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Early Neolithic diets at Baijia, Wei River valley, China: stable carbon and nitrogen isotope analysis of human and faunal remains

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ABSTRACT

Stable carbon and nitrogen isotope values are presented for faunal and human bone collagen from Baijia, in the Wei River valley region of Shaanxi Province, China. The remains have a calibrated age range of ca. 5709–5389 BC, and correspond with the early Neolithic Laoguantai Period. Stable isotopic results indicate that human diets included millet and probably aquatic foods such as fish and shellfish. Bovid samples are tentatively identified as water buffalo, and have a mean $\delta^{13}C$ value of $-14.6‰$, which reflects some millet consumption. Whether bovids were grazing on wild millet, or had diets directly influenced by humans, is not known. The single *Sus* sample from Baijia had a diet dominated by C3 plants and is thus unlikely to have been a domesticated animal. Overall, the stable isotope results presented here conform to the current concept that the people of the Laoguantai culture were millet farmers, who had subsistence strategies that included hunted wild foods.

1. Introduction

The oldest cultivated millet remains reported to date come from the Cishan site (see Fig. 1), and date to ca. 10,300 cal yr BP (Lu et al., 2009). It seems an indigenous system of agriculture emerged at this time in the middle and lower reaches of the Yellow River valley, and was one centred on cultivating broomcorn (*Panicum miliaceum*) and foxtail (*Setaria italica*) millet. The Cishan remains predate other millet remains in northern China by about 2000 years; it is not until about 8000 years ago that millet farming is found at other sites: the Wei River valley (e.g. Dadiwan and Baijia sites); the middle Yellow River valley (e.g. Peligang site); the lower Yellow River valley (e.g. Xiaojingshan and Yuezhuang sites); and along the border of modern-day Inner Mongolia and Liaoning Provinces (e.g. Xinglonggou and Xinglongwa sites) (Bettinger et al., 2010; Lu et al., 2009). By this time the domestic pig (*Sus*) and chicken (*Gallus*) were included in the northern Chinese agricultural complex (Flad et al., 2007; Lee et al., 2007; Underhill, 1997) and current evidence points towards an original centre for pig domestication in the middle and lower reaches of the Yellow River valley (Cucchi et al., 2011; Larson et al., 2010).

The Neolithic of northern China contrasts with those of southwestern Asia and Mesoamerica by its continued emphasis on hunting as a means for food procurement (Bettinger et al., 2010). Hunting tools and faunal remains of wild taxa are reported at northern Chinese Neolithic settlement sites, and it appears that the Neolithic farmers were cultivating millet for duel purposes i) providing themselves with a reliable food source and ii) providing their hunting dogs with food (Barton et al., 2009; Bettinger et al., 2010).

The Wei River valley is a key region for understanding early agriculture in northern China, and the first farmers belonged to the Laoguantai period (ca. 8500–7000 BP), a time when settlements were composed of small groups of people and the regional population density was low (Bettinger et al., 2010). Only about 20 archaeological sites belonging to the Laoguantai period are known to date, this is much less than the subsequent Yangshao period (ca. 7000–5000 BP) for which there are about 1200 sites, and the Longshan period (ca. 5000–4000 BP) for which there are about 700 sites (Liu, 2004). Despite the scarcity of remains, the Laoguantai

