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Stable Isotope Analysis of Human and Animal Remains at the Qijiaping Site in Middle Gansu, China

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ABSTRACT Intercontinental exchanges between communities living in different parts of Eurasia during the late prehistoric period have become increasingly popular as a topic of archaeological research. The Qijia culture, found in northwest China, is one of the key archaeological cultures that can shed light on trans-Eurasian exchange because a variety of imports are found in this cultural context. These imports include new cereals and animals, which suggest that human diets may also have changed compared with previous periods. To understand human and animal diets of the Qijia culture, carbon and nitrogen isotope ratios from human and animal skeletal remains were analysed from the type site of the Qijia culture at Qijiaping. The results demonstrate that human diet at the site mainly consisted of millet and animals fed on millet. C_3 cereals, such as wheat and barley, did not contribute significantly to human diet, and no isotopic differences were found between adult and subadult diets. Furthermore, three outlying human results raise the possibility of exogenous individuals, perhaps in relation to the parallel movement of animals, crops and goods. This study provides human and animal dietary information for evaluating the nature of exchange and diffusion in eastern Eurasia at this time. Copyright © 2013 John Wiley & Sons, Ltd.

Key words: Qijiaping; Gansu; stable isotopes; collagen; diet; Bronze Age

Introduction

Intercontinental exchanges between communities living in different parts of Eurasia during the late prehistoric period have increasingly drawn research attention (e.g., Sherratt, 2006; Hanks, 2010; Jones *et al.*, 2011; Boivin *et al.*, 2012). These exchanges were characterised by long-distance movements of various elements, including metallurgy, livestock, crops and so forth. The timing and geography of these exchanges are topics of ongoing inquiry. The period around 2000 BC was a dynamic period throughout Eurasia, with many areas (northwestern China included) receiving a variety of imports at roughly the same time. Recently, considerable interest has focused on the pathway between east and west Eurasia offered by the Hexi Corridor and the articulation of this pathway with the upper reaches of the Yellow River before and after 2000 BC. It is because the early Chinese bronze objects, wheat and barley remains, sheep/goat and cattle bones and so on, which were first found in southwest Asia, appeared in this region during roughly the same period (before and after 2000 BC). These cultural elements are thought to be imports from the west, although this is debated. A crucially important cultural complex for this region and epoch is the Qijia culture, which was named after the type site of Qijiaping (Figure 1). Qijiaping was first excavated in 1924 (Andersson, 1943). It was excavated again in 1975 and yielded human and animal skeletons, pottery, stone and bone tools, and an early Chinese bronze mirror (Sun & Han, 1997; Chen *et al.*, 2012). The skeletal collections provide us an opportunity to explore a central element of trans-Eurasian exchange: the exchange of eastern and western cereals, primarily Asian millets from the east,

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Figure 1. The location of Qijiaping and other sites mentioned in the text. (1) Dadiwan (Barton *et al.*, 2009), (2) Zongri (Cui *et al.*, 2006), (3) Lajia (Zhang, 2006), (4) Qijiaping and (5) Shangsunajia (Zhang *et al.*, 2003).

and wheat and barley from the west. These two groups of cereals (millet versus wheat and barley) have contrasting photosynthetic pathways (C_4 versus C_3) and consequently different stable carbon isotope signatures in the bones of their consumers.

During the second millennium BC, the Qijia culture occupied an area covering today's east and middle Gansu and east Qinghai provinces of China. Previous accounts of the Qijia material culture have highlighted various traits reflecting western influences, particularly the appearance of bronze objects (Sun & Han, 1997; Mei, 2003).

The subsistence of the Qijia culture is thought to have been based on millet cultivation and the raising of livestock, including pig, sheep/goat and cattle and supplemented by hunting and gathering (e.g. Wu, 1990; Shui, 2001; Flad *et al.*, 2007). However, the evidence for this derives largely from intensive excavations of cemeteries and thus may not reflect daily life (Xie, 2002, 112–136; Shelach, 2009, 49–50). Archaeobotanical and zooarchaeological research has a relatively short history in northwest China, with only a limited number of macrofossil assemblages from Qijia settlements published to date (e.g. Li *et al.*, 2007; An *et al.*, 2010; Zhao, 2010; Zhang, 2012; Jia *et al.*, 2013). In each case, broomcorn and foxtail millet have been reported in large quantities. Although Chinese millets dominate most Qijia period archaeobotanical assemblages, wheat and barley are also present in second millennium BC assemblages from Gansu and Qinghai provinces (Flad *et al.*, 2010; Jia, 2012; Zhang, 2012).

In this study, we report the results of stable isotope analysis of human and animal bone samples from the type site of the Qijia culture in Qijaping. We aim to (i) assess the probable composition of human and animal diets at Qijiaping and (ii) evaluate the dietary importance of staple cereals (i.e. millet, wheat and barley).

