagen is still present in bones, it may be too much altered to yield material suitable for isotopic analysis. In the case of human samples from Egypt of about the same age (Iacumin *et al.*, 1996), a good correlation was found between these two variables suggesting that %N in bone could give information about the available amount of collagen.

According to the results obtained it seems that a good preservation of bone collagen is prevented by burial in a warm and dry environment, as previously discussed by Grupe (1995) and Grupe & Schutkowski (1989), particularly when the remains are not protected by sarcophagi or by a leather cover as is sometimes the case with animal samples (Saliège, Person & Paris, 1995).

For the following discussion only the samples with a good C/N ratio are considered.

Animal isotopic values

Isotopic values for herbivores vary according to species. Modern donkeys have the lowest $\delta^{15}N$ and the highest $\delta^{13}C$ values, modern cattle the highest $\delta^{15}N$ and modern caprine the lowest $\delta^{13}C$; normally, browsers show lower $\delta^{13}C$ values than grazers (e.g. Ambrose & DeNiro, 1986). The measured isotopic values result from the intake of different plants, C_4 plants prevailing in the donkeys' diet and C_3 plants in the goats' diet, as well as from physiological differences. Cattle show the highest $\delta^{15}N$ values among domestic animals from the same area. Dogs, belonging to an omnivorous species, have $\delta^{15}N$ values higher than those of herbivores.

The isotopic values of coprolites refer directly to the value of the last meals and therefore suggest shifts in food habits that may have occurred recently before faecal excretion (Tieszen & Fagre, 1993).

We also analysed several ancient caprine samples, but only two yielded reliable isotopic data (C/N ratios lower than 3·6), namely samples 190/3 and 189/9.The two values were similar to those obtained from modern specimens (Figure 2), suggesting a basic intake of C_3 plants for this mammal species.

A cattle horn sheath (keratin) from CK was sampled through a section perpendicular to the growth direction to measure $\delta^{13}C$. The results obtained are shown graphically in Figure 3. Despite the fact that the existing relationships between isotopic values of keratin and those of diet are poorly known, the results obtained and their large oscillations from isotopically lighter to considerably heavier values could be related to the intake of different percentages of C_3 and C_4 plants in winter and summer. White (1993) interpreted

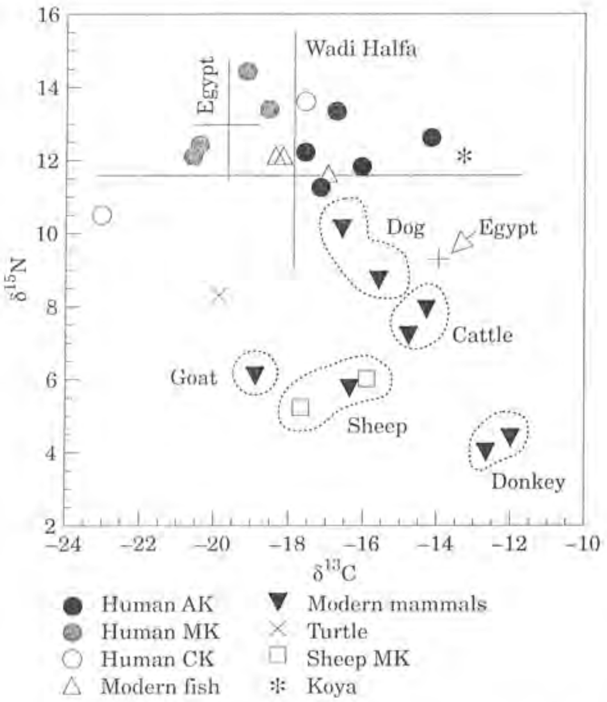

Figure 4. $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen from Kerma human and fossil and recent animal samples compared with the overall range of values from Egyptian and historic Nubian human samples (see text for explanation).

the shifting of isotopic values along the length of hair strands of the ancient inhabitants of Nubia in this same way.