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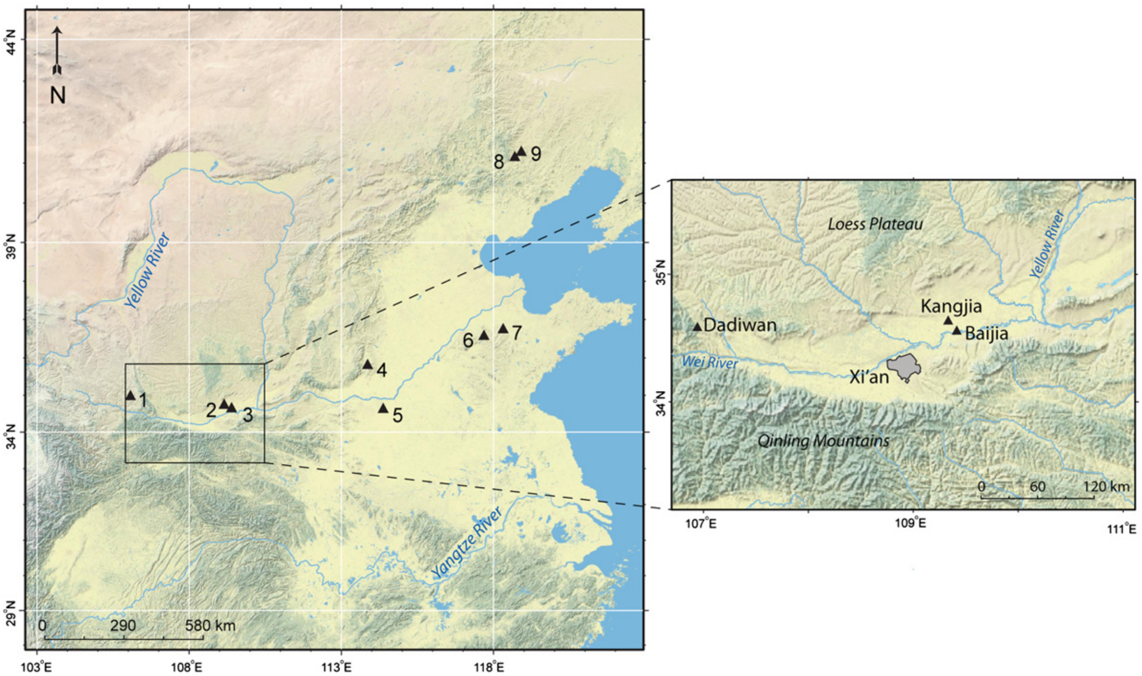

Fig. 1. Location of archaeological sites mentioned in the text: 1 Dadiwan; 2 Kangjia; 3 Baijia; 4 Cishan; 5 Peligang; 6 Yuezhuang; 7 Xiaojingshan; 8 Xinglongwa; 9 Xinglonggou.

period is regarded as a critical bridge between the highly mobile hunter-gatherer people that once inhabited northern China and the settled societies whose domesticates and agricultural fields are still farmed today.

1.1. Stable isotope analysis and diet reconstruction in northern China

Ratios of stable carbon and nitrogen isotopes in human and faunal remains are now commonly used to assess dietary patterns in ancient populations (see recent reviews by Hedges and Reynard, 2007; Lee-Thorp, 2008). The technique stems from the principle that the isotopic composition of bone collagen, or bioapatite, quantitatively reflects that of food consumed, after fractionation relating to the transfer of dietary components to animal tissue is accounted for (Ambrose and Norr, 1993; DeNiro and Epstein, 1978). The diet to collagen $\delta^{13}C$ offset is around 5‰ for herbivores consuming a plant diet. At higher trophic levels the offset is around 1–2‰ (Lee-Thorp, 2008; van der Merwe and Vogel, 1978), however considerable variation occurs between trophic levels when individual compounds are measured (see Grice et al., 1998; Grice and Brocks, 2011; Klein Breteler et al., 2002). In some cases the $\delta^{13}C$ of individual sterols, in copepods for example, show no isotopic enrichment with trophic level (Grice et al., 1998). The diet to collagen offset for $\delta^{15}N$ values is around 3–5‰ per trophic level (Bocherens and Drucker, 2003; Schoeninger and DeNiro, 1984).