Study site

Qijiaping (Figure 1), the type site of the Qijia culture, covers an area of 0.12 km^2. It is located on a terrace above the Tao River in Guanghe County, Gansu Province, with cultural deposits between 0.5 and 1.5-m thick (Bureau of National Cultural Relics, 2011). The site is of outstanding interest for the Qijia culture because of the presence of both settlement and burial evidence.

Qijiaping was excavated in 1924 and 1975, but no details of the latter excavation (1975) were published. Analysis of the human bones recovered indicated that 63 of the human burials have associated burial details, whereas 29 do not have contextual information

(Wei Meili, personal communication). Animal bones were sampled from trench T31② and from one grave (T16M96). These animal bones were identified as domesticated forms of pigs, cattles and dogs. Two horse bones were also identified, but it is not clear whether they are wild or domesticated.

Stable carbon and nitrogen isotopes and dietary reconstruction in north China

Body tissues are constructed from the food and drink consumed during one's lifetime. Stable isotope ratios in bone collagen reflect the average isotopic composition of an individual's dietary intake over a period of years (Schwarcz & Schoeninger, 1991; Ambrose, 1993). Carbon stable isotope values ($\delta^{13}C$) are generally used to provide information on a diet's ecological basis, which is either C_3 versus C_4 ecosystems (Van Der Merwe & Vogel, 1978) or marine versus terrestrial food webs (Schoeninger & DeNiro, 1984). Archaeologists generally use $\delta^{13}C$ values from humans and animals to establish broad patterns of dietary change (C_3 versus C_4 foodstuffs or marine versus terrestrial foodstuffs) in space and time, as well as to compare diets between individuals. Millets, the main C_4 cereals in north China, have distinct $\delta^{13}C$ values compared with the natural vegetation, which is dominated by C_3 plants and other C_3 cereals (e.g. wheat, barley and rice) because of the different mechanisms of CO_2 uptake during photosynthesis.

Nitrogen isotopic ratios ($\delta^{15}N$) reflect the position of an individual in the food chain and provide an estimate of the proportion of protein in the diet because $\delta^{15}N$ values increase with trophic level. The $\delta^{15}N$ offset between the bone collagen of a consumer and its prey is approximately 3‰–5‰ (Bocherens & Drucker, 2003) and may reach around 6‰ (O'Connell *et al.*, 2012). However, interpreting nitrogen isotopic ratios is complicated by many other factors, such as manuring, nursing, aridity, consumer physiology and nutritional stress (Ambrose & DeNiro, 1987; Ambrose, 1991; Hobson *et al.*, 1993; Mays *et al.*, 2002; Fuller *et al.*, 2005; Bogaard *et al.*, 2007).

Stable isotopic analysis has been used in dietary reconstruction to address various topics related to early agriculture in north China. These topics include identifying domestication (Barton *et al.*, 2009; Atahan *et al.*, 2011a) and intensified cereal consumption (Barton *et al.*, 2009; Atahan *et al.*, 2011b; Liu *et al.*, 2012). Studies on these topics are relatively rare in west China, especially for sites that date to the second millennium BC. This research attempts to explore subsistence practices at Qijiaping by reconstructing human and animal diets through the use of stable isotope analysis.

Materials and methods

Sample selection

All samples in this study are from the Qijiaping site (listed in Tables 1 and 2). There are 42 human (34 adults and eight subadults younger than 16 years of age) and 19 animal (nine pigs, two dogs, two horses and six cows) samples. All human samples were taken from the best preserved bones (see Table 1 for the skeletal element selected).

Two human bone samples were selected for accelerator mass spectrometry radiocarbon dating (Table 3). The analysis was conducted in the Laboratory of Quaternary Geology and Archaeological Chronology at Peking University, Beijing. All dates were calibrated by Calib6.02 programme (Stuiver & Reimer, 1993; Stuiver *et al.*, 2005) with the IntCal09 curve (Reimer *et al.*, 2009).

Collagen preparation and analysis

Bone collagen was extracted according to the method described in Richards & Hedges (1999) with some modifications. Bone fragments were cleaned of sediment and demineralized in 0.5 mol/L hydrochloric acid (HCl) at 5 °C. The HCl solution was refreshed every 2 days until the bone was soft and no effervescence was observed. Samples were rinsed with distilled water, soaked in 0.125 mol/L NaOH for 20 h and then rinsed again with distilled water. Thereafter, the samples were gelatinized in an acidic solution (pH 3) at 75 °C for 48 h and filtered. Finally, the liquid samples were freeze-dried to obtain the 'collagen'.

All collagen samples were isotopically analysed in triplicate with an automated carbon and nitrogen analyzer coupled in continuous-flow mode to a Finnigan MAT 253 mass spectrometer (Finnigan, Germany) at the Godwin Laboratory, University of Cambridge. The carbon and nitrogen isotopes were measured relative to Vienna Pee Dee Belemnite and atmospheric nitrogen standards, respectively. The analytical precision on the results of samples repeated in triplicate was better than 0.2‰.

