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Stable isotopes and diet at Ancient Kerma, Upper Nubia (Sudan)

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Abstract

Carbon and nitrogen stable isotope values were measured from bone collagen extracted from archaeological Nubian human ($n = 54$) and faunal ($n = 61$) populations from the site of Kerma, Sudan. Collagen suitable for isotopic analysis was extracted from 22 faunal and 48 human samples from the Eastern cemetery site, dated to the Middle Kerma (c. 2050–1750 BC) and Classic Kerma (c. 1750–1500 BC) periods respectively. The isotopic data indicate that the human dietary regimen included a mix of C_3 and C_4 plant-derived components, with a larger C_4 component than previously reported in archaeological Egyptian Nile Valley populations. Elevated $\delta^{15}N$ values are attributed to consumption of dietary resources from a ^{15}N-enriched terrestrial ecosystem. The faunal isotope data also indicate the consumption of C_3 and C_4 plants. The large range of $\delta^{13}C$ values measured in both the human and faunal samples supports previous work suggesting that a significant portion of the populations buried at Kerma may have originated elsewhere, further confirming the Nile Valley as a major corridor for population movement in the region.

Keywords: Nubia; Kerma; Stable isotope analysis; Carbon; Nitrogen; Bone collagen; Palaeodiet

1. Introduction

Stable isotope analysis is an established and widely applied approach to reconstructing ancient diet and subsistence strategies (see recent reviews: Katzenberg and Pfeiffer, 2000; Mays, 2000; Sealy, 2001). This technique relies upon characteristic differences in the natural abundances of stable isotopes caused by isotopic fractionation, as heavier and lighter isotopes of the same element undergo reactions at different rates. This usually results in more of the lighter isotope in the product of a reaction compared to its starting reactants. These isotopic signatures are recorded in animal and human tissues, including bone, teeth and hair, enabling broad reconstructions of past dietary habits and environmental conditions.

The samples used in this study originate from Kerma in ancient Nubia, now Sudan. The Kerma culture was a powerful, independent neighbour of Egypt, with which it had a dynamic and tempestuous relationship. The purpose of this study was to present new isotopic data from the extraordinary 'royal' burials of the Eastern cemetery which date to the Classic Kerma, a period from which little isotopic data have been published. The data set measured from fauna of the Middle Kerma period was analysed in an attempt to provide an isotopic baseline and add to the existing body of data from this period, further building on previous studies investigating diet and subsistence at Kerma.

2. The site of Kerma

Kerma is located in the Northern Dongola Reach, Upper Nubia (Northern Sudan), south of the 3rd Cataract of the Nile and approximately 6 km east of the Nile (Fig. 1). Kerma

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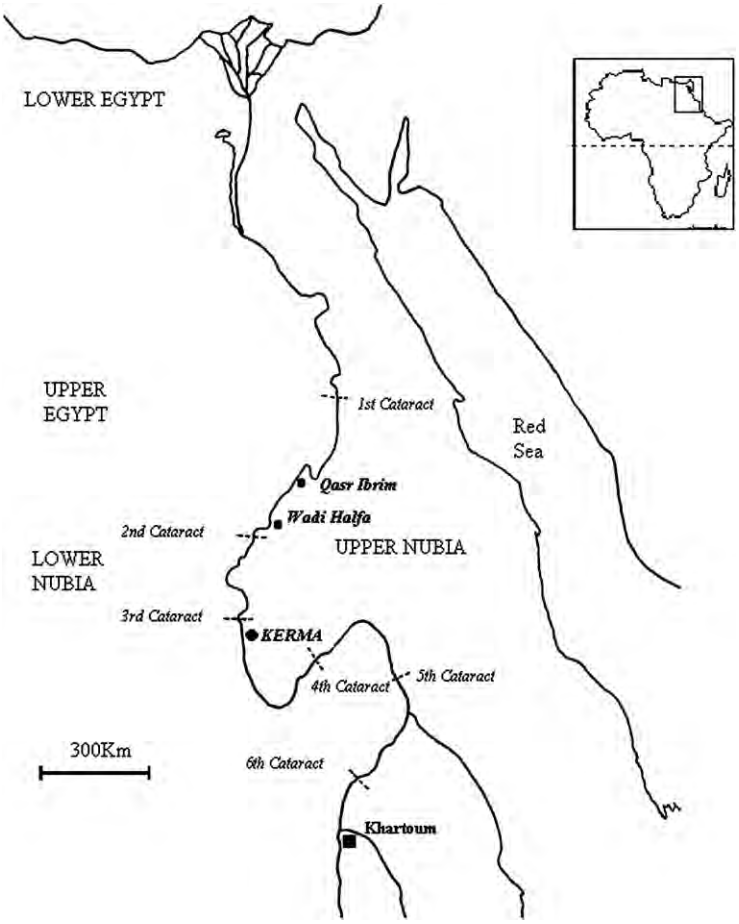

Fig. 1. Map of the Nile Valley indicating sites mentioned in the text.

culture is divided into three main phases, Ancient Kerma (AK, c. 2500–2050 BC), Middle Kerma (MK, c. 2050–1750 BC) and Classic Kerma (CK, c. 1750–1500 BC) (Edwards, 2004). Mortuary evidence from the large necropolis suggests that society was highly stratified, although this is not reflected in the architecture of the town site, which became one of the first African urbanised centres. (Bonnet, 1992; Taylor, 1991). Kerma's strategic position on one of the widest floodplains along the Upper Nubian Nile undoubtedly contributed to its success, enabling productive agriculture in an otherwise harsh environment (Adams, 1977), access to local mineral resources and control of Egypt's trade routes with Africa. Recently, the geographical extent of the Kerma cultural tradition along the Nubian Nile Valley to the north and south of Kerma itself has emerged (Edwards, 2004).

Reisner excavated the Eastern cemetery between 1913 and 1915. The scale of the site and rich material culture led to his interpretation of Kerma as an Egyptian trading colony (Reisner, 1918). However, Kerma civilisation is now considered to have grown from indigenous roots and Egyptian artifacts such as ceramics and scarabs reflect trade with Egypt, rather than an Egyptian presence (Bonnet, 1997). The Swiss Archaeological Mission's more recent excavations have revealed major mud-brick structures in the town as well as more of the Eastern cemetery (Bonnet, 1986).

The human remains analysed here were excavated by Reisner from the four massive 'royal' tumuli, or burial mounds (KIII, KIV, KX and KXVI) and one further associated tumulus (KXVIII) in the Eastern Cemetery (Reisner, 1923a,b). This vast necropolis has an estimated 30,000 burials and expanded southwards as it developed (Bonnet, 1992). Reisner dated the tumuli to the MK, however a more recent assessment of their location places them in the later CK (Bonnet, 1986). The tumuli were large mounds of earth and stone, which centred on a primary burial and also contained multiple secondary interments. Tumuli KX and KIII also had associated temples. Retainer sacrifice was practiced on a large scale at Kerma (Bonnet, 1990; Reisner, 1923a,b). The primary and often the subsidiary burials contained multiple individuals. The quality of the grave furnishings from the Classic Kerma period is remarkable and examples from these tumuli include ivory-inlaid wooden beds, fine ceramics and metal objects (Kendall, 1997).

3. Reconstructing diet through stable carbon and nitrogen isotope analysis

Bone collagen, the main protein component of bone, has a slow turnover rate (estimated between 10 and 30 years; Stenhouse and Baxter, 1979) so its isotopic composition is an integrated reflection of long-term diet. Animal feeding

experiments indicate that on diets with sufficient protein content, protein is routed to collagen synthesis (Ambrose and Norr, 1993; Tiezen and Fagre, 1993). Therefore isotopic data from bone collagen only enable the reconstruction of the protein component of the diet and whole-diet cannot be inferred.

In terrestrial ecosystems carbon isotope ratios ($\delta^{13}C$) primarily reflect the types of plants consumed, either directly or by animals from which protein was consumed. The majority of terrestrial plants follow one of two photosynthetic pathways, known as C_3 or C_4, which have characteristic, discrete ranges of $\delta^{13}C$ values. C_3 plants include temperate grasses, shrubs, trees and domesticates such as wheat and barley and their $\delta^{13}C$ values average around $-26‰$ (DeNiro, 1987). C_4 plants are typically arid adapted species, and this smaller group includes tropical grasses and domesticates such as millet, which tend to have more average $\delta^{13}C$ values around $-12.5‰$ (DeNiro, 1987).