Human carbon isotopic composition

There are no apparent dietary differences between males and females (Table 1) although the number of samples is not large enough to be statistically significant. A temporal difference in diet may instead be observed between MK and AK samples: the $\delta^{13}C$ values of MK samples are lower than -18 (mean value $-19{\cdot}7$), while those of AK samples are higher than -18 (mean value $-16{\cdot}4$) (Figure 4). The sample from the Christian period shows the most ^{13}C-enriched value.

According to their $\delta^{13}C$ values, the three fossil plants are C_3 plants, as expected from the photosynthetic pathway of their modern representatives (Table 4). However, a good proxy exists for $\delta^{13}C$ values of modern plants along the Nile Valley (Batanouny, Stichler & Ziegler, 1988; White, 1993): C_3 plants decrease with decreasing latitude, being mainly represented by winter annual and perennial grasses active in winter, while summer annuals and the other perennials are C_4 species. The approximate percentage of C_4 plants in the diet can be estimated by the method of Schwarcz *et al.* (1985):

$$\%C_4 = \left(\frac{\delta_c - \delta_3 - 5}{\delta_4 - \delta_3}\right) \times 10$$

where δ_c is the measured collagen value, δ_3 and δ_4 are the mean carbon isotopic values of local C_3 and C_4 plants ($-26{\cdot}5$ and $-11{\cdot}5$ respectively, White & Schwarcz, 1994) and 5 is the per mil fractionation between diet and collagen. However, this equation should be applied with caution since: (1) the isotopic composition of collagen and other protein tissues of consumers mainly reflects that of the protein component of the diet (either plants and animals may form the diet of a consumer); (2) the collagen-diet spacing of 5‰ occurs when protein and non-protein compounds have the same $\delta^{13}C$ and this may not always apply (Ambrose & Norr, 1993; Tieszen & Fagre, 1993). The range of $\delta^{13}C$ values of the Middle Kerma period indicates that diets were mainly based on the consumption of C_3 plants, with minor quantities of C_4 plants (from 0 to 20%). During the Ancient period the food intake was quite rich in C_4 plants, the proportion varying from 26 to 50%. This may also be partially related to the increasing importance of caprine in the diet during the Middle phase: indeed, goats and sheep (both fossil and recent) show $\delta^{13}C$ values definitely lower than those of cattle (Figure 4).

The two samples from the Classic period show very different $\delta^{13}C$ values (-23 and $-17{\cdot}6$), suggesting that C_3 plants were still very important. The $\delta^{13}C$ value of -23‰ is quite negative for this environment. However, White & Schwarcz (1994) obtained similar $\delta^{13}C$ values for human samples from Nubia, even though the samples were of considerably younger age. The sample from the Christian period shows a considerably heavier $\delta^{13}C$ ($-13{\cdot}3$‰) which may result from a very important C_4 dependency (55%).

Human nitrogen isotopic composition

The $\delta^{15}N$ values are linked to the consumption of proteins coming from terrestrial animals, fish or legumes. If isotopic data from caprine and cattle are used as reference data (without considering the wide variability of $\delta^{15}N$ values of plants) the expected $\delta^{15}N$ values of human collagen should range between 9 and $11{\cdot}5$‰ (if caprine or cattle respectively are predominant in diet). The measured $\delta^{15}N$ of humans is slightly higher (mean value $12{\cdot}2$ for AK and $13{\cdot}1$ for MK). Lake Nasser modern fish has $\delta^{15}N$ values of about 12‰. If we consider that the Kerma population were also fish eaters, particularly during the MK period, the high $\delta^{15}N$ measured for humans may be better understood, as was probably the case with the Egyptian samples (Iacumin *et al.*, 1996). If legumes had been a substantial part of the diet, the nitrogen isotopic values of collagen would have been considerably lower than those observed.