The two main photosynthetic pathways used by plants—C3 and C4—lead to distinctly different carbon isotopic composition of plant tissue (see Grice and Brocks, 2011 for a review). In C4 photosynthesis, CO_2 is concentrated in bundle sheath cells prior to release into the ribulose bisphosphate carboxylase/oxygenase (Rubisco) cycle. C3 photosynthesis does not include this step, and as a result greater net discrimination of ^{13}C occurs in C3 photosynthesis (Farquhar et al., 1989; O'Leary, 1981). C4 plant bulk $\delta^{13}C$ values usually range from about −9 to −17‰, while C3 plant bulk $\delta^{13}C$ values range from about −24 to −36‰ (Deines, 1980; Lee-Thorp, 2008; Smith and Epstein, 1971; Tieszen, 1991). C4 plants are concentrated amongst the grasses and shrubs, and competition for light is a key factor that affects their distribution in temperate regions (Collatz et al., 1998; Sage et al., 1999). Where C4 plant growth is not limited by temperature (i.e. warmest month mean temperature $\geq \sim 22$ °C) tall vegetation characteristically outcompetes C4 plants unless other factors, such as limited water or nutrient levels or periodic flooding, limit the growth of taller plants (see Collatz et al., 1998; Sage et al., 1999).

The distinct carbon isotope composition of C3 and C4 plants, and consumer bone collagen, is useful for investigating cultivation histories of C4 plants. Cai and Qiu (1984) were the first to demonstrate the value of this technique for archaeological remains from northern China, where the $\delta^{13}C$ values of millet, which is typical of C4 plants, contrast markedly with the C3 plant dominated natural vegetation of northern China (Wang, 2003, 2005). High $\delta^{13}C$ values in skeletal remains from Neolithic sites in northern China have continued to be used as evidence for consumption of cultivated millet (see Barton et al., 2009; Fu et al., 2010; Hu et al., 2006, 2008; Pechenkina et al., 2005; Wang, 2004).

The increase in $\delta^{15}N$ values of around 3–5‰ per trophic level (Bocherens and Drucker, 2003; Schoeninger and DeNiro, 1984) is thought to be mainly due to the preferential excretion of ^{14}N in waste products, such as urea and uric acid (Kendall, 1998; Steele and Daniel, 1978). As food chains are typically longer in aquatic ecosystems compared with terrestrial ecosystems, the $\delta^{15}N$ values of aquatic organisms are generally higher (Minagawa and Eitaro, 1984). Consumption of aquatic organisms has been reported to result in human $\delta^{15}N$ values as high as 15‰ (e.g. Richards et al., 2006; Schoeninger and Moore, 1992). Primary producer $\delta^{15}N$ values vary widely however, in response to mechanisms associated with the nitrogen cycle. Plant $\delta^{15}N$ values can range from as much as −5 to 15‰ (Garten, 1993; Murphy and Bowman, 2009).

The relative amount and bioavailability of various sources of nitrogen, and the isotopic signature of those nitrogen sources, are the key environmental factors that lead to variation in $\delta^{15}N$ values of plants (Kendall, 1998). Denitrification involves the reduction of NO_3^- to N_2 or N_2O under anaerobic conditions, and results in a residual substrate that is enriched in ^{15}N (Koba et al., 1997; Korom, 1992). Denitrification is typically concentrated in soils of down-slope and water-logged areas, and is thought to be a key cause for the observed elevation of plant $\delta^{15}N$ values in these areas (Billy et al., 2010; Garten, 1993; Hartman and Danin, 2010; Kendall, 1998). Use of manure fertilisers is another factor that has been shown to elevate $\delta^{15}N$ values in soils and plants, as the greater rates of ammonia volatilisation from soil in these areas lead to a substrate enriched in ^{15}N (Bogaard et al., 2007; Kerley and Jarvis, 1996; Kreitler, 1979; Kriszan et al., 2009). Arid environments are also linked with higher plant $\delta^{15}N$ values, and this is thought to be due to the sparser or more 'open' nature of the vegetation and the resulting greater availability of soil nitrogen to plants (Austin and Vitousek, 1998; Heaton, 1987; Murphy and Bowman, 2006, 2009; Schuur and Matson, 2001; Schwarcz et al., 1999). The measurement of stable nitrogen isotopic composition in individual amino acids is a promising tool for identifying the cause of ^{15}N enrichment in organisms, and particularly for distinguishing when ^{15}N enrichment is caused by consumption of aquatic foods (see Naito et al., 2010; Styring et al., 2010). This tool is yet to be widely applied to palaeodietary investigations.