It is possible to estimate the percentage of C_4 plants in diet using a two end-member linear mixing model after Schwarcz et al. (1985) as below:

$$\%C_4 = \frac{\delta_c - \delta_3 + \Delta_{dc}}{\delta_4 - \delta_3} \times 100$$

where δ_c is the measured $\delta^{13}C$ value of bone collagen, δ_3 is the mean $\delta^{13}C$ value for C_3 plants ($-26.5‰$) (White and Schwarcz, 1994), δ_4 is the mean $\delta^{13}C$ value of C_4 plants ($-11.5‰$) (White and Schwarcz, 1994) and Δ_{dc} is the fractionation factor between diet and bone collagen, (estimated at $-5‰$). (These $\delta^{13}C$ value estimates are higher than those previously given because they are local values and water-stressed plants in arid environments tend to have higher $\delta^{13}C$ values (Heaton, 1999).) We have chosen not to apply this simple two end-member linear mixing model here to estimate *human* diet at Kerma. The model assumes that all dietary components contribute equally to the carbon found in bone collagen, subsequently shown not to be the case. In most cases, dietary protein is routed to bone collagen (Ambrose and Norr, 1993). Omnivorous mammals such as humans, especially from complex, urban societies, are also not necessarily suited to analyses that account for only a few dietary end members. However, we believe that it is appropriate to apply this model to herbivorous species where dietary protein sources are limited.

Stable nitrogen isotope values ($\delta^{15}N$) indicate both the trophic level from which dietary protein was derived as well as aridity. $\delta^{15}N$ values increase between trophic levels, estimated at $3–5‰$ per level from studies of ancient and modern ecosystems (Bocherens and Drucker, 2003; Schoeninger and DeNiro, 1984). Studies of modern human hair also demonstrate increased $\delta^{15}N$ values as animal protein consumption rises (Bol and Pflieger, 2002; O'Connell and Hedges, 1999; Petzke et al., 2005). Where significant quantities of aquatic protein are consumed, greater ^{15}N enrichment is observed as such food chains are longer (Dufour et al., 1999; Katzenberg, 1989; Katzenberg and Weber, 1999; Sealy, 2001). Arid environments also tend to increase $\delta^{15}N$ values in animals and to a lesser degree plants (Ambrose and DeNiro, 1986; Heaton et al., 1986; Heaton, 1987; Schwarcz et al., 1999), as isotopically light ammonia volatilises preferentially from soil in arid environments, increasing baseline ^{15}N enrichment (Schwarcz et al., 1999). This effect may be enhanced by the inhibition of nitrogen-fixing bacteria in hot climates, decreasing the availability of isotopically lighter N_2 from the atmosphere (Ambrose, 1991). In order to conserve water, physiological adaptations in drought-adapted species such as browsing herbivores enable them to excrete urine with high concentrations of ^{15}N-depleted urea. A consequence of this is the ^{15}N-enrichment of tissues (Ambrose and DeNiro, 1986). A further cause of ^{15}N-enrichment in herbivores is nitrogen recycling by gut microbial flora, as they synthesise proteins that are eventually digested and absorbed (Sealy et al., 1987). These combined factors mean that distinguishing the cause of observed ^{15}N-enrichment in arid environments such as Nubia may be problematic.

4. Diet at ancient Kerma

4.1. Archaeological evidence for diet

Archaeozoological remains from the town and necropolis provide most of the evidence for human diet and the ritual role of animals at Kerma. Animals were included in burials to provide for the occupant in the afterlife and those studied here date to the MK, when animal sacrifices began to be replaced by humans.

Sheep, goats, cattle and dogs were the most common domestic species present at Kerma (Chaix, 1993a). Cattle played a significant role, particularly during the Ancient Kerma period when they dominate faunal assemblages. Cattle bucrania (frontal cranial bones) and hides were present in large numbers in the necropolis, and remains were found at the town site, supporting the idea of a strong cattle-herding tradition in the Kerma culture (Chaix and Grant, 1992). The quantities of cattle support theories that either the climate was moist enough during the third millennium BC to maintain a large cattle population, or that cattle were brought in from surrounding regions as tribute (Chaix and Grant, 1992). Sheep excavated from the necropolis were generally juvenile males and were usually found whole, although later ritually butchered joints were also included (Chaix and Grant, 1987; Chaix, 1993b). They were both economically and ritually important, and several with pierced horns and decorative ornaments have been excavated (Chaix and Grant, 1987). Dogs were included in burials as companions to the deceased, sometimes placed in a herding position at the head of a group of sheep or goats (Chaix, 1999). Rare finds of wild species at Kerma include river species such as hippopotamus, turtle and crocodile, as well as large herbivores such as giraffe, gazelle and elephant (Chaix, 1993a). Despite soil sieving at the town site, fish remains were rare (Chaix, 1986) however, dorsal spines and vertebrae from Nile perch (Chaix, 1980), tilapia (Chaix, 1995) and catfish (Chaix, 1993a) were reported.

Despite the exceptional organic preservation at Kerma, archaeobotanical evidence is scarce. At the town site cereals were excavated from bakeries which housed rows of ovens capable of producing large quantities of bread (Bonnet, 1988). The cemetery also yielded grains of barley (*Hordeum vulgare*), cucurbits (*Curcurbitaceae*) and legumes (Leguminosae), as well as strands of flax associated with sheep (Chaix, 1984). The Northern Dongola Reach survey reported archaeobotanical remains from the Kerma period that included barley (*Hordeum* sp.), wheat (*Triticum* sp.), weed species associated with cultivation and multiple species of wild grasses (Cartwright, 2001). The cultivation of sorghum and millet has been reported from the Meroitic period onwards at Qasr Ibrim (Rowley-Conwy, 1989), however no evidence was found at Kerma where most plant species are C_3. However C_4 grass species consumed by livestock at Kerma would provide a ^{13}C-enriched signal to human diet.

4.2. Previous stable isotope evidence for human diet in Nubia

Previous isotopic studies on archaeological remains from Nubia have been conducted on bone, hair and skin samples, an opportunity afforded by excellent preservation (Copley et al., 2004; Schwarcz and White, 2004; White et al., 1999, 2004; White, 1993; White and Schwarcz, 1994; White and Armelagos, 1997) (Table 1). The data have generally suggested that Nubian diet contained more C_4 plant-derived foods than seen in the northerly Egyptian Nile valley (Dupras and Schwarcz, 2001; Dupras et al., 2001; Iacumin et al., 1996; Thompson et al., 2005). Studies on human hair suggested that the seasonal availability of C_3 and C_4 resources reflected the agricultural regime during later periods (Schwarcz and White, 2004; White, 1993; White and Schwarcz, 1994).

Iacumin et al. (1998) carried out the only previously published isotopic study of human and faunal bone collagen from Kerma. Isotopic data from the MK suggested a similar diet to Egypt, with a larger C_3 signal than during other phases (Iacumin et al., 1996). A comparison with faunal isotope data suggested that aquatic resources were consumed throughout Kerma's history. Terrestrial protein came from sheep, goat and cattle, although the latter become less important during the MK and CK phases. In a later study δ^{13}C and δ^{15}N were measured in fossil cattle horn keratin to investigate seasonal dietary changes and the origins of the large numbers of cattle bucrania recovered from Kerma (Iacumin et al., 2001). The isotopic analysis of sections of cattle horn reflected the seasonal availability of C_3 and C_4 resources throughout the year. The authors also suggested that the wide variety of mean δ^{13}C and δ^{15}N values they observed across the population was due to differing geographical origins, supporting the hypothesis that cattle were brought in as tribute.