Table 3. Elemental and isotopic composition of soft tissue (skin) from Kerma mummies

N. Tomb	%C	%N	C/N	$\delta^{13}C$	$\delta^{15}N$
186	44·1	14·8	3·5	−12·8	11·0
116	53·4	10·2	6·1	−21·2	16·2
187	48·2	13·0	4·3	−19·7	15·7
50	36·6	10·8	4·0	−15·1	17·0
188/a	31·0	6·5	5·6	−21·2	15·8
171/1	47·5	13·8	4·0	−19·2	16·8
44	43·3	12·9	3·9	−13·5	18·4

Soft tissues

The skin values are representative of diet for periods of less than 1 year before death. Therefore, these data may potentially reveal short-term dietary changes which are not detectable from bone collagen. The results obtained from skin samples (Table 3) are sometimes very different (up to 5‰ for carbon and 6‰ for nitrogen) from the corresponding collagen samples (Figure 5). Generally, skin samples are ^{13}C and ^{15}N enriched when compared with bone collagen, suggesting a diet with a higher percentage of C_4 plants and, perhaps, freshwater fish. However, the carbon isotopic difference between AK and MK is confirmed by the $\delta^{13}C$ values of skin. The mean $\delta^{13}C$ and $\delta^{15}N$ values of skin are more positive than those of bone collagen by about 0·5–0·8‰ and 2–4‰ respectively. Vogel (1978) found a mean difference between hide and bone $\delta^{13}C$ values of −0·6‰ for modern samples and White & Schwarcz (1994) reported a mean difference of −0·6 and 2·7‰ between skin and bone $\delta^{13}C$ and $\delta^{15}N$ values, respectively, for Nubian populations. This difference was explained by White & Schwarcz (1994) as the result of food intake shortly before death, suggesting large seasonal changes in the diet regime and a fast turnover rate of C and N in the skin. However, this could also be related, at least partially, to an effect of a different bone and skin isotopic enrichment when compared to diet. This kind of physiological process is not well known and therefore cannot be quantitatively assessed. Consequently the observed variations could also be partially referred to a slight amount of diagenetic alteration of skin samples.

Comparison with other Nilotic populations

The mean $\delta^{13}C$ and $\delta^{15}N$ values of samples from the Middle period are identical to the mean values of Egyptian human remains (Iacumin *et al.*, 1996), suggesting similar dietary regimens.

Table 4. Elemental and isotopic composition of prehistoric plants from Kerma

Vegetal type	%C	%N	C/N	$\delta^{13}C$	$\delta^{15}N$
Acacia beans (92 tomb)	35·2	6·2	6·6	−24·6	1·7
Barley seeds (K.N.)	44·2	2·9	17·8	−23·1	9·1
Fruit of dum palm (K.T.)	51·4	0·9	69·0	−23·8	8·9

K.N. = Kerma necropolis; K.T. = Kerma town.