2. Study site

The Wei River is a large tributary of the Yellow River, flowing west to east across central Shaanxi Province. The Wei River valley follows the northern margin of the Qinling Mountains and marks the southern border of the Loess Plateau (Fig. 1). The climate of the region is suited to agriculture; the 570 mm/yr mean annual precipitation falls mostly during the warmer months and mean monthly temperatures range from about 26.6 °C in July to about 0 °C in January.

Baijia site lies north of the Wei River (34° 33′ 7.53″ N; 109° 24′ 38.60″ E), approximately 60 km northeast of Xi'an. Baijia is one of the larger archaeological sites belonging to the Laoguantai culture. Cultural remains unearthed at the site during its initial excavation include tools for preparing freshwater mussels, sickles for harvesting grain and plant remains which include millet (*P. miliaceum*) and rapeseed (*Brassica* sp.) (Institute of Archaeology (CASS), 1994). Of the faunal remains identified, those of pig and water buffalo (*Bubalus* sp.) were most abundant. Dog, chicken, fish, mollusc, red deer (*Cervus elaphus*), Chinese water deer (*Hydropotes inermis*), Mongolian gazelle (*Procapra gutturosa*), racoon (*Nyctereutes procyonoides*), cat (*Felis* sp.) and bamboo rat (*Rhizomys sinensis*) are also reported (Zhou, 1994). Initial radiocarbon dates yielded calibrated ages that ranged between 5640 and 4340 yr BC (Institute of Archaeology (CASS), 1991).

Two human skeletons from the site have been investigated previously by Wang Rui (2004). Bone collagen mean $\delta^{13}C$ and $\delta^{15}N$ values were −13.3‰ and 10.8‰ respectively, and this was reported to reflect diets composed of moderate proportions of millet as well as aquatic foods such as fish and shellfish (Wang, 2004).

3. Materials and methods

Faunal and human bone fragments were recovered from sediment samples taken from a 1.4 m deep exposed sediment profile at Baijia site during a visit in 2009. The sediment samples were transported to the laboratories of the Chinese Academy of Sciences in Xi'an, where they were searched for bone fragments and other fossils. It was possible to identify thirty two of the recovered bone fragments; these fragments were prepared for stable isotope analysis. Bone collagen from five samples was directly dated by AMS ^{14}C dating.

Bone collagen was prepared using the ultra-filtration method (Brock et al., 2007; Bronk Ramsey et al., 2004; Brown et al., 1988; Higham et al., 2006). About one gram of clean ground bone was used, with compact bone used whenever possible, and preparation involved removal of the outer bone surface by abrasion; acid-alkali-acid treatment (0.5M HCl, 0.1M NaOH); gelatinisation (pH 3, 75 °C, 20 h); Ezee-filtration (4–8 μm); ultra-filtration (30 kDa); and freeze-drying.

Stable isotopic analyses and AMS ^{14}C dating was carried out in the AMS chemistry laboratories at the Australian Nuclear Science and Technology Organisation (ANSTO). $\delta^{13}C$, $\delta^{15}N$, C%, N% and atomic C/N ratio were measured on an Elemental Analyser (EuroVector EA3000) and an Isotope Ratio Mass Spectrometer (GV Instruments IsoPrime). The reference materials used were: $\delta^{13}C$ − IAEA C8 oxalic acid with a consensus value of −18.3‰ VPDB (Gonfiantini et al., 1995; Le Clercq et al., 2006); $\delta^{15}N$ − IAEA N-3 with a consensus value $\delta^{15}NAIR = 4.7‰$ and IAEA N-2 with a consensus value of $\delta^{15}NAIR = 20.3‰$ (Bohlke and Coplen, 1995); 3:1 atomic ratio standard − Internal standard of 2-*iso*-propylimidazole; 'Chitin Organic Analytical Standard' with respective carbon and nitrogen values of 44.7% and 6.8% (Elemental Microanalysis Catalogue No. B2160); and an internal standard of undenatured bovine Achilles tendon collagen. Samples were run in duplicate and the analytical precision was 0.1‰ for $\delta^{13}C$ values and 0.2‰ for $\delta^{15}N$ values. AMS ^{14}C dating was carried out at ANSTO using the STAR Accelerator.