Differences in mean isotope values among age groups and different sites were determined with Mann–Whitney tests. The significance level was set at $p < 0.05$. All statistical analyses were performed with SPSS15.0 for Windows (SPSS, USA).

Table 1. Bone collagen carbon and nitrogen isotopic results for humans from Qijiaping

Lab code	Provenience, age (years)	Skeletal element	Col wt. %	C wt. %	N wt. %	C : N	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰
QJP211	M10-1, 45–50	Rib	14.6	51.0	18.6	3.2	−9.6	9.8
QJP212	M10-2, 20–25	Clavicle	6.9	44.7	16.4	3.2	−9.1	9.8
QJP214	M22-1, adult	Phalanx	13.4	43.6	16.0	3.2	−7.5	9.0
QJP215	M22-4-1, 40–50	Radius	13.9	42.4	15.5	3.2	−8.2	10.0
QJP217	M22-4-4,adult	Femur	8.0	44.2	16.2	3.2	−8.4	9.3
QJP218	M25-1, ~40	Mandible	12.2	42.8	15.6	3.2	−10.7	9.6
QJP219	M89-1, 18–22	Tibia	14.0	46.6	17.2	3.2	−8.6	9.2
QJP220	M89-2, adult	Tibia	12.4	46.8	17.1	3.2	−8.4	9.2
QJP222	M95-1, adult	Ulna	9.5	46.7	17.1	3.2	−8.1	9.3
QJP223	M95-2, adult	Ulna	3.5	45.2	16.6	3.2	−11.0	9.6
QJP225	M98-1, adult	Radius	13.7	44.3	16.3	3.2	−8.7	10.0
QJP227	M99, 18–20	Ulna	13.1	47.3	17.2	3.2	−8.4	9.0
QJP228	M100-1, adult	Femur	7.0	44.3	16.2	3.2	−8.7	10.6
QJP229	M100-2, adult	Tibia	9.3	44.3	16.4	3.2	−8.2	9.6
QJP230	M103, adult	Pelvis	14.9	44.8	16.3	3.2	−8.2	10.3
QJP232	M104-2, adult	Femur	16.6	46.5	17.0	3.2	−10.4	14.1
QJP233	M105-1,adult	Femur	7.2	46.4	17.0	3.2	−8.8	9.8
QJP235	M108-1-1, adult	Humerus	4.6	42.5	15.7	3.2	−8.7	8.9
QJP236*	M108-2, adult	Femur	15.8	45.9	16.8	3.2	−8.8	11.3
QJP237	M108-4-1, adult	Tibia	15.2	44.4	16.3	3.2	−8.0	9.7
QJP238	M108-4-2, adult	Tibia	11.7	46.5	17.0	3.2	−8.0	9.8
QJP239	M109, 20–15	Ulna	11.8	44.0	16.2	3.2	−8.4	9.8
QJP240	M110-1-1, adult	Long Bone	15.4	43.5	15.9	3.2	−13.4	12.1
QJP241	M110-1-2, 20–15	Tibia	5.5	50.6	18.5	3.2	−9.7	10.0
QJP243	M110-1-4, adult	Femur	10.4	48.9	17.8	3.2	−8.7	10.1
QJP244	M110-2-2, adult	Radius	15.2	47.8	17.5	3.2	−8.9	9.9
QJP245	M110-3-1, adult	Radius	4.4	44.8	16.4	3.2	−8.6	9.8
QJP246	M110-3-2, adult	Femur	2.8	45.3	16.6	3.2	−8.7	9.6
QJP247	M110-5-1, adult	Femur	9.7	46.0	16.8	3.2	−8.7	9.0
QJP248	M110-5-2, adult	Humerus	10.9	46.6	17.0	3.2	−8.5	9.7
QJP249	M110-6-1, adult	Humerus	12.7	42.7	15.8	3.2	−8.6	10.0
QJP250	M110-6-2, adult	Humerus	10.3	45.8	16.8	3.2	−8.1	9.4
QJP251	M110-7-3, adult	Ulna	8.4	44.0	16.2	3.2	−8.8	10.1
QJP252	M111, 18–20	Humerus	1.3	42.1	15.6	3.2	−10.3	8.9
QJP213	M10-3, 13–14	Mandible	13.1	46.0	16.8	3.2	−7.7	9.4
QJP216	M22-4-2, juvenile	Long Bone	5.1	44.3	16.2	3.2	−8.9	9.3
QJP221	M90-1, 12–16	Tibia	9.0	41.7	15.3	3.2	−8.4	9.7
QJP224	M96-1, 11–13	Radius	4.9	43.8	16.2	3.1	−8.6	9.2
QJP234	M105-2, 11–16	Femur	3.4	43.8	16.0	3.2	−9.4	10.1
QJP242	M110-1-3, 7–8	Tibia	3.7	47.4	17.3	3.2	−8.0	10.0
QJP231	M104-1, juvenile	Tibia	6.0	46.1	16.9	3.2	−9.4	9.0
QJP226	M98-2, juvenile	Humerus	5.7	44.9	16.4	3.2	−7.6	9.4

*The sample is used for radiocarbon dating. Half of the bone was sent for dating and then measured the isotopes on the other half.