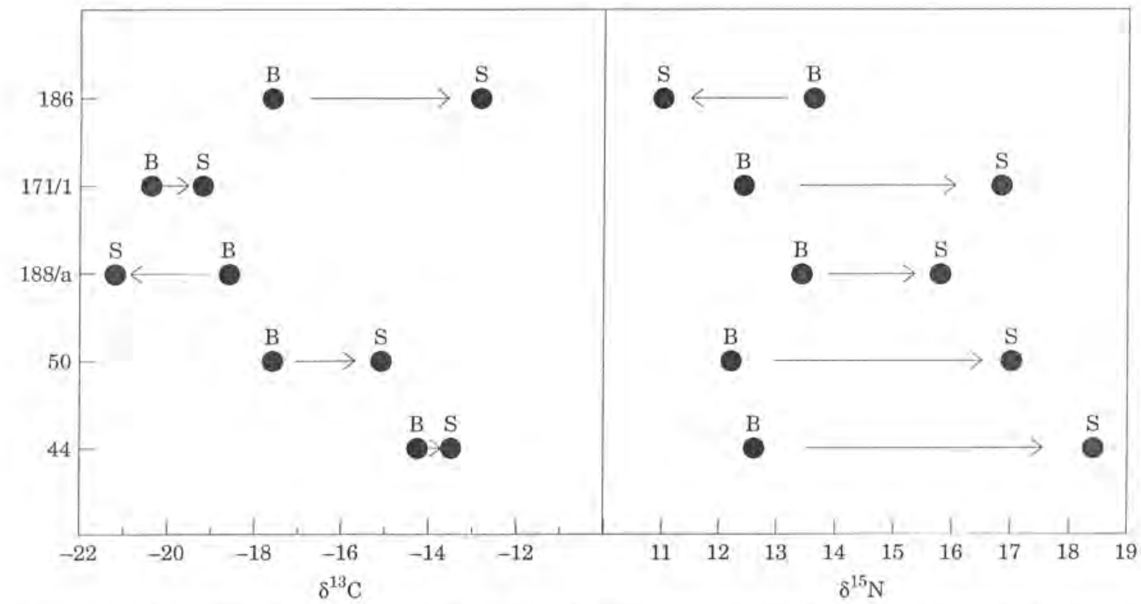

Figure 5. $\delta^{13}C$ and $\delta^{15}N$ values of skin samples (S) compared to the same values obtained from bone collagen (B) (same specimens).

Ancient Kerma samples lie within the field of variation of samples from Nubian Meroitic and Christian periods, and tend to be shifted toward higher values. However, this field includes the Egyptian samples.

One of the Egyptian mummies studied (Iacumin *et al.*, 1996), whose country of origin was supposed to be outside Egypt, shows a $\delta^{13}C$ value similar to AK samples but a lower $\delta^{15}N$ value. This probably indicates a different diet and may be in agreement with the hypothesis of a different native country, even though it lies in the lower part of the Wadi Halfa samples (Figure 4).

A supplementary isotope study on the same samples devoted to the phosphate and carbonate–oxygen and carbon isotopic composition of bone apatite is in progress. Carbon in biogenic apatite is also related to diet and may therefore confirm the isotopic results from collagen carbon.

Conclusions

The reported data suggest that the collagen of bone samples stored in a warm and dry environment suffers some chemical alteration, hampering its quantitative extraction. The preservation of collagen is better in human than in animal remains, probably because the former were protected by sarcophagi or by leather covers.

Carbon isotope ratios from bone and skin support a mixture of C_4 and C_3 plants in the diet throughout both long-term (Kerma civilization) and short-term annual cycles. During the Middle period, a significant increase in the consumption of C_3 plants is evident, the $\delta^{13}C$ values being similar to those already found in Egyptian populations. Given that C_4 plants are indigenous and grow better in arid environments, this could be related to a variation in the humid conditions and/or to the variation of the Nile level. Nitrogen isotope ratios indicate that protein resources throughout the Kerma civilization included fish in addition to protein from caprine and cattle, cattle consumption probably being more important during the Ancient period.

Acknowledgements

The authors are deeply indebted to Professor Christian Simon of the University of Geneva for kindly supplying the human fossil material from Kerma Necropolis. This research was carried out with the financial support of the Italian National Research Council which is gratefully acknowledged.

References

Ambrose, S. H. (1990). Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science* **17**, 431–451.

Ambrose, S. H. (1993). Isotopic analysis of paleodiets: methodological and interpretative considerations. In (M. K. Sandford, Ed.) *Investigations of Ancient Human Tissue*. Gordon & Breach, pp. 59–130.

Ambrose, S. H. & DeNiro, M. J. (1986). Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios. *Nature* **319**, 321–324.

Ambrose, S. H. & DeNiro, M. J. (1987). Bone nitrogen isotope composition and climate. *Nature* **321**, 201.

Ambrose, H. & Norr, L. (1993). Experimental evidence for the relationship of carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In (J. B. Lambert & G. Grupe, Eds) *Prehistoric Human Bone. Archaeology at the Molecular Level*. Berlin: Springer-Verlag, pp. 1–37.

Batanouny, K. H., Stichler, W. & Ziegler, H. (1988). Photosynthetic pathways, distribution, and ecological characteristics of grass species in Egypt. *Oecologia* **75**, 539–548.