5. Materials and methods

5.1. Human samples

Bone samples from 54 adult skeletons were selected from the Duckworth Collection, curated by the Leverhulme Centre for Human Evolutionary Studies, University of Cambridge, UK (Table 3). (This collection has previously been the subject of research assessing health and disease and inter-personal violence at Kerma (Judd, 2000, 2004).) Individuals who were excavated from supplementary interments ($n = 44$), as well as those from the sacrificial corridors of tumuli KIV and KX ($n = 10$) were sampled. Some of the skeletal remains were previously assigned biological sex using modern osteological techniques by Judd (2000) (male $n = 12$, female $n = 5$, possibly female $n = 4$, unknown $n = 4$).

5.2. Faunal samples

The faunal samples were from the collection at the Muséum d'histoire Naturelle, Geneva, Switzerland. The Swiss Archaeological mission at Kerma recently excavated this material from both the Eastern cemetery and town sites. The faunal

Table 1
δ^{13}C and δ^{15}N data from previously published stable isotope studies on archaeological human remains from Nubia

Study	Site	Period[a]	*N*	Tissue	Mean δ^{13}C	SD	Mean δ^{15}N	SD
White (1993)	Wadi Halfa	X-Group	9	Bone collagen	−17.1	1.1	–	–
White (1993)	Wadi Halfa	X-Group	9	Hair	−16.6	1.9	–	–
White (1993)	Wadi Halfa	Christian	5	Hair	−16.7	2.3	–	–
White and Schwarcz (1994)	Wadi Halfa	Meroitic	31	Bone collagen	−18.1	1.0	12.3	–
White and Schwarcz (1994)	Wadi Halfa	X-Group	35	Bone collagen	−17.0	0.8	11.1	–
White and Schwarcz (1994)	Wadi Halfa	Christian	24	Bone collagen	−18.7	1.6	10.6	–
White and Armelagos (1997)	Wadi Halfa	X-Group	27	Bone collagen	−16.9	0.7	11.1	1.2
Iacumin et al. (1998)	Kerma	Ancient Kerma	5	Bone collagen	−16.4	1.3	12.2	0.7
Iacumin et al. (1998)	Kerma	Middle Kerma	4	Bone collagen	−19.7	0.8	13.1	0.9
Iacumin et al. (1998)	Kerma	Classic Kerma	2	Bone collagen	−20.3	–	12.1	–
Iacumin et al. (1998)	Kerma	Christian	1	Bone collagen	−13.3	–	12.1	–
White et al. (1999)	Wadi Halfa	X-Group–Christian	14	Skin collagen	−18.6	–	–	–
White et al. (2004)	Wadi Halfa	X-Group	46	Bone collagen	−16.9	1.3	11.6	1.3
White et al. (2004)	Wadi Halfa	Christian	16	Bone collagen	−18.4	2.1	10.4	1.3

[a]Dates of periods mentioned in table: Ancient Kerma, 2500–2050 BC; Middle Kerma, 2050–1750 BC; Classic Kerma, 1750–1500 BC; Meroitic, 350 BC to AD 35. X-Group, AD 350–550; Christian, AD 500–1400).

remains excavated from the necropolis mostly date to the Middle Kerma period, while those from middens at the town site date to the Classic Kerma period (Table 2). Bone samples were obtained from four domestic species: goats (*Capra*, $n = 19$), sheep (*Ovis*, $n = 23$), cattle (*Bos*, $n = 12$) and dogs (*Canis*, $n = 7$). Specimens were previously identified to species at the Muséum d'histoire Naturelle, Geneva.

5.3. Sample collection and preparation

Depending upon the condition of the remains, cortical bone was sampled wherever possible. Sampling strategy was discussed with museum curators prior to bone removal, and remains were sampled in accordance with museum guidelines from previously damaged or non-diagnostic areas. The selection of samples was determined by which specimens met the above criteria. Many individuals were not deemed suitable for analysis. Whole bone fragments weighing approximately 500–1000 mg were removed with a hand-held drill, wrapped in foil and placed in specimen bags labelled with the museum accession number. These samples were larger than are usually taken, as we anticipated low collagen yields.

The outer surface of the samples was removed using air-abrasion and approximately 500 mg of whole cleaned bone was demineralised in 0.5 M HCl at 4 °C over a number of days. Samples were rinsed with deionised water until pH was neutral, placed in sealed tubes and gelatinised at 70 °C in a dilute HCl solution at pH 3 for 48 h. Insoluble debris was removed by filtration through 5–8 μm mesh Ezee filters (Elkay Laboratory Products). The resulting solution was filtered to remove products of molecular weight <30 kDa (Ultrafree®-4 Centrifugal filter units, Biomax-30 membrane, Millipore), based upon the method of Brown et al. (1988). The supernatant was lyophilised for 48 h and 300–500 μg of the resultant purified "collagen" was weighed in duplicate for bulk isotopic analysis. Isotopic analyses were performed using a continuous-flow Europa 20–20 isotope ratio mass spectrometer, coupled to an ANCA elemental analyser in the Department of Archaeological Sciences, University of Bradford, UK. The analytical error for both $\delta^{13}C$ and $\delta^{15}N$ measurements was determined to be $\pm 0.2‰$ (1σ) or better, based upon the reproducibility of isotopic measurements of internal and international standards.

6. Results and discussion

6.1. Collagen preservation

Collagen recovery was predicted to be low as bone from hot, arid environments often shows poor preservation (Grupe, 1995). Furthermore, the use of ultrafilters to remove molecular contaminants is known to decrease collagen yield by approximately 60% as low-weight protein fractions are also removed (Jay and Richards, 2006). However, the human samples were exceptionally well preserved and collagen suitable for analysis was extracted from 48 of the 54 skeletons sampled (Table 3). These "collagen" samples met the criteria established to screen out poorly preserved, chemically altered collagen (i.e. C/N ratios were between 2.9 and 3.6, C >13.0%, N >4.8%, collagen yields over 1%) (Ambrose, 1990; DeNiro, 1985). Only three samples had C/N ratios that exceeded 3.6 (see Table 3) and isotopic data from these individuals are not discussed.

Collagen extraction from the faunal samples was not as successful. Collagen could not be extracted from the town site samples. The poor preservation of osteological material from the site was previously noted and attributed to the floodplain location of the site and wind erosion (Chaix, 1993a; Iacumin et al., 1998). The necropolis samples were more successful and data from 22 individuals are presented (Table 2). It is unclear why collagen recovery from the faunal remains was less successful than the human remains. It is possible that local environmental conditions varied between the different locations of the remains within the necropolis. It is also possible that some of the animal samples were treated differently before burial, and may have been, for example, partially cooked before deposition or else deposited in different states of decomposition. The cattle bucrania were situated on the exposed surface of burials and it was unsurprising that these samples were poorly preserved.

6.2. Isotopic data

6.2.1. Faunal samples

The $\delta^{13}C$ data from the fauna generally indicate mixed C_3 and C_4 diets, with a greater C_4 input than the human population (Figs. 2 and 4, Table 2). The sheep and goat populations have similar mean $\delta^{13}C$ and $\delta^{15}N$ values. The mean $\delta^{13}C$ value for the goats is slightly higher than the sheep, expected as goats are browsers and consume more C_3 plants than sheep grazing in the same environment (Balasse and Ambrose, 2005). $\delta^{13}C$ values from the modern goats were similar to the archaeological population, with the exception of a single individual. (Modern $\delta^{13}C$ values are on average about 1‰ lower than archaeological samples due to the release of ^{12}C from fossil fuel burning (Friedli et al., 1986). However, even if this is taken into account the $\delta^{13}C$ values are similar to the archaeological specimens). $\delta^{15}N$ values from the modern goats are lower than the archaeological samples, which was also observed by Iacumin et al. (1998). The archaeological goat samples analysed here also have higher $\delta^{13}C$ values than the single modern individual (−18.9‰) analysed by Iacumin et al. (1998). The Swiss team who collected the modern samples from the Kerma region noted that the diet of local goats consisted of marginal grazing and the consumption of refuse including plastics, so modern diets are not comparable to ancient diets.