Results and discussion

Sample preservation and chronology

Isotopic data, collagen quality indicators and basic information on the sampled individuals are shown in Tables 1 (humans) and 2 (animals), and are summarised in Table 4. The collagen of all samples was well preserved, with atomic C : N ratios of 3.1 to 3.2 ($n = 61$, DeNiro, 1985; Ambrose, 1990;). Collagen contents varied from 1.6% to 16.6%, with 53 of 61 samples yielding more than 5% and thus indicating that all samples are well preserved (Ambrose, 1990, 1993).

The two radiocarbon dates show that the Qijiaping settlement was dated from 1515 cal BC to1264 cal BC at 1 sigma (Table 3). The pottery assemblage indicates that the settlement was occupied for a short period (Wei Meili, personal communication). The excavation report of Qijiaping is in preparation and will be published in the future.

Animal analysis

Stable isotope analysis of animal bones provides a baseline to understand the food web (Figures 2 and 3). The 19 animal results are presented in Tables 2 and 3 and are plotted in Figures 2 and 3. Herbivore $\delta^{15}N$ values fall within a narrow range from 6.7‰ to 8.5‰ (mean = 7.4 ± 0.7‰). The $\delta^{15}N$ values of dogs and pigs have a range of 6.0–8.7‰ with a mean of 7.4 ± 0.7‰.

Table 2. Bone collagen carbon and nitrogen isotopic results for animals from Qijiaping

Lab code	Species	Skeletal element	Col wt. %	C wt. %	N wt. %	C : N	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰
QJP253	Pig, subadult	Scapula	13.2	47.5	17.3	3.2	−8.0	8.1
QJP254	Pig, subadult	Skull	12.6	46.5	17.0	3.2	−8.3	7.6
QJP262	Pig, subadult	Mandible	11.1	47.5	17.3	3.2	−9.2	7.1
QJP263	Pig, subadult	Mandible	8.0	47.2	17.1	3.2	−7.1	8.7
QJP255	Pig, adult	Tibia	15.0	43.4	16.0	3.2	−17.5	6.0
QJP256	Pig, adult	Pelvis	11.8	46.0	16.8	3.2	−7.9	7.3
QJP257	Pig, adult	Mandible	13.9	48.8	17.8	3.2	−10.0	7.4
QJP264	Pig, adult	Skull	13.9	47.1	17.1	3.2	−9.8	7.2
QJP265	Pig, adult	Pelvis	12.4	46.5	17.0	3.2	−13.0	7.2
QJP270	Dog	Mandible	16.0	45.0	16.5	3.2	−10.7	7.6
QJP271	Dog	Mandible	11.9	43.2	15.8	3.2	−10.2	7.6
QJP266	Horse	Radius	14.7	44.9	16.5	3.2	−16.3	6.7
QJP267	Horse	Pelvis	15.4	44.7	16.4	3.2	−17.4	8.5
QJP258	Cattle	Skull	16.1	45.9	16.8	3.2	−16.1	7.1
QJP259	Cattle	Radius	12.7	41.6	15.3	3.2	−17.2	7.7
QJP260	Cattle	Pelvis	16.5	44.4	16.2	3.2	−17.8	8.2
QJP261	Cattle	Tibia	15.2	44.3	16.3	3.2	−15.8	6.9
QJP268	Cattle	Phalanx III	15.8	46.3	17.0	3.2	−17.4	6.7
QJP269	Cattle	Mandible	13.9	46.7	17.1	3.2	−13.0	6.9

Three groups could be observed in the animal $\delta^{13}C$ values (Figure 2 and Table 2) and thus reflect three diets: predominantly C_3, mainly C_4 and mixed C_3 and C_4. With the exception of sample QJP269, all herbivore (five cows and two horses) $\delta^{13}C$ values fall between −17.8‰ and −15.8‰, suggesting a predominantly C_3 plant-based diet for these animals. Only one pig exhibited a predominantly C_3 plant-based diet (QJP255, $\delta^{13}C = -17.5$‰). By contrast, seven out of nine pigs and two dogs consumed largely C_4 diets (with carbon isotope values ranging from −10.7‰ to −7.1‰). One cow and one pig, which have the same $\delta^{13}C$ value (−13.1‰), have mixed C_3 and C_4 diets. These dietary contrasts could have resulted from differences in access to food resources between free-ranging and deliberately fed domesticated animals, whose isotopic signatures have been discussed adequately elsewhere (Barton *et al.*, 2009). The predominately C_3 plant eaters might have ranged free and consumed wild foods because C_3 plants dominate the natural vegetation of north China (Gu *et al.*, 2003; Auerswald *et al.*, 2009; Liu *et al.*, 2011). Significantly, the C_4 food eaters are likely to have been provisioned with millet, a result implying that the dogs and pigs were incorporated into the millet-based economy. The mixed C_3 and C_4 food eaters may have ranged free and consumed both wild and domesticated foods, including domesticated and wild millets. The $\delta^{15}N$ average in the young pigs is 0.9‰ higher than that in adult pigs. Their consumption of maternal milk is likely responsible for this slight elevation (e.g. Fuller *et al.*, 2006).