AMS ^{14}C dates were calibrated using Calib Rev 6.0.1 software and the INTCAL09 dataset (Reimer et al., 2009; Stuiver and Reimer, 1993). Statistical analyses were conducted using the R statistical package (Version 1.12.1) (R Development Core Team, 2010).

4. Results and discussion

4.1. Collagen preservation

The preservation of bone collagen in the Baijia samples was variable. Of the 32 samples prepared, 22 yielded collagen (Table 1). The quality of preserved collagen was assessed by comparing the collagen yield (% by weight), C%, N% and atomic C/N ratio of each sample with standard ranges that are considered to generally reflect acceptable preservation for carbon and nitrogen stable isotopic analysis (DeNiro, 1985; van Klinken, 1999). Of the bone samples yielding collagen, all produced acceptable C/N ratios, C% and N% measurements according to the standard ranges. Collagen yields were low overall, and four samples yielded less than 0.5% collagen by weight. Samples that are prepared using the ultra-filtration method have been found to yield lower proportions of collagen; due to the removal of small (<30 kDa) degraded collagen fragments (Jørkov et al., 2007). Therefore, as the four samples yielding less than 0.5% collagen produced C/N ratio, C% and N% within acceptable ranges, and had $\delta^{13}C$ and $\delta^{15}N$ values that were not outliers compared to other samples of the same taxa, these samples have been included in this study.

4.2. Radiocarbon dates

Radiocarbon dates on five bone collagen samples yielded calibrated ages that fell within a period of 320 years, from ca. 5709–5389 cal. BC (Table 2). This slightly predates the previously reported age range for Baijia site (ca. 5640–4340 cal. BC), and roughly corresponds with the previously reported age of faunal remains from the site (Institute of Archaeology (CASS), 1991; Zhou, 1994).

Table 1
Bone collagen, elemental and isotopic data for Baijia samples. * Samples dated by AMS ^{14}C (see Table 2).

Lab code	Taxon	% collagen (>30 kDa)	Carbon content (%)	Nitrogen content (%)	Atomic C/N	δ^{13}C	δ^{15}N
SI1596*	human	1.56	44	15	3.3	−14.5	11.1
SI1597	cervid (*Hydropotes* sp.)	0.35	43	15	3.2	−20.5	3.5
SI1598	cervid	0.98	44	15	3.3	−21.6	4.0
SI1599	cervid (*Capreolus capreolus*)	0	–	–	–	–	–
SI1600	cervid	0.23	44	15	3.3	−21.1	3.3
SI1601	cervid (*Cervus nippon* Temminck)	1.66	44	15	3.3	−18.8	4.1
SI1602	cervid	0	–	–	–	–	–
SI1603	cervid	1.82	44	15	3.3	−21.6	4.0
SI1604	cervid (*Hydropotes* sp.)	0.25	43	15	3.3	−21.6	3.8
SI1605	*Sus*	2.48	45	15	3.2	−21.7	4.9
SI1606	cervid (*Hydropotes* sp.)	0.87	43	15	3.2	−20.6	4.4
SI1607	cervid (*Hydropotes* sp.)	0	–	–	–	–	–
SI1608	cervid	0	–	–	–	–	–
SI1609	cervid	0.61	43	15	3.3	−20.0	5.2
SI1610	bovid	0.67	44	15	3.3	−14.1	5.4
SI1611	bovid	2.07	44	15	3.3	−13.6	5.4
SI1612	cervid	0	–	–	–	–	–
SI1613*	bovid	2.00	43	15	3.2	−16.3	6.6
SI1614	*Gallus*	0.85	45	15	3.3	−15.5	6.5
SI1615	cervid	0.55	45	16	3.3	−21.5	5.0
SI1616	cervid	2.84	45	16	3.2	−17.4	4.2
SI1618	cervid	2.36	43	15	3.2	−21.7	4.0
SI1619	cervid (*Hydropotes* sp.)	0	–	–	–	–	–
SI1620*	bovid	1.34	44	15	3.3	−14.0	5.1
SI1622	cervid (*Hydropotes* sp.)	0.64	44	15	3.3	−21.1	5.0
SI1623	cervid	0	–	–	–	–	–
SI1624*	bovid	3.47	44	16	3.2	−15.2	5.8
SI1625	cervid	0	–	–	–	–	–
SI1626	cervid (*Cervus nippon* Temminck)	0.18	43	14	3.3	−19.3	5.6
SI1627	cervid (*Hydropotes* sp.)	0	–	–	–	–	–
SI1628	cervid	0	–	–	–	–	–
SI1629*	cervid	1.08	45	16	3.2	−21.9	3.8