The sheep sample contains individuals with higher $\delta^{13}C$ values than previously observed in either modern or archaeological samples (Iacumin et al., 1998). If the linear model described above is applied to estimate the percentage of C_4 plants in the diet, the $\delta^{13}C$ values of −18.5 to −11.9‰ represent a range of between 20 and 67% C_4 consumption. This large range suggests a variety of long-term feeding strategies

Table 2
Isotopic data measured from Kerma faunal bone collagen

Species	Site	Accession number	δ^{13}Cvs. PDB	δ^{15}Nvs. AIR	C:N	% C	% N	% collagen yield
Sheep	**KCE**	**T125−3**	**−17.2**	**11.7**	**4.0**	**40.3**	**11.7**	**2.47**
Sheep	KCE	T125−4	−17.1	9.9	3.6	40.8	13.4	2.39
Sheep	KCE	T125−5	−17.2	10.3	3.6	35.9	11.6	3.75
Sheep	KCE	T119−2	−14.0	7.7	3.4	38.3	13.4	4.18
Sheep	**KCE**	**T126−1***	**−18.7**	**8.4**	**3.7**	**24.9**	**7.83**	**0.60**
Sheep	**KCE**	**T126−2***	**−21.2**	**8.6**	**5.3**	**41.2**	**9.1**	**0.27**
Sheep	**KCE**	**T126−3**	**−19.8**	**8.9**	**3.8**	**21.5**	**6.6**	**0.44**
Sheep	KCE	T128−3	−13.2	10.9	3.3	33.7	11.9	0.72
Sheep	KCE	T107−6	–	–	–	–	–	0.0
Sheep	KCE	T107−4	–	–	–	–	–	0.25
Sheep	KCE	T115−1	−11.9	10.2	3.5	35.5	12.1	2.31
Sheep	KCE	T5	−14.5	11.2	3.5	34.5	11.8	1.45
Sheep	KCE	T117−1	−13.4	9.1	3.5	29.5	10.0	1.37
Sheep	KCE	T117−2	−16.2	7.6	3.3	31.7	11.1	1.33
Sheep	**KCE**	**T114**	**−14.3**	**11.8**	**3.7**	**34.7**	**11.0**	**1.92**
Sheep	**KCE**	**T212−3***	**−15.6**	**7.9**	**3.7**	**38.4**	**12.3**	**1.59**
Sheep	KCE	T212−4	−15.2	6.6	3.4	36.1	12.5	0.24
Sheep	**KCE**	**T185−1**	**−16.4**	**8.4**	**3.7**	**43.4**	**13.9**	**1.10**
Sheep	KCE	T185−2	−18.5	6.5	3.5	32.0	10.9	0.85
Sheep	KCE	T185−3	−16.6	8.5	3.4	35.8	12.6	2.20
Sheep	KCE	T189−9	−14.4	8.9	3.3	35.2	12.3	1.76
Sheep	KCE	T177	−13.2	8.9	3.5	32.0	10.8	1.35
Sheep	**KCE**	**T1−95−1***	**−17.5**	**10.3**	**3.8**	**8.9**	**2.7**	**0.42**
Goat	KCE	T89−3	−17.7	7.3	3.3	38.5	13.7	6.33
Goat	KCE	T1.1	−17.0	7.9	3.4	36.4	12.7	3.08
Goat	**KCE**	**T171***	**−14.7**	**10.4**	**5.5**	**41.8**	**8.8**	**0.14**
Goat	KCE	T.1−3	−15.9	8.9	3.5	32.6	11.1	0.56
Goat	KCE	T93−1	–	–	–	–	–	0.19
Goat	KCE	T93−2	–	–	–	–	–	0.00
Goat	KCE	T89−2	−17.6	5.9	3.6	36.1	11.7	2.38
Goat	KCE	T115−2	−15.8	11.3	3.4	37.0	12.8	2.06
Cow	KCE	T161−1	−7.0	12.7	3.3	27.6	9.9	2.23
Cow	KCE	300	–	–	–	–	–	0.48
Cow	KCE	207	–	–	–	–	–	0.33
Dog	KCE	T151−1	−13.6	11.6	3.4	37.9	13.2	1.81
Dog	**KCE**	**T89−1**	**−15.6**	**11.6**	**3.7**	**42.1**	**13.4**	**1.55**
Dog	KCE	T133−4	–	–	–	–	–	0.00
Dog	KCE	T249−1	–	–	–	–	–	0.00
Dog	KCE	T249−2	–	–	–	–	–	0.31
Dog	KCE	T238−1	–	–	–	–	–	0.02
Dog	KCE	T238−2	–	–	–	–	–	0.19
Cow	KV	KV-1	–	–	–	–	–	0.28
Cow	KV	KV-2	–	–	–	–	–	0.45
Cow	KV	KV-3	–	–	–	–	–	0.36
Cow	KV	KV-4	–	–	–	–	–	0.27
Cow	KV	KV-5	–	–	–	–	–	0.71
Cow	KV	KV-6	–	–	–	–	–	0.38
Cow	KV	KV-7	–	–	–	–	–	0.27
Cow	KV	KV-8	–	–	–	–	–	0.61
Cow	KV	KV-9	–	–	–	–	–	0.38
Goat	KV	KV-10	–	–	–	–	–	0.28
Goat	KV	KV-11	–	–	–	–	–	0.49
Goat	KV	KV-12	–	–	–	–	–	0.54
Goat	KV	KV-13	–	–	–	–	–	0.32
Goat	KV	KV-14	–	–	–	–	–	0.25
Goat	KV	KV-15	–	–	–	–	–	0.38
Goat	KV	KV-16	–	–	–	–	–	0.29
Goat	KV	KV-17	–	–	–	–	–	0.42
Goat	KV	KV-18	–	–	–	–	–	0.51
Goat	KV	KV-19	–	–	–	–	–	0.33
Goat	KV	KV-20	–	–	–	–	–	0.31
Goat	**Modern**	**C-1**	**−15.3**	**8.2**	**3.9**	**48.2**	**14.5**	**5.78**
Goat	Modern	C-2	−15.4	4.7	3.6	38.0	12.1	3.56
Capra	Modern	C-3	−16.8	6.6	3.3	39.3	13.9	3.24
Capra	Modern	C-4	−19.7	5.7	3.6	45.7	14.7	9.70
Goat	Modern	C-5	−16.7	5.8	3.2	41.0	14.8	5.24

All δ^{13}C and δ^{15}N data are mean values from duplicate analyses except those marked with an asterisk. Samples in bold type had C/N ratios >3.6). KCE, Kerma Eastern Cemetery; KV, Kerma Town site; Modern, modern specimens from Kerma.