Overall diet of the Qijiaping population

Data for the human sample are presented in Tables 1 and 4 and are plotted in Figures 2 and 3. The human $\delta^{13}C$ values range from −13.4‰ to −7.5‰ ($n = 42$), with a mean of -8.9 ± 1.1‰. The $\delta^{15}N$ values range from 8.9‰ to 14.1‰ ($n = 42$), with a mean of 9.8 ± 0.9‰. The mean human $\delta^{15}N$ value, which is enriched by 2.4‰ relative to the herbivore $\delta^{15}N$ value, is less than the generally stated trophic level offset of 3–5‰ (Bocherens & Drucker, 2003). The human isotopic values at Qijiaping are generally consistent with a C_4 terrestrial diet (Figures 2 and 3). As millet grains dominate Qijia archaeobotanical assemblages at other sites (Zhao, 2010; Jia *et al.*, 2013), we can infer that the C_4 signal in human diets at Qijiaping came from the consumption of millet and from animals fed on millet.

Table 3. Radiocarbon dates from Qijiaping

Laboratory code	Material	Provenience	^{14}C Age (BP)	Calibrated range (cal BC) 1σ (68.2%)
BA120220	Human bone	M97	3050 ± 50	1393–1264
BA120221	Human bone	M108-2	3215 ± 40	1515–1440

Table 4. Summary of the Qijiaping isotopic data

		$\delta^{13}C$ (‰)			$\delta^{15}N$ (‰)		
Species	Number	Mean	SD	Range	Mean	SD	Range
Human	42	−8.9	1.1	5.9	9.8	0.9	5.3
Herbivore (horse and cattle)	8	−16.4	1.5	4.8	7.4	0.7	1.8
Omnivore (pig and dog)	11	−10.2	2.9	10.4	7.4	0.7	2.7

Subadults

The carbon and nitrogen isotopic values of subadult (i.e. individuals younger than 16 years old, n = 8) and adult (*n* = 34) humans were very similar (Table 1 and Figure 2). No significant isotopic differences were found between subadults and adults ($Z = -0.737$, $P = 0.461$ for $\delta^{13}C$ and $Z = -0.913$, $P = 0.361$ for $\delta^{15}N$), a result indicating that the dietary difference between subadults and adults is not statistically significant. The elevated trophic level of nursing infants as a result of consuming maternal milk was not observed at Qijiaping (Fogel *et al.*, 1989; Fuller *et al.*, 2006).

Human outliers

Three individuals of interest are QJP232, QJP240 and QJP236 (marked on Figure 3). These adult individuals show elevated $\delta^{15}N$ values of 14.1‰, 12.1‰ and 11.3‰, respectively. The values for QJP232 and QJP240 are considered extreme outliers, because the distances between them (the values of QJP232 and QJP240) and quartile 3 (10.0‰) are more than triple the interquartile range (0.7‰). QJP236 is an outlier, because the distance from it to the quartile 3 (10.0‰) is within 1.5 to 3 times of interquartile range (0.7‰). No physical anomalies were observed in the bones of the three individuals. The grave goods from the three burial sites are no different from those in the rest of the cemetery. The $\delta^{15}N$ value of sample QJP236, which showed 3.9‰ enrichment relative to the mean herbivore $\delta^{15}N$ of 7.4‰, is within the offset of 3–5‰ between humans and herbivores. This individual most likely consumed a larger amount of C_4 animal protein than the other individuals analysed.