Bender, M. M. (1971). Variations in the 131C/12C ratios of plants in relation to the pathway of photosynthetic carbon dioxide fractionation. *Phytochemistry* **10**, 1234–1244.

Bonnet, C. (Ed.) (1990). *Kerma, Royaume de Nubie.—L'antiquité Africaine au Temps des Pharaons*. Genève: Editions Tribune.

Chaix, L. (1986). *Les Troupeaux et les Morts a Kerma (Soudan) (3000 à 1500 avant J.C.). Anthropologie Physique et Archéologie*. Paris: Editions CNRS, pp. 297–304.

Chaix, L. (1993*a*). Nouvelles données de l'archéozoologie au nord du Soudan. In (*Hommages à Jean Leclant, Vol. 2. Nubie, Soudan, Ethiopie*. BdE 106/2, pp. 105–110.

Chaix, L. (1993*b*). The archaeozoology of Kerma (Sudan). In (W. V. Davies & R. Walker, Eds) *Biological Anthropology and the study of Ancient Egypt*. London: British Museum Press, pp. 175–185.

Chaix, L. & Grant, A. (1993). Palaeoenvironmental and economy at Kerma, Northern Sudan, during the third millennium B.C.: archaeozoological and botanical evidence. In (Poznar, Ed.) *Environmental Change and Human Culture in the Nile Basin and Northern Africa until the Second Millennium B.C.*, pp. 399–404.

Cheng, H. H., Bremmer, J. M. & Edwards, A. P. (1964). Variations of nitrogen-15 abundances in soils. *Science* **146**, 1574–1575.

DeNiro, M. J. (1985). Post-mortem preservation and alteration of "in vivo" bone collagen ratios: implication for palaeodietary analysis. *Nature* **317**, 806–809.

DeNiro, M. J. (1987). Stable isotopy and archaeology. *American Scientist* **75**, 182–191.

Grupe, G. (1995). Preservation of collagen in bone from dry, sandy soil. *Journal of Archaeological Science* **22**, 193–199.

Grupe, G. & Schutkowskis, H. (1989). Dietary shift during the 2nd millennium BC in prehistoric Shimal, Oman Peninsula. *Paléorient* **15/2**, 77–84.

Heaton, T. H. E., Vogel, J. C., von la Chevallerie, G. & Collett, G. (1986). Climatic influence on the isotopic composition of bone nitrogen. *Nature* **322**, 822–823.

Heaton, T. H. E. (1987). The 15N–14N ratios in plants in Southern Africa and Namibia. *Oecologia* **74**, 236–246.

Iacumin, P., Bocherens, H., Mariotti, A. & Longinelli, A. (1996). An isotopic palaeoenvironmental study of human skeletal remains from the Nile Valley. *Palaeogeography, Palaeoclimatology, Palaeoecology* **126**, 15–30.

Katzenberg, M. A. & Krouse, H. R. (1989). Application of stable isotope variation in human tissues to problems of identification. *Canadian Society Forensic Science Journal* **22**, 7–19.

Mariotti, A., Pierre, D., Vedy, J. C., Bruckert, S. & Guillemont, J. (1980). The abundance of natural nitrogen 15 in the organic matter of soils along an altitudinal gradient. *Catena* **7**, 293–300.

Rodière, E., Bocherens, H., Angibault, J.-M. & Mariotti, A. (1996). Particularités isotopiques chez le chevreuil (*Capreolus capreolus* L.): implications pour les reconstitutions paléoenvironnementales. *Comptes Rendus Acad. Sci. Paris* **323**, 179–185.

Rowley-Conwy, P. (1989). Nubia AD 0–550 and the "Islamic" agricultural revolution: preliminary botanical evidence from Qasr Ibrim, Egyptian Nubia. *Archaeologie du Nil Moyen* **3**, 131–138.

Saliège, J.-F., Person, A. & Paris, F. (1995). Preservation of $^{13}C/^{12}C$ original ratio and ^{14}C dating of the mineral fraction of human bones from Saharan tombs, Niger. *Journal of Archaeological Science* **22**, 301–312.