Table 3
Isotopic data measured from human bone collagen samples

Sample accession number	δ^{13}C vs. PDB	δ^{15}N vs. AIR	C:N	% C	% N	% collagen yield	Burial context	Sex
K309A	−19.3	14.2	3.5	41.4	13.9	5.63	Sub	–
III313	−15.4	15.4	3.4	43.1	14.8	3.08	Sub	M
323B	**−20.3**	**13.3**	**4.0**	**44.2**	**13.1**	**2.15**	Sub	–
332B	−15.3	13.7	3.4	43.0	14.6	3.61	Sub	–
339B	−18.6	12.9	3.3	38.2	13.4	3.00	Sub	–
K420i	−14.3	13.5	3.5	38.1	13.2	4.63	Sub	–
IT420i	−19.3	13.9	3.4	40.5	13.8	3.61	Sub	–
K420A	−17.7	14.1	3.5	38.8	13.1	0.83	Sub	M
K421	−19.1	14.7	3.4	43.0	15.0	4.38	Sub	F
K423	−17.6	14.0	3.6	44.0	14.5	4.32	Sub	M
K424	–	–	–	–	–	0.20	Sub	M
K425B	−18.3	14.3	3.6	45.5	15.0	4.08	Sub	M
437C	−12.3	16.1	3.4	40.2	13.8	3.28	Sub	–
IVBFA	−16.5	13.8	3.4	42.5	14.7	4.44	Sac	F?
IVBWA	–	–	–	–	–	0.21	Sac	M
IVBDA	−18.7	13.4	3.4	37.9	13.1	1.20	Sac	–
IVBSA	−18.7	13.9	3.5	39.5	13.3	1.75	Sac	–
IV414E	−18.3	13.6	3.4	43.8	15.1	4.10	Sac	–
1024	−19.2	12.6	3.4	44.3	15.4	4.39	Sub	–
1024(2)	−18.7	14.0	3.3	44.8	15.8	5.87	Sub	–
B1026	–	–	–	–	–	0.28	Sub	–
1029	−18.4	14.8	3.4	41.7	14.6	2.89	Sub	–
1029.2	−16.3	15.0	3.5	41.6	14.2	3.27	Sub	
IA1029	−18.1	14.7	3.4	40.5	14.0	3.95	Sub	F?
1029AII	−11.9	14.3	3.4	45.6	15.8	2.58	Sub	F?
1030B	−18.7	13.1	3.4	41.8	14.6	4.38	Sub	–
1030X	−18.1	14.1	3.5	39.0	13.2	2.73	Sub	–
1041D	−16.3	13.9	3.4	40.0	13.8	2.86	Sub	M
1042	−19.6	13.3	3.4	40.4	13.9	2.56	Sub	–
1044	−18.6	14.7	3.6	39.5	13.0	1.60	Sub	–
1044X	−17.9	12.9	3.4	41.0	14.1	3.64	Sub	–
1045II	−17.7	14.3	3.5	35.5	11.8	2.56	Sub	–
1045III	−17.3	13.5	3.4	41.4	14.2	3.33	Sub	F
1045B	−17.5	13.5	3.4	44.5	15.2	2.75	Sub	F
1048.2	−18.3	13.6	3.5	41.3	14.1	3.78	Sub	–
1048.1	−17.5	14.0	3.6	36.2	12.1	1.20	Sub	–
1050A	−18.1	13.8	3.5	34.4	11.7	1.74	Sub	M
1058IIB	−17.6	13.7	3.3	41.1	14.4	4.91	Sub	–
1058D	−17.0	14.2	3.3	40.3	14.1	4.56	Sub	–
1065II	−18.4	14.2	3.3	42.0	15.0	2.28	Sub	–
1065G	−17.4	12.5	3.4	39.8	13.8	3.89	Sub	M
1067	**−19.6**	**13.9**	**3.8**	**45.4**	**13.9**	**2.33**	Sub	–
1084	−19.9	12.8	3.6	43.9	14.4	3.90	Sub	F
1088A	−18.4	12.4	3.4	43.4	14.8	4.69	Sub	–
XBZC	−19.6	13.8	3.5	42.5	14.2	7.14	Sac	F
XBZIT	−17.2	14.6	3.5	41.6	13.9	3.63	Sac	M
XBTIT	−17.7	14.1	3.4	34.7	11.9	2.14	Sac	–
XBMB	−18.1	13.1	3.5	37.4	12.6	1.20	Sac	–
XBOCA*	−18.9	13.9	3.4	35.2	12.0	1.49	Sac	F?
1625D	−19.0	13.4	3.3	23.9	8.4	0.96	Sub	–
C1802	**−18.9**	**13.3**	**4.0**	**40.8**	**12.0**	**1.67**	Sub	M
IIG1803	−18.6	13.5	3.6	35.5	11.4	1.74	Sub	M
D1803	−17.2	14.6	3.4	42.3	14.6	2.75	Sub	–
1805	−18.7	14.4	3.4	39.2	13.6	4.91	Sub	–

All δ^{13}C and δ^{15}N data are mean values from duplicate analyses except those marked with an asterisk. Samples highlighted had C/N ratios >3.6. The sample accession number refers to the tumulus that the individual was excavated from. (Numbers refer to a primary, supplementary burial in the tumulus (sub) and roman numerals refer to sacrificial individuals (sac)).

for sheep that involved feeding from different environmental contexts. Ranges of 1.2‰ (mean carbonate δ^{13}C) and 2.8‰ (dentine δ^{13}C) were observed in modern sheep from Kenyan and Mongolian herds that had known diets (Balasse and Ambrose, 2005; Makarewicz and Tuross, 2006). The larger range at Kerma suggests that not all of the sheep originated from a local herd, particularly the more ^{13}C-enriched individuals. Sheep are known to have had special funerary

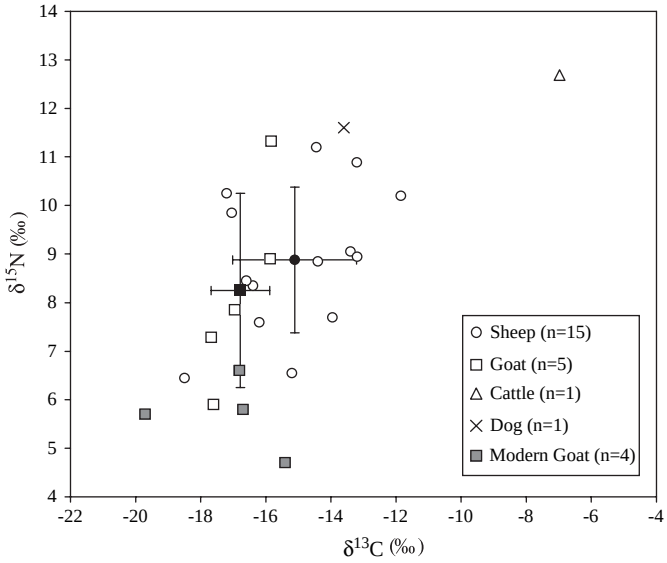

Fig. 2. Plot of δ^{13}C and δ^{15}N data measured from Kerma faunal bone collagen samples (closed symbols are mean values with standard deviation $\pm 1\sigma$ indicated by bars).

significance at Kerma, and individuals 119/2 and 115/1 which have amongst the highest δ^{13}C values (Table 2), were excavated with decorative ostrich feather discs between their horns, similar to images in Saharan rock carvings (Chaix and Grant, 1987; Chaix, 1993b).

δ^{15}N values from the sheep and goats are higher than previously seen at Kerma (Iacumin et al., 1998) (spanning large ranges of 4.7‰ and 5.4‰ respectively), although these values are comparable to other sites in the region (Copley et al., 2004; Thompson et al., 2005). This range may reflect access to different grazing resources within the Kerma area, with higher values reflecting more marginal grazing towards the arid desert edge.

The single cattle sample analysed has a very positive δ^{13}C value of −7.0‰, indicating an almost exclusively C_4-based diet (estimated at 97%). Similarly ^{13}C-enriched values have been published from East African savannah cattle (Ambrose and DeNiro, 1986) and other grazing bovidae (Cerling et al., 2003). The δ^{15}N value of +12.4‰ is higher than previously measured data from Nubian cattle collagen (Copley et al., 2004). However, we reported similarly elevated δ^{15}N values from cattle bone collagen samples from the Egyptian Nile valley and the Kharga Oasis (Thompson et al., 2005). Kerma cattle horn keratin had elevated δ^{15}N values (Iacumin et al., 2001) and as discussed above, the authors of this study suggested that cattle were brought into the region from other locations. Even though a direct comparison of data from different tissues is not possible our data support this, suggesting that the cattle sample was probably not local to Kerma.

The single dog analysed has similar δ^{13}C values to the sheep and goats, suggesting a diet with a relatively high C_4-based input (see Fig. 2). Modern dogs had lower δ^{13}C values and less elevated δ^{15}N values (Iacumin et al., 1998). The dog's δ^{15}N value is higher than the means of the sheep and goats, suggesting the consumption of protein from this source. Some of the dogs excavated at Kerma were so well preserved that remains of sub-adult sheep and 'large Nilotic fish' were found in their stomach cavities (Chaix, 1999). Our data supports this observation, although comparison with mean δ^{15}N values from Nile fish species from Lake Nasser (+14.5‰) (Iacumin et al., 1998) suggests that it is unlikely that the dog consumed much aquatic protein.