Samples QJP232 and QJP240 display extremely high $\delta^{15}N$ values 6.7‰ and 4.7‰ greater than the mean herbivore $\delta^{15}N$. The enrichment of 6.7‰ (QJP232) is too high to be interpreted as the difference of a single trophic level. Consumption of freshwater fish could result in high $\delta^{15}N$ values. However, the few isotopic results from north Chinese archaeological fish show a $\delta^{13}C$ value of −24.9‰, which makes the consumption of large amounts of freshwater fish unlikely (Hu *et al.*, 2008). In the absence of fish bones

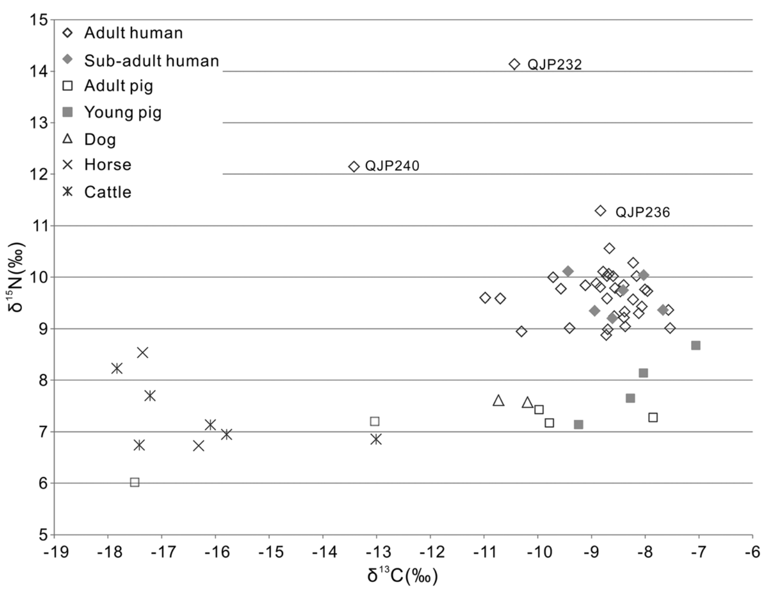

Figure 2. Human and animal bone collagen carbon and nitrogen isotopic values from Qijiaping.

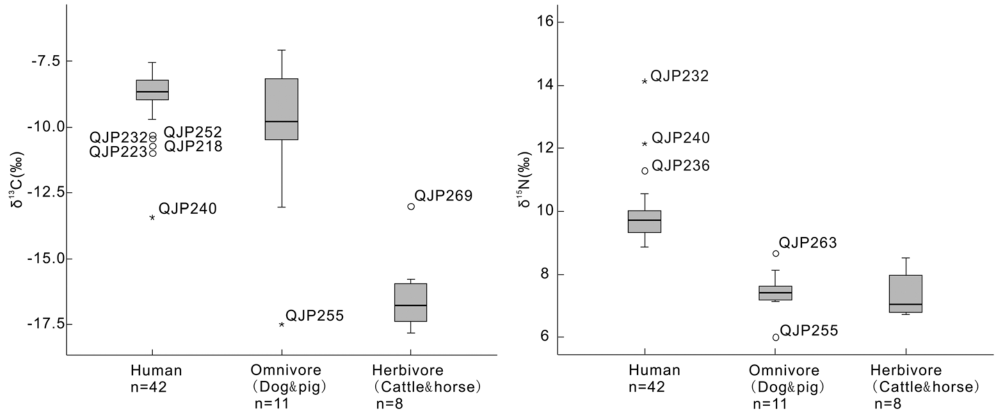

Figure 3. Box plots comparing δ13C and δ15N values of humans, omnivores and herbivores at Qijiaping.

for analysis, entirely excluding freshwater fish as a dietary input is not possible. Nevertheless, the isotopic evidence, together with the regional archaeobotanical dataset (e.g. Flad *et al.*, 2010; Zhao, 2010; Jia, 2012; Jia *et al.*, 2013), indicates that the most parsimonious explanation for the isotopic results of samples QJP232 and QJP240 is their consumption of mainly C_4 and mixed C_3/C_4 diets, respectively.

Some studies (e.g. Haubert *et al.*, 2005; Mekota *et al.*, 2006) have found that starvation can elevate the δ^{15}N value of individuals. However, the δ^{15}N value of starvation diets presents approximately 1.5‰ enrichment relative to normal diets (Mekota *et al.*, 2006); this value is less than the 4.3 and 2.3‰ differences seen in the present case. Moreover, collagen reflects an average dietary protein intake over a period of 10–25 years (Manolagas, 2000). The existence of QJP232 and QJP240 on a starvation diet for such a length of time is therefore unlikely in the absence of supporting skeletal evidence (e.g. Garnett *et al.*, 1969; Rosling *et al.*, 2011).

Although stable carbon and nitrogen isotope ratios are not commonly used to trace human mobility, the most plausible theory is that both QJP232 and QJP240 moved from surrounding areas where people ate different diets. In this case, very dry conditions could be considered, such as those in the Hexi Corridor in west Gansu and Xinjiang, because plants in arid conditions have high δ^{15}N values (Sealy *et al.*, 1987; Hartman, 2011). These high δ^{15}N values are then passed up the food chain. As a result, humans living in dry conditions exhibit high δ^{15}N values.