Schoeninger, M. J. & DeNiro, M. J. (1984). Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimicha Acta* **48**, 625–639.

Schwarcz, H. P., Melbye, F. J., Katzenberg, M. A. & Knyf, M. (1985). Stable isotopes in human skeletons of Southern Ontario: reconstructing paleodiet. *Journal of Archaeological Science* **12**, 187–206.

Sealy, J. C., van der Merwe, N. J., Lee Thorp, J. A. & Lanham, J. L. (1987). Nitrogen isotopic ecology in southern Africa: implications for environmental and dietary tracing. *Geochimica et Cosmochimicha Acta* **51**, 2707–2717.

Simon, C., Kramar, C. & Susini, A. (1990). Etude des ossements humains. In (C. Bonnet, Dir.) *Kerma, Royaume de Nubie—L'antiquité Africaine Autemps des Pharaons*. Genève: Editions Tribune, pp. 101–107.

Smith, B. N. & Epstein, S. (1971). Two categories of $^{13}C/^{12}C$ ratios for higher plants. *Plant Physiology* **47**, 380–384.

Smith, B. N., Martin II, G. E. & Boutton, T. W. (1979). Carbon isotopic evidence for the evolution of C_4 photosynthesis. Stable isotopes. Proc. of the 3rd Int. Conf. Academic Press, pp. 231–237.

Stenhouse, M. J. & Baxter, M. S. (1979). The uptake of bomb 14C in humans. In (R. Berger & H. Suess, Eds.) *Radiocarbon Dating*. Berkeley, CA: University of California Press, pp. 324–341.

Tieszen, L. L. & Fagre, T. (1993). Effect of diet quality and composition on the isotopic composition of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In (J. B. Lambert & G. Grupe, Eds.) *Prehistoric Human Bone, Archaeology at the Molecular Level*. Berlin: Springer-Verlag, pp. 121–155.

Tieszen, L. L., Boutton, T. W., Tesdahl, K. G. & Slade, N. A. (1983). Fractionation and turnover of stable carbon isotopes in animal tissues: implications for $\delta^{13}C$ analysis of diet. *Oecologia* **57**, 32–37.

Tuross, N., Fogel, M. L. & Hare, P. E. (1988). Variability in the preservation of the isotopic composition of collagen from fossil bone. *Geochimicha et Cosmochimicha Acta* **52**, 929–935.

Van der Merwe, N. J. (1982). Carbon isotopes, photosynthesis and archaeology. *American Scientist* **70**, 596–606.

Van der Merwe, N. J. & Vogel, J. C. (1978). Carbon content of human collagen as a measurement of prehistoric diet in Woodland North America. *Nature* **276**, 815–816.

Van Gerven, D., Hummert, J. R., Moore, K. P. & Sandford, M. K. (1990). Nutrition, disease and human life cycle: a bioethnography of a medieval Nubian Community. In (J. De Rousseau, Ed.) *Primate Life History and Evolution*. New York: Wiley-Liss, pp. 297–323.

Vogel, J C. (1978). Isotopic assessment of the dietary habits of ungulates. *South African Journal of Science* **74**, 298–301.

Vogel, J. C. & Van der Merwe, N. J. (1978). Isotopic evidence for early maize cultivation in New York state. *American Antiquity* **42**, 238–242.

Wendorf, F., Close, A. E., Schild, R., Wasylikowa, K., Housley, R. A., Harlan, J. R. & Krolok, H. (1992). Saharan exploitation of plants 8,000 years BP. *Nature* **359**, 721–724.

White, C. D. (1993). Isotopic determination of seasonality in diet and death from Nubian mummy hair. *Journal of Archaeological Science* **20**, 657–666.

White, C. D. & Schwarcz, H. P. (1994). Temporal trends in stable isotopes for Nubian mummy tissues. *American Journal of Physiological Anthropology* **93**, 165–187.