6.2.2. Human samples

The human δ^{13}C values have a remarkably large variation of 8‰ across the total population, (range −19.9‰ to −11.9‰, mean $= -17.7 \pm 1.6$‰ (1σ)) (Table 3, Fig. 3). The δ^{15}N values measured show less variation and are relatively elevated, as expected for a population inhabiting a hot, arid region (range +12.4‰ to +15.4‰, mean $= +13.9 \pm 0.7$‰ (1σ)). Although the faunal samples date from the earlier MK and the climate may have differed, the isotopic data from the human population are interpreted relative to these data as they represent the same species present during the CK and no other data from this period are currently available (see Fig. 4).

Most individuals have δ^{13}C values indicative of the consumption of both C_3 and C_4-derived protein, in broad agreement with previously measured Nubian data sets. The large range of δ^{13}C values is comparable with those previously reported from both Kerma and the Wadi Halfa sites (Table 1). Iacumin et al. (1998) concluded that their δ^{13}C data indicated a dietary shift at Kerma, with a larger C_4 input during the AK. The CK data they reported is limited to two individuals, one of

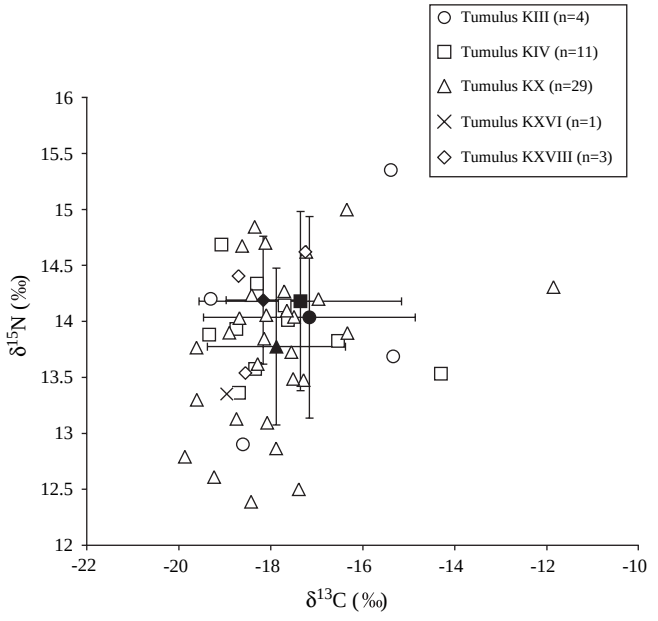

Fig. 3. Plot of δ^{13}C and δ^{15}N data measured from Kerma human bone collagen samples (closed symbols are mean values for each tumulus population with standard deviation $\pm 1\sigma$ indicated by bars).

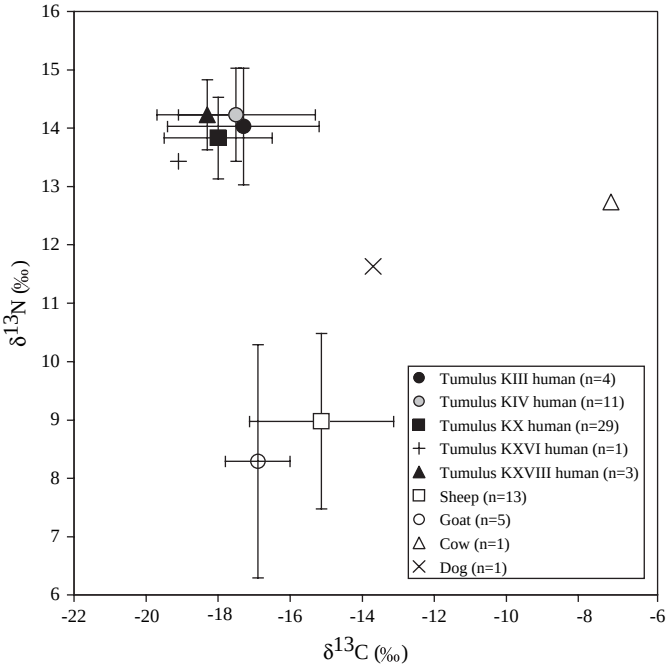

Fig. 4. Plot of mean isotopic δ^{13}C and δ^{15}N data measured from human and faunal bone collagen samples from Kerma (standard deviation $\pm 1\sigma$ indicated by bars).

which had a low δ^{13}C value of −23‰. The range of values we measured encompasses the previously reported data from the AK and MK periods. This suggests that either there was another dietary shift during the CK period and the whole range of dietary resources consumed by earlier residents was available, or that this reflects the migration of individuals with access to a range of C_3 and C_4-based diets.

The widest range of δ^{13}C data is seen between burials 1084 and 1029 IIA, both from tumulus KX. These individuals had δ^{13}C values of −19.9‰ and −11.9‰ respectively, suggestive of distinct differences in diet. Seasonal differences in the availability of C_3 and C_4 grazing to herbivores at Kerma would cause δ^{13}C values similar to 1084, however a much larger C_4 component is suggested for 1029 IIA (Table 3, Fig. 3). In such an extreme case, this may be attributed to the movement of 1029 IIA to Kerma from an area where the ecosystem was based on C_4 plants. Objects such as carved ostrich eggshells, which are thought to originate from the Sahara, as well as the practice of adorning sheep with ostrich-feather disks, demonstrates contact and trade with outside Saharan groups (Bonnet, 1986). Contact to the east also existed, evidenced by ceramic items similar to those from Kerma found towards the Red Sea (Bonnet, 1993). Any migration may have either been voluntary, as burial close to royalty must have been very desirable, or involuntary as people were regarded as part of the spoils of war in the region. Regardless of the reasons for their presence, the wide range of δ^{13}C values may be interpreted as evidence for migration into Kerma from elsewhere.

The mean δ^{13}C value measured at Kerma is slightly more positive than in Egyptian Nile Valley populations (Thompson, 2004), consistent with the higher percentage of C_4 grasses prevailing at the more southerly latitude (Batanouny et al., 1988). The faunal data discussed above generally have more positive δ^{13}C values than the human population (Fig. 4). This is not necessarily the expected relationship if these animals formed the main protein intake for the human population, as a slight shift to higher δ^{13}C values is expected with an increase in trophic level (Bocherens and Drucker, 2003). As these animals were excavated from the necropolis rather than the town, they may not be representative of animals that provided more regular protein sources. Comparing the outlying humans with high δ^{13}C values to the faunal data, a better fit is observed. The δ^{13}C values from the human population at Kerma are likely indicative of an agricultural system producing a seasonal mixture of C_3 and C_4-based dietary protein through the year. Crop scheduling was observed during later time periods at Wadi Halfa during the X-group (AD 350–550) and Christian periods (AD 500–1400) (White, 1993; White and Schwarcz, 1994).

The enriched δ^{15}N values are consistent with data from previous isotopic studies from the region (Table 1). A similar 3‰ range of δ^{15}N values was observed in the Egyptian Nile Valley, although the mean δ^{15}N from Kerma is slightly higher (Thompson, 2004) and approximately 2‰ higher than previously reported from Kerma (Iacumin et al., 1998). The mean human δ^{15}N value is approximately 5‰ more positive than the sheep and goats, at the top end of the suggested range of 3–5‰ per trophic level (Bocherens and Drucker, 2003). This suggests that herbivores with δ^{15}N values in this range may have provided protein to the human population, however the higher δ^{13}C values discussed above make some of these individuals unlikely. The isotopic values from the only cattle sample that contained acceptable collagen are not typical of an animal from Kerma, as discussed above. Even if such animals were consumed ritually in connection with burials, this would not constitute a large part of human diet. Unfortunately, none of the faunal samples from the town context, which may be more representative of typical diet, contained collagen to allow this comparison.

The elevated δ^{15}N values may be attributed to the arid conditions (Heaton, 1987; Schwarcz et al., 1999). There is some evidence to suggest that, compared to modern day conditions, the region was slightly moister during the Kerma period and that Nile river levels were higher than present (Chaix and Grant, 1993). However our high δ^{15}N data from Kerma period humans and fauna do not support this. The consumption of aquatic resources could also have contributed to the elevated δ^{15}N values observed in the human population, as suggested by other studies (Iacumin et al., 1998; White and Schwarcz, 1994). However this interpretation is problematic because of ^{15}N-enrichment due to the arid conditions, and the archaeozoological evidence for fish is scant (see Section 3.1). The application of manure to arable land has also been proposed to account for enriched δ^{15}N values observed in Nubia (White et al., 2004) and this may be the case at Kerma. Unfortunately, the δ^{15}N values of modern samples from the region may not be useful in clarifying the source of ^{15}N-enrichment, due to the application of modern ^{15}N-depleted chemical fertilisers.