Human collagen isotopes derived from several Bronze Age and early Iron Age sites in the arid region of China show higher δ^{15}N and lower δ^{13}C values than the mean human isotopic values from Qijiaping (Zhang *et al.*, 2003; Zhang & Li, 2006; Zhang *et al.*, 2009, 2010). The outliers from Qijiaping (samples QJP232 and QJP240), which exhibit high δ^{15}N and mixed δ^{13}C values, show an isotopic composition of human collagen that is close to that from the arid region (Figure 4). Therefore, the two individuals might not have been local but may have moved from other regions with dry conditions, such as the Hexi Corridor or Xinjiang. This mobility may have been related to the animals, cereals and other goods present in the region and may thus be another reflection of the interactions between regions, as discussed at the beginning of this paper. However, further studies that use other isotopes (e.g. oxygen and strontium) are necessary to characterise the isotopic baseline of Xinjiang and the Hexi Corridor and to confirm the migratory status of individuals in these areas.

Comparison with other sites in east Qinghai and middle Gansu

Stable carbon isotope analysis of human bones complements archaeobotany in tracking the development of millet agriculture in the Neolithic period in middle Gansu and east Qinghai provinces, which can be grouped into one cultural and environmental region at this time. Only a few studies have focused on palaeodietary reconstruction through stable isotope analysis of human bones from archaeological sites in this area. Therefore, comparing the data from the present study with previously published isotopic data from other prehistoric sites in northwest China is important to understand the development of millet agriculture and the level of consumption of C_3 cereals (wheat, barley, etc.). Figure 5 is a plot of human δ^{13}C values from five sites (Figure 1), namely, Dadiwan (Barton *et al.*, 2009) and Qijiaping in middle Gansu and Zongri, Lajia

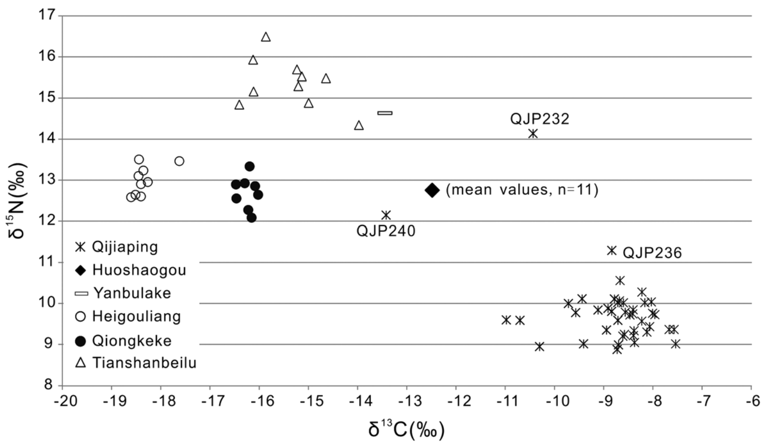

Figure 4. Human isotopic values at Qijiaping compared with those at other Bronze Age and earlier Iron Age sites in the arid region of China, such as the Hexi Corridor and Xinjiang (Zhang *et al.*, 2003; Zhang and Li, 2006; Zhang *et al.*, 2009, 2010).

and Shangsunjia in east Qinghai (Zhang *et al.*, 2003; Cui *et al.*, 2006; Zhang, 2006). The isotopic data are also shown in Table 5 and Figure 5.

Humans from the second phase (4300–3000 cal BC) at Dadiwan consumed varying amounts of millet ($n = 6$, $\delta^{13}C$ values between −14.2‰ and −6.5‰, with mean $\delta^{13}C$ value = −9.8 ± 3.0‰, Table 5 and Figure 5). This consumption pattern reflects that millet agriculture was established in this area from 4300 to 3000 cal BC (Barton *et al.*, 2009). Humans at Zongri ($n = 24$, mean $\delta^{13}C$ value = −10.1 ± 1.1‰, Table 5 and Figure 5) from 3200 to 2100 cal BC (Cui *et al.*, 2006) mainly consumed C_4 foods (most likely millet). This finding implies that millet agriculture had expanded to the northeast margin of the Qinghai-Tibet Plateau by that time. Lajia humans ($n = 12$, mean $\delta^{13}C$ value = −6.9‰, Table 5 and Figure 5) consumed large amounts of millet from 2400 to 1700 cal BC (^{14}CLASTERC IA CASS, 2003, 2005; Zhang, 2006), and this result indicates that millet was more important to the people at Lajia than it was to people in other places at earlier times. Subsequently, the degree of millet consumption in this area decreased slightly, with the human mean $\delta^{13}C$ values 2‰ less at Qijiaping (1500–1300 BC, $n = 42$, mean $\delta^{13}C$ value = −8.9 ± 1.1‰, Table 5 and Figure 5) than that at Lajia (2400– 1700 BC, $n = 12$, mean $\delta^{13}C$ value = −6.9‰). The isotopic results from Shangsunjia ($n = 18$, mean $\delta^{13}C$ value = −16.1 ± 1.3‰, Table 5 and Figure 5) in the subsequent millennium (IA CASS, 1992; Zhang *et al.*, 2003) show that human diets in the study area shifted to include more C_3 resources (Qijiaping versus Shangsujia, $Z = -6.081$, $p < 0.001$). Flotation at other sites in east Qinghai suggests that these C_3 resources were barley and wheat (Jia, 2012).