4.3. Wild faunal samples

A dominance of C3 plants in the diets of cervids is indicated by their low δ^{13}C values (mean = −20.6 ± 1.3‰) and confirms the dominance of C3 plants in the vegetation surrounding Baijia. Low δ^{15}N values for the cervid samples (mean = 4.3‰ ± 0.7) reflects their herbivorous diet. The single *Sus* sample yielded isotope values similar to those of the cervids (δ^{13}C value −21.7‰; δ^{15}N value = 4.9‰) (Fig. 2), indicating that it also consumed predominantly C3 plants. High C3 plant consumption is observed in roughly contemporaneous *Sus* from Dadiwan site; about 300 km to the west (see Barton et al., 2009). Barton et al. (2009) suggest that the absence of millet in the diets of these Dadiwan *Sus* reflects their pre-domesticated existence. The Baijia *Sus* is similarly unlikely to have been a domestic animal.

4.4. Human samples

The stable isotope values for the human sample presented here, together with stable isotope values for two human samples from Baijia previously reported by Wang (2004), comprise the existing isotopic information for human remains of the Laoguantai culture.

Table 2
Radiocarbon ages for bone collagen collected from Baijia site.

Lab code	Taxon	Sample type	AMS ^{14}C age (BP)	Calibrated age range (2σ)
OZN207	human	bone collagen	6710 ± 40	5709–5558 BC
OZN208	bovid	bone collagen	6560 ± 35	5609–5475 BC
OZN209	bovid	bone collagen	6600 ± 35	5616–5484 BC
OZN210	cervid	bone collagen	6545 ± 40	5614–5389 BC
OZN322	bovid	bone collagen	6655 ± 40	5641–5494 BC

The human δ^{15}N value presented here (11.1‰) lies within the range of those reported by Wang (2004) (12.0‰ and 9.7‰) and the mean of all three human samples is 6.2‰ higher than the mean δ^{15}N value for faunal samples from Baijia. A ^{15}N enrichment of this magnitude can be explained by the consumption of aquatic organisms, and the recovery of freshwater mussel remains, and tools for preparing them, from the site supports this conclusion (Institute of Archaeology, 1994; Zhou, 1994). When compared with human bone collagen from other archaeological sites in the Wei River valley, the Baijia human δ^{15}N values appear high (see Table 3).

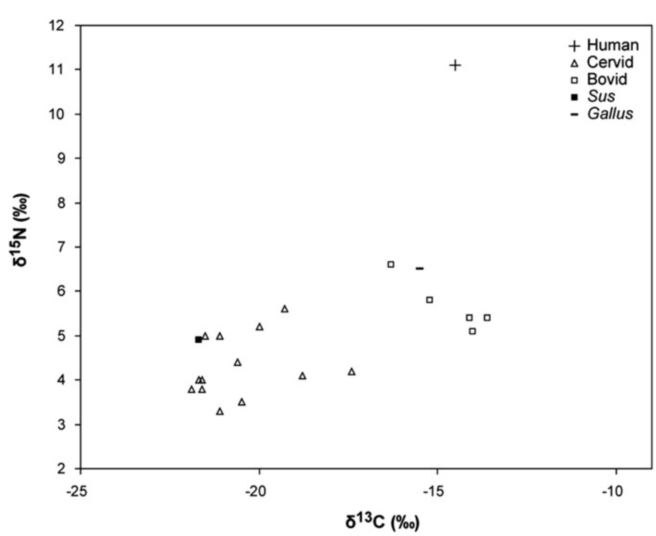

Fig. 2. δ^{13}C and δ^{15}N values for faunal and human bone collagen from Baijia site.

Table 3
Mean $\delta^{13}C$ and $\delta^{15}N$ values for human bone collagen from sites in the Wei River valley.

Site	Sample size	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	Associated culture or calibrated age range	Reference
Baija	2	−13.3 ± 1.8	10.8 ± 1.7	Laoguantai	Wang, 2004
Dadiwan	6	−9.8 ± 3.0	9.7 ± 0.8	Yangshao	Barton et al., 2009
Jiangzhai	8	−9.7 ± 0.9	9.1 ± 0.6	Yangshao	Pechenkina et al., 2005; Wang, 2004
Shijia	9	−10.0 ± 0.7	8.1 ± 0.4	Yangshao	Pechenkina et al., 2005
Banpo	5	−14.8 ± 1.9	9.1[a]	Yangshao	Cai and Qiu, 1984; Pechenkina et al., 2005
Yuan Junmiao	1	−18.5	11.0	Yangshao	Wang, 2004
Beishouling	3	−13.8 ± 0.9	–	Yangshao	Cai and Qiu, 1984
Taosi	5	−11.3 ± 1.2	–	Longshan	Cai and Qiu, 1984
Huxizhuang	1	−13.7	–	Longshan	Cai and Qiu, 1984
Xujianian	1	−11.1	–	925–665 BC	Cai and Qiu, 1984

[a] Measurement only taken on one of the samples.

Aquatic resources might have been unusually important at Baijia, at least compared with most of the other sites where isotopic analysis has been conducted.

The $\delta^{13}C$ value of the human reported here (−14.5‰) is similar to the two values previously reported by Wang (2004) for Baijia human bone collagen (−14.6‰ and −12.1‰) and reflects diets composed of both C3 and C4 plants, and foods from animals feeding on both C3 and C4 plants. The single *Gallus* bulk $\delta^{13}C$ value of −15.5‰ indicates that the bird's diet was composed of a similar mix of C3 and C4 foods. It is apparent that cultivated millet was being consumed by several animals at Baijia. The precise proportion of millet in the diets is difficult to estimate however, as the stable isotopic signatures of all food sources in the area at the time, and particularly those of aquatic foods, are unknown. The millet consumption of Baijia humans may be comparable to that of the Yangshao humans studied at Banpo and Beishouling archaeological sites, where human $\delta^{13}C$ values average −14.8 ± 1.9‰ and −13.8 ± 0.9‰ respectively (Pechenkina et al., 2005). Humans at other Yangshao sites, however, appear to have consumed considerably more millet. At the Yangshao Jiangzhai and Shijia sites, mean human bone collagen $\delta^{13}C$ values are −9.7 ± 0.9‰ and −10.0 ± 0.7‰, respectively (Pechenkina et al., 2005). At Dadiwan site, similarly elevated human bone collagen $\delta^{13}C$ values (mean = −9.8 ± 0.8‰) also suggest higher millet consumption compared with Baijia. Conversely, a low $\delta^{13}C$ value is reported for a single human sample from Yuan Junmiao site (−18.5‰) (Wang, 2004), which suggests that millet was consumed only in minor amounts there, if at all.

The evidence for a human diet at Baijia that included millet as well as aquatic resources is based on only a small number of samples, but it does conform with the view of Laoguantai people being low-level millet producers who gained substantial amounts of food by hunting (Barton et al., 2009; Bettinger et al., 2010). Previous work shows millet cultivation to intensify in the Wei River valley in the Yangshao Period (Huang et al., 2000; Li et al., 2009a, 2009b), and the Baijia human bulk $\delta^{13}C$ values support this by lying at the lower end of the range produced by Yangshao humans, excluding the single human sample from Yuan Junmiao site (Pechenkina et al., 2005; Wang, 2004). On the whole, isotopic information shows millet consumption at Laoguantai and Yangshao sites to vary from low to high levels. Wild food availability undoubtedly varied between sites, particularly availability of aquatic foods such as fish and shellfish, and this is perhaps behind the heterogeneous pattern of millet consumption observed in the Wei River valley. As stable isotope techniques, coupled with AMS ^{14}C dating, are applied to more early Neolithic archaeological sites in the Wei River valley, a more detailed understanding will emerge of the increasing intensification of millet farming in this early agricultural region of northern China.

4.5. Bovid samples

Morphological examination was unable to assign a high taxonomic level to the bovid specimens collected for this study. Early investigation of the Baijia bovid remains used morphological characteristics to identify them as domestic water buffalo (*Bubalus bubalis*) (Zhou, 1994). However, subsequent re-analysis of those remains, and remains from other sites in the Wei River valley, reclassified them as the now extinct species *Bubalus mephistopheles* (Liu, 2004; Flad et al., 2007). This identification has been confirmed by a later study of D-loop mitochondrial DNA sequences (Yang et al., 2008). The bovid remains collected for this study are tentatively assigned to the same taxa. The range of water buffalo in China presumably extended further northwards than present during the Neolithic period, when conditions in Northern China were warmer and wetter (An et al., 2000; Liu, 2004; Feng et al., 2006). A northwards expansion in range at this time is noted for a suite of species that currently occur in warmer regions, to the south of the Wei River valley (Tong, 2007).

The mean bovid bulk $\delta^{15}N$ value of 5.7 ± 0.6‰ is significantly higher than that of the cervids' according to a Welch's two-sample *t*-test ($t = -4.36$, df = 8.21, $P < 0.01$). Difference in grazing or browsing areas may account for the isotopic offset, as water buffalo are common in areas near to water, such as river floodplains, marshes and swamps (Nowak, 1999; NRC, 1984). Plants growing in down-slope or water-logged areas tend to have elevated $\delta^{15}N$ values compared with better drained, up-slope areas (Billy et al., 2010; Garten, 1993; Hartman and Danin, 2010; Kendall, 1998), and water buffalo feeding on these plants would thus be expected to have $\delta^{15}N$ value that are similarly elevated. Elevated $\delta^{15}N$ values in herbivores from archaeological sites in Britain and Germany have previously been attributed to grazing in wetland areas (Britton et al., 2008; Oelze et al., 2011).

The mean bovid bulk $\delta^{13}C$ value (−14.6 ± 1.1‰) is markedly higher than that of the cervids, indicating their greater consumption of C4 plants, which in this area is almost certainly millet. Similar $\delta^{13}C$ values are reported for two water buffalo samples from nearby Kangjia site (−14.20‰ and −15.11‰), which date to the Longshan period (Pechenkina et al., 2005). In this temperate region, wild millet growth would concentrate in areas of broken canopy cover, in swamps or along river and lake banks for example, or in areas where human activities disturb natural vegetation and reduce the extent of taller plants (Collatz et al., 1998; Sage et al., 1999). Wild millet plants colonising these areas may account for the elevated bulk $\delta^{13}C$ values of the bovids investigated here. However, humans provisioning them with millet fodder or permitting their grazing on millet stubble in fields could also account for the elevated bulk $\delta^{13}C$ values. In light of the above isotopic evidence for millet consumption, further investigation into the domestication status of Neolithic water buffalo in the Wei River valley is warranted.

5. Conclusions

The stable carbon and nitrogen isotope data discussed here supports the view that Laoguantai people were millet farmers whose subsistence included hunted wild foods. The isotope results suggest that humans were consuming aquatic organisms such as fish and shellfish. This finding is supported by previous isotopic analyses, and the recovery of shellfish remains from the site. The diet of the single *Sus* was dominated by C3 plants, indicating that it is unlikely to have been a domesticated animal. The bovid remains investigated here are tentatively identified as water buffalo. Their $\delta^{13}C$ values are similar to those of the Baijia humans, and indicate the presence of millet in their diets. Whether these bovids were being managed by humans to some degree, or were consuming wild millet plants, remains to be explored further. The isotopic values presented here provide preliminary insight into dietary patterns at a Laoguantai settlement.

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