Table 4
Mean isotopic data measured from human bone collagen samples from Kerma tumuli

Tumulus	*n*	Mean $\delta^{13}C$ vs. PDB	Range $\delta^{13}C$	$\delta^{13}C$ SD	$\delta^{13}C$ RSD	Mean $\delta^{15}N$ vs. AIR	$\delta^{15}N$ range	$\delta^{15}N$ SD	$\delta^{15}N$ RSD
KIII	4	−17.2	−15.3 to −19.3	2.1	12.2	+14.0	+12.0 to +15.4	1.0	7.1
KIV	11	−17.4	−19.3 to −16.5	2.2	12.6	+14.2	+13.4 to +14.7	0.8	5.6
KX	29	−17.9	−19.9 to −11.9	1.5	8.4	+13.8	+12.4 to −15.0	0.7	5.1
KXVI	1	−19.0	–	–	–	+13.4	–	–	–
KXVIII	12	−18.2	−18.7 to −17.2	0.8	4.4	+14.2	+13.5 to +14.6	0.6	4.2

n, number of samples that collagen was successfully extracted from; SD, standard deviation (1σ); RSD, relative standard deviation.

The mean isotopic values from all tumuli were similar (Table 4). Interestingly, the individuals from tumuli KIV and KX. who were noted in Reisner's excavation reports to have been found in the 'sacrificial corridor' of the tumulus versus those from the supplementary burials (Table 3), do not cluster separately to the rest of the population in either $\delta^{13}C$ or $\delta^{15}N$ isotopic values. These limited data suggest that the diet of these people, and so possibly their origin or status, was not distinct to the rest of the population at Kerma, despite their different burial circumstances. However, the status of primary and sacrificial individuals in the supplementary burials was not determined as it was not clear in the excavation reports, and this may explain the lack of difference between the populations. The $\delta^{13}C$ values measured from the individuals assigned a definite biological sex (i.e. either male ($n = 9$) or female ($n = 5$)) were compared using a Student's t-test and no statistically significant difference was found between males and females ($P = 0.055$).

7. Conclusions

The isotopic data measured in this study suggest a mixed C_3/C_4 diet for the faunal and human populations. A large range of isotopic values, particularly $\delta^{13}C$, was observed in both populations. These data support previous suggestion that cattle were moved into the site from elsewhere for ritual purposes, and this interpretation may be extended to movement of sheep into Kerma. Human diet at Kerma may not be fully explained by the animal isotope values, as the faunal samples derive from an earlier mortuary context and may not have isotope values typical of more regularly consumed animals. Unfortunately the midden context faunal samples, which may represent a more local or typical isotopic signal, did not yield any collagen for comparison.

The high $\delta^{15}N$ values measured from both the human and faunal populations reflect the baseline ^{15}N-enrichment observed in arid regions and agree with those observed in previous Nile Valley studies. The consumption of herbivores with elevated $\delta^{15}N$ values is likely to account for the values observed in the human population in this study, as although previous isotopic work suggested that freshwater dietary resources were also consumed, there is very little archaeozoological evidence for this. However, it is important to note the context of these burials in a very high status cemetery, and that the diet of these individuals may not be reflective of the larger population.

The large range of isotopic values observed in the human population may also support the idea of migration along the Nile Valley into Kerma. The population at Kerma is not isotopically homogenous, and while this may be due to differing dietary practices between individuals, it is likely that these values reflect both indigenous and immigrant populations. Further investigation into other sources of isotopic information such as $\delta^{18}O$ values from bone phosphate, Sr isotope ratios of tooth enamel, or $\delta^{34}S$ values from bone collagen could provide better information as to the origins of the population.

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References

Adams, W.Y. (Ed.), 1977. Nubia: Corridor to Africa. Allen Lane, London.
Ambrose, S.H., DeNiro, M.J., 1986. The isotopic ecology of East African mammals. Oecologia 69, 395–406.
Ambrose, S.H., 1990. Preparation and characterisation of bone and tooth collagen for stable isotopic analysis. Journal of Archaeological Science 17, 431–451.
Ambrose, S.H., 1991. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. Journal of Archaeological Science 18, 293–317.
Ambrose, S.H., Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Lambert, J., Grupe, G. (Eds.), Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, pp. 1–37.
Balasse, M., Ambrose, S.H., 2005. Distinguishing sheep and goats using dental morphology and stable carbon isotopes in C_4 grassland environments. Journal of Archaeological Science 32, 691–702.
Batanouny, K.H., Stichler, W., Ziegler, H., 1988. Photosynthetic pathways, distribution and ecological characteristics of grass species in Egypt. Oecologia 75, 539–548.
Bocherens, H., Drucker, D., 2003. Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. International Journal of Osteoarchaeology 13, 46–53.
Bol, R., Pflieger, C., 2002. Stable isotope (^{13}C, ^{15}N and ^{34}S) analysis of the hair of modern humans and their domestic animals. Rapid Communications in Mass Spectrometry 16, 2195–2200.
Bonnet, C., 1986. Archaeological excavations at Kerma (Sudan): preliminary report on the 1984–1985 and 1985–1986 seasons, In: Bonnet, C., Privati,

B., Simon, C., Chaix, L., DePaepe, P. (Eds.), Triage a parte de Geneva, I-VII.

Bonnet, C., 1988. Les fouilles archéologiques de Kerma (Soudan). Genava N.S. 36, 5–20.

Bonnet, C., 1990. Kerma royaume de Nubie: L'antiquité Africaine au temps des pharaons. Mission archaéologique de L'Université de Genève au Soudan, Geneva.

Bonnet, C., 1992. Excavations at the Nubian royal town of Kerma: 1975–91. Antiquity 66, 611–625.

Bonnet, C., 1993. Upper Nubia from 3000 to 1000 BC. In: Davies, W.V. (Ed.), Egypt and Africa: Nubia from Prehistory to Islam. British Museum Press, London, pp. 112–117.

Bonnet, C., 1997. A-Group and Pre-Kerma. In: Wildung, D. (Ed.), Sudan: Ancient Kingdoms of the Nile. Flamarillion, Paris and New York, pp. 37–39.

Brown, T.A., Nelson, D.E., Southon, J.R., 1988. Improved collagen extraction by a modified Longin method. Radiocarbon 30, 171–177.

Cartwright, C., 2001. The plant remains. In: Welsby, D. (Ed.), Life on the Desert Edge: Seven Thousand Years of Settlement in the Northern Dongola Reach. British Museum Press, London, pp. 556–561.

Cerling, T.E., Harris, J.M., Passey, B.H., 2003. Diets of East African Bovidae based on stable isotope analysis. Journal of Mammology 84, 456–470.

Chaix, L., 1980. Note préliminaire sur la faune de Kerma (Soudan). Genava N.S. 28, 63–64.

Chaix, L., 1984. Troisième note sur la faune de Kerma, Soudan. Campagnes 1983-1984. Genava N.S. 32, 31–34.

Chaix, L., 1986. Quatrième note sur la faune de Kerma (Soudan). Campagnes 1885 et 1986. Genava N.S. 34, 35–40.

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

Chaix, L., 1993b. Les Moutons Décorés de Kerma (Soudan): Problèmes d'Interprétation. In: L'Arte e l'Ambiente del Sahara Preistorico: Dati e Interpretazioni. Memorie della Società Italiana di Scienze Naturali e del Museo Civico di Storia Naturale di Milano, Milan, pp. 161–164.

Chaix, L., 1995. Kerma: sixième note sur la faune (Campagnes 1989–1995). Genava N.S. 43, 53–57.

Chaix, L., 1999. The dogs from Kerma (Sudan) 2700 to 1500 BC. In: Becker, C., Manhart, H., Peters, J., Schibler, J. (Eds.), Historia Animalium ex Ossibus. Verlag Marie Leidorf, Rahden, pp. 109–126.