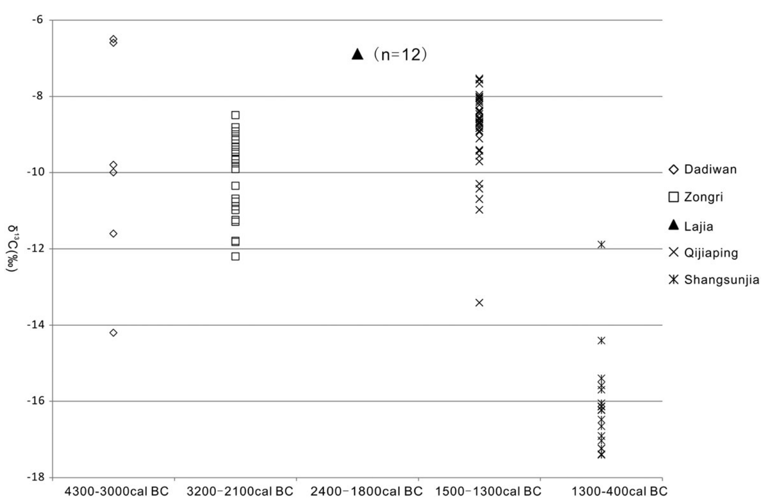

Figure 5. Human carbon isotopic values in this study compared with those of other sites in east Qinghai and middle Gansu (Zhang *et al.*, 2003; Cui *et al.*, 2006; Zhang, 2006; Barton *et al.*, 2009). Only mean isotopic values are available from the Lajia site (Zhang, 2006).

Table 5. Human collagen carbon and nitrogen isotopic results from sites in east Qinghai and middle Gansu

			$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
Site	Approximate date (cal BC)	N	Mean	SD	Range	N	Mean	SD	Range	Source
Dadiwan	4300–3000	6	−9.8	3.0	7.7	6	9.7	0.8	2.1	Barton *et al*., 2009
Zongri	3200–2100	24	−10.1	1.1	3.7	24	8.3	0.5	1.6	Cui *et al*., 2006
Lajia*	2400–1700	12	−6.9	—	—	11	10.3	—	—	^{14}CLASTERC IA CASS, 2003, 2005; Zhang, 2006
Qijiaping	1500–1300	42	−8.9	1.1	5.9	42	9.8	0.9	5.3	This study
Shangsunajia	1300–400	18	−16.1	1.3	5.5	2	8.8	0.9	1.2	IA CASS, 1992; Zhang *et al*., 2003

*The results from the Lajia site are only mean values.

The current evidence therefore suggests that wheat and barley agriculture was developed in middle Gansu and east Qinghai (the upper reaches of the Yellow River valley) after 1300 cal BC. Such a development came a little later than that of wheat agriculture in the Hexi corridor (at least as early as the first half of the second millennium BC at the Donghuishan site, Flad *et al*., 2010). This finding is consistent with the idea that C_3 staple cereals, wheat and barley were introduced from the western steppe regions through the Hexi Corridor. However, the lack of animal and plant isotopic baseline values compromises the assessment of the level of crops and animal protein consumed. Hence, it is not possible to exclude the possibility that there were some C_3 resources in animals' diets. Further studies on humans, animals and cereals from other late Neolithic and Bronze Age sites in Gansu and Qinghai will help address these issues.

Conclusion

The bone collagen $\delta^{13}C$ and $\delta^{15}N$ values for humans and animals from the Bronze Age at Qijiaping, middle Gansu indicate that throughout the period of use of the cemetery, human diet did not change significantly. Furthermore, no dietary differences on the basis of age were found. This diet can be characterised as one which was high in millet and animals fed on millet. C_3 plants (e.g. wheat and barley) did not significantly contribute to human diet. However, three human outliers were identified, and these were likely adult individuals who have been geographically mobile, probably from dry environments.

The data presented in this paper are the first for the Qijia culture in Gansu Province. This work is one of the few isotope palaeodiet studies that interpreted human isotopic data with animal isotope values from the same site in northwest China. The human outliers are interesting in relation to geographic mobility and regional interaction. Further studies will help determine whether these outliers relate to exogamy. Comparison with other sites indicates that the shift in isotopic signals (from C_4 to mixed C_3/C_4), which marked the change from millet eaters to millet, wheat and barley consumers, might have occurred around 1000 BC in the upper reaches of the Yellow River valley or later than the shift that occurred in the Hexi corridor. However, additional studies are needed to confirm this theory.

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