SCIENCE CHINA
Earth Sciences

• RESEARCH PAPER •

April 2011 Vol.54 No.4: 519–527
doi: 10.1007/s11430-011-4170-9

Stable carbon and nitrogen isotope evidence of human and pig diets at the Qinglongquan site, China

GUO Yi[1,2,3,4], HU YaoWu[2,3*], ZHU JunYing[5], ZHOU Mi[5], WANG ChangSui[2, 3] & Michael P. RICHARDS[1]

[1] *Department of Human Evolution, Max-Planck Institute for Evolutionary Anthropology, Leipzig, D-04103, Germany;*
[2] *Lab of Human Evolution, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China;*
[3] *Department of Scientific History and Archaeometry, Graduate University of Chinese Academy of Sciences, Beijing 100049, China;*
[4] *Department of Cultural Heritage and Museology, School of Humanities, Zhejiang University, Hangzhou 310028, China;*
[5] *Hubei Provincial Institute of Cultural Relics and Archaeology, Wuhan 430077, China*

Received February 4, 2010; accepted September 7, 2010

Previous studies on the Rice-Millet (foxtail millet and common millet) Blended Zone in Chinese Neolithic have not clearly addressed such questions as the importance of primitive rice-millet mixed agriculture to human lifestyle and livestock managements within this region, the relationship among the development of the agriculture, paleoenvironment, and cultural interactions, and so on. Here stable carbon and nitrogen isotope analysis of human and pig bones from the Qinglongquan site was conducted, covering two cultural phases, namely the Qujialing Culture (3000 BC to 2600 BC) and the Shijiahe Culture (2600 BC to 2200 BC). Based on this analysis, we further discussed the diets of ancient humans and pigs in the site, investigated the importance of rice-millet mixed agriculture to human and pig diets, and explored the relationship among the primitive rice agriculture and millet agriculture, cultural interactions, and paleoenvironment. The $\delta^{13}C$ values of human bone collagen (−16.7‰ to −12.4‰, averaging −14.6‰ ±1.3‰, n=24) revealed that both C_3 and C_4 foods were consumed, probably from the contribution of rice (C_3 plant) and millets (C_4 plants) due to the coexistence of these crops at this site. In addition, the human mean $\delta^{13}C$ value suggested that millet agriculture was only minor in human diets. The human $\delta^{15}N$ values (6.6‰ to 10.8‰, averaging 9.0‰ ±1.2‰, n=24) showed that animal resources played a significant role in human diets, and varied greatly. The mean $\delta^{13}C$ value of the pigs (−14.3‰ ±2.5‰, n=13) was quite similar to that of the humans, but the mean $\delta^{15}N$ value of the pigs was slightly less (1.3‰). The similar $\delta^{13}C$ and $\delta^{15}N$ values between humans and pigs suggested that the pigs consumed a lot of humans' food remains. No correlations of the $\delta^{13}C$ and $\delta^{15}N$ values between humans and pigs showed that both human and pig diets were based mainly on plant foods, which might be related to highly developed rice-millet mixed agriculture at that time. In comparison with the human and pig diets between the two periods, millet agriculture contributed more than 10% in the Shijiahe Culture, if a simple mixing model was used. This apparent dietary shift matched the climatic variation and agricultural development through the time. In warm and humid climate with the expansion of the Qujialing Culture northwards, rice was widely cultivated. However, when the climate was cold and arid, northern culture was expanding southwards. Thus, millet agriculture became more important.

paleodiet, the Rice-Millet Blended Zone, stable isotope, cultural interaction, paleoenvironment

Citation: Guo Y, Hu Y W, Zhu J Y, et al. Stable carbon and nitrogen isotope evidence of human and pig diets at the Qinglongquan site, China. Sci China Earth Sci, 2011, 54: 519–527, doi: 10.1007/s11430-011-4170-9

Although a dichotomy appeared in the early Neolithic period between the primitive rice agriculture in southern China and the primitive millet agriculture (foxtail millet and common millet) in northern China, the two agricultural sys-

*Corresponding author (email: ywhu@gucas.ac.cn)

tems also interacted with each other during their development and expansion. In fact, their interaction is one of the most important parts of the cultural interactions between northern and southern China [1], and a focal aspect of agricultural archaeological studies.

Archaeobotany, such as plant seeds, pollen, and phytolith, has recently become a primary means to reveal the rice agriculture and millet agriculture. Previous researches indicated that from 7000 BC to 5000 BC, the primitive rice agriculture and the millet agriculture were distributed respectively in southern China and northern China [2]. Although there was no direct interaction between them, rice remains were found in the north sporadically, such as at the Jiahu site [3] in Henan Province and the Yuezhuang site [4] in Shandong Province (Figure 1). From 5000 BC to 3500 BC, the millet agriculture had developed and expanded southwards and eastwards to the northern part of Hubei Province and the Yellow River valley and Huaihe River valley. Meanwhile, the rice agriculture had diffused northwards to the Guanzhong area near the Yangtze River valley and the Hanjiang River valley [5], and also to some sites characteristic of the Yangshao Culture in the Central Plains and Shandong Province [6]. During this period, the Rice-Millet Blended Zone was formed basically between the Yangtze River valley and the Yellow River valley (Figure 2). From 3500 BC to 2000 BC, the rice agriculture and the millet agriculture were both highly developed, and the range of the Rice-Millet Blended Zone was enlarged to a region within 33° to 35°N, 107° to 120°E. Within this broad area, both rice and millet agricultural remains were found at the Anban site in Fufeng City of Shaanxi Province [7], the Yuchisi site in Mengcheng City of Anhui Province [8], the Dahecun site in Zhengzhou City [9] and the Huanglianshu site in Xichuan City of Henan Province [10], the Diaolongbei site in Zaoyang City of Hubei Province [11], the Qinglongquan site in Yunxian City of Hubei Province [12], and so on (Figure 3).

Previous studies on the Rice-Millet Blended Zone have not adequately addressed such questions as the importance of the rice-millet mixed agriculture to human lifestyle

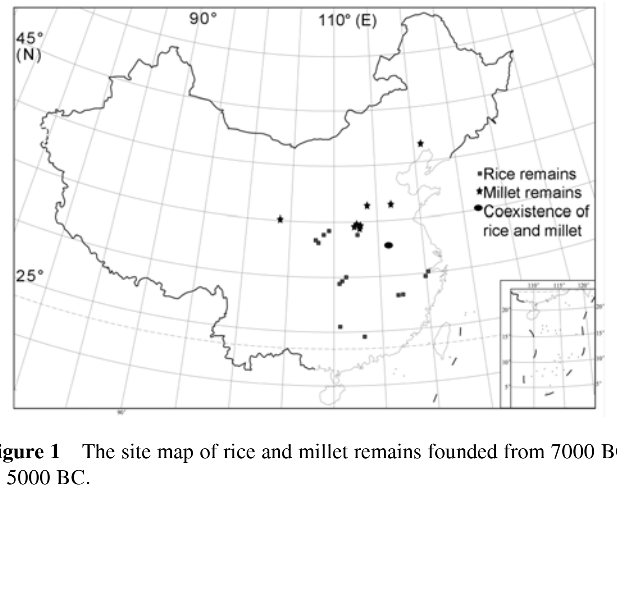

Figure 1 The site map of rice and millet remains founded from 7000 BC to 5000 BC.

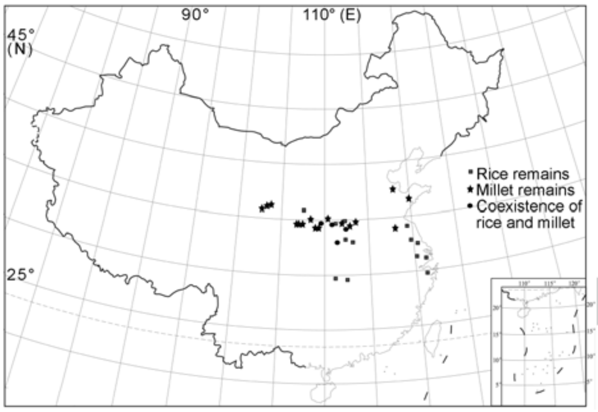

Figure 2 The site map of rice and millet remains founded from 5000 BC to 3500 BC.

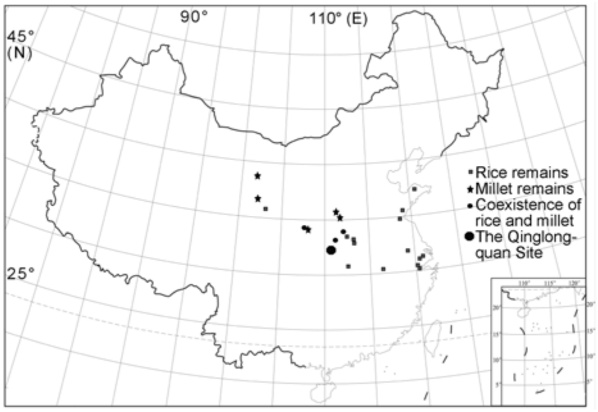

Figure 3 The site map of rice and millet remains founded from 3500 BC to 2000 BC.

within this region, and the influence of the agriculture to the husbandry of domestic animals, and the relationship among the development of primitive agriculture, paleoenviroment, and cultural interactions.

The carbon and nitrogen stable isotope analysis has become a well-established technique to address such important issues as agricultural origin, development, and spread. The basic principle of this technique is that the isotopic composition of human bone collagen could directly correspond to the isotopic composition of human's diets. The stable isotopic values of human bone collagen will be different if humans have different food resources. Hence, the stable isotope analysis of bone collagen could reveal the information about the human diets [13], as well as the origin and development of agriculture [14]. For instance, based on the stable carbon isotope analysis on human bone collagen, Vogel and van Der Merwe [15] discussed the spread of maize agriculture in New York State. This method was also used to analyze human and animal materials from the Dadiwan site in Gansu Province to understand the origin of millet agriculture and that of animal domestication in northern China [16]. The stable isotopic analysis of human and animal bone collagen from the Yuezhuang site and the Xiaojingshan site in Shandong Province [17] indicated that from 7000 BC to 5000 BC, people from some regions of the Yellow River valley had already consumed C_4 foods such as millets. The analysis of the materials from the Jiahu site in Henan Province [13] suggested that people from the Huaihe River valley had already consumed a lot of C_3 foods, which probably came partially from rice. Previously, the carbon and nitrogen stable isotopic analysis on human bones unearthed at the Gouwan site in Xichuan County of Henan Province, which dated back from 5000 BC to 2600 BC, indicated that both millets and rice were consumed and the millet agriculture was not dominant. During the Yangshao Culture Period, under the suitable climate, the rice agriculture spread northwards with the influence of the southern culture. However, in the Qujialing Period, a relatively cold climate in this region affected its rice agriculture and reduced its dominance [18]. In the present study, the stable carbon and nitrogen isotopic analysis was employed to human and pig bone samples from the Qinglongquan site in Yunxian City of Hubei Province [19], and the human and pig diets of the Qujialing Culture Period and the Shijiahe Culture Period were reconstructed. We further discussed the influence of rice-millet mixed agriculture to human lifestyle and pig domestication as well as the relationship among the ancient rice-millet mixed agriculture, cultural interactions, and paleoenviromental change.

1 Archaeological background

The northern part of Hubei Province was a very important pathway between the Yellow River Culture Circle and the Yangtze River Culture Circle. The main trunk of the Hanjiang River and the Sui-Zao Corridor was a crucial passage to the southwards expansion of the Yangshao Culture or northwards expansion of the Qujialing Culture and the Shijiahe Culture [20].

The Qinglongquan site