Chaix, L., Grant, A., 1987. A study of a prehistoric population of sheep (*Ovis aries* L.) from Kerma, Sudan. Archaeozoologica 1, 77–92.

Chaix, L., Grant, A., 1992. Cattle in Ancient Nubia. Anthropozoologica 16, 61–66.

Chaix, L., Grant, A., 1993. Palaeoenvironment and economy at Kerma, Northern Sudan, during the third millennium BC: archaeozoological and botanical evidence. In: Krzyzaniak, L., Kobusiewicz, M. (Eds.), Environmental Change and Human Culture in the Nile Basin and Northern Africa until the Second Millennium BC. Poznan Archaeological Museum, Poznan, pp. 399–404.

Copley, M.S., Jim, S., Jones, V., Rose, P., Clapham, A., Edwards, D.N., Horton, M., Rowley-Conwy, P., Evershed, R.P., 2004. Short- and long-term foraging and foddering strategies of domesticated animals from Qasr-Ibrim, Egypt. Journal of Archaeological Science 31 (9), 1273–1286.

DeNiro, M.J., 1985. Post-Mortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317, 806–809.

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

Dufour, E., Bocherens, H., Mariotti, A., 1999. Palaeodietary implications of isotopic variability in Eurasian Lacustrine fish. Journal of Archaeological Science 26, 617–627.

Dupras, T., Schwarcz, H.P., 2001. Strangers in a strange land: stable isotope evidence for human migration in the Dakhleh Oasis, Egypt. Journal of Archaeological Science 28, 1199–1208.

Dupras, T.L., Schwarcz, H.P., Fairgrieve, S.I., 2001. Infant feeding and weaning practices in Roman Egypt. American Journal of Physical Anthropology 115, 204–212.

Edwards, D.N. (Ed.), 2004. The Nubian Past: an Archaeology of the Sudan. Routledge, London & New York.

Friedli, H., Lötscher, H., Oeschger, H., Siegenthaler, U., Stauffer, B., 1986. Ice core record of the $^{13}C/^{12}C$ ratio of the atmospheric CO_2 in the past two centuries. Nature 324, 237–238.

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

Heaton, T.H.E., 1987. The $^{15}N/^{14}N$ ratios of plants in South Africa and Namibia: relationship to climate/saline environments. Oecologia 74, 236–246.

Heaton, T.H.E., 1999. Spatial, species and temporal variations in the $^{13}C/^{12}C$ ratios of C_3 plants: implications for palaeodiet studies. Journal of Archaeological Science 26, 637–649.

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

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.

Iacumin, P., Bocherens, H., Chaix, L., Mariotti, A., 1998. Stable carbon and nitrogen isotopes as dietary indicators of ancient Nubian populations (Northern Sudan). Journal of Archaeological Science 25, 293–301.

Iacumin, P., Bocherens, H., Chaix, L., 2001. Keratin C and N stable isotope ratios of fossil cattle horn from Kerma (Sudan): a record of dietary changes. Il Quaternario (Italian Journal of Quaternary Sciences) 14 (1), 41–46.

Jay, M., Richards, M.P., 2006. Diet in the Iron Age cemetery population at Wetwang Slack, East Yorkshire, UK: carbon and nitrogen stable isotope evidence. Journal of Archaeological Science 33, 653–662.

Judd, M., 2000. Trauma and interpersonal violence in Ancient Nubia during the Kerma Period (ca. 2500–1500 BC). Ph.D. Dissertation, Department of Anthropology, University of Alberta, Edmonton, Canada.

Judd, M., 2004. Trauma in the city of Kerma: ancient versus modern injury patterns. International Journal of Osteoarchaeology 14, 34–51.

Katzenberg, M.A., 1989. Stable isotope analysis of archaeological faunal remains from Southern Ontario. Journal of Archaeological Science 16, 319–329.

Katzenberg, M.A., Pfeiffer, S., 2000. Stable isotope analysis: a tool for studying past diet, demography and life history. In: Katzenberg, M.A., Saunders, S.A. (Eds.), Biological Anthropology of the Human Skeleton. Wiley-Liss, New York, pp. 305–328.

Katzenberg, M.A., Weber, A., 1999. Stable isotope ecology and palaeodiet in the Lake Baikal region of Siberia. Journal of Archaeological Science 26, 651–659.

Kendall, T., 1997. Kerma and the Kingdom of Kush: the archaeological discovery of an ancient Nubian empire. Smithsonian Institution, Washington, DC.

Makarewicz, C., Tuross, N., 2006. Foddering by Mongolian pastoralists is recorded in the stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes of caprine dentinal collagen. Journal of Archaeological Science 33, 862–870.

Mays, S., 2000. New directions in the analysis of stable isotopes in excavated bones and teeth. In: Cox, M., Mays, S. (Eds.), Human Osteology in Archaeology and Forensic Science. Greenwich Medical Media, London, pp. 425–438.

O'Connell, T.C., Hedges, R.E.M., 1999. Investigations into the effect of diet on modern human hair isotopic values. American Journal of Physical Anthropology 108, 409–425.

Petzke, K.J., Boeing, H., Metges, C.C., 2005. Choice of dietary protein of vegetarians and omnivores is reflected in their hair protein ^{13}C and ^{15}N abundance. Rapid Communications in Mass Spectrometry 19, 1392–1400.

Reisner, G.A. (Ed.), 1918. Outline of the Ancient History of the Sudan, Sudan Notes and Records. French Institute of Oriental Archaeology, Cairo, pp. 3–15. 57–79, 217–237.

Reisner, G.A. (Ed.), 1923a. Kerma (I–III). Harvard African Studies, Cambridge, MA.

Reisner, G.A. (Ed.), 1923b. Kerma (IV–V). Harvard African Studies, Cambridge, MA.

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

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

Schwarcz, H.P., White, C.D., 2004. The grasshopper or the ant? Cultigen-use strategies in ancient Nubia from C-13 analyses of human hair. Journal of Archaeological Science 31, 753–762.

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

Schwarcz, H.P., Dupras, T.L., Fairgrieve, S.I., 1999. ^{15}N enrichment in the Sahara: in search of a global relationship. Journal of Archaeological Science 26, 629–636.

Sealy, J.C., 2001. Body tissue chemistry and palaeodiet. In: Brothwell, D.R., Pollard, A.M. (Eds.), Handbook of Archaeological Sciences. John Wiley & Sons, Chichester, UK, pp. 269–279.

Sealy, J.C., van der Merwe, N.J., Lee Thorp, J.A., Lanham, J.L., 1987. Nitrogen isotope ecology in southern Africa: Implications for environmental and dietary tracing. Geochimica et Cosmochimica Acta 51, 2707–2717.

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

Taylor, J.H. (Ed.), 1991. Egypt and Nubia. British Museum Press, London.

Thompson, A.H., 2004, Isotopic analysis of human and faunal bone collagen from Egyptian and Nubian populations. Unpublished PhD thesis, Department of Archaeological Sciences, University of Bradford, Bradford, UK.

Thompson, A.H., Richards, M.P., Zakrzewski, S.R., Shortland, A., 2005. Isotopic palaeodietary studies of Ancient Egyptian fauna and humans. Journal of Archaeological Science 32, 451–463.

Tiezen, L.L., Fagre, T., 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO2, bone collagen, bioapatite and soft tissues. In: Lambert, J., Grupe, G. (Eds.), Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, pp. 121–155.

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., Armelagos, G.J., 1997. Osteopenia and stable isotope ratios in bone collagen of Nubian female mummies. American Journal of Physical Anthropology 103, 185–199.

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

White, C.D., Longstaffe, F.J., Law, K.R., 1999. Seasonal stability and variation in diet as reflected in human mummy tissues from the Kharga Oasis and the Nile Valley. Palaeogeography, Palaeoclimatology, Palaeoecology 147, 209–222.

White, C., Longstaffe, F.J., Law, K.R., 2004. Exploring the effects of environment, physiology and diet on oxygen isotope ratios in ancient Nubian bones and teeth. Journal of Archaeological Science 31, 233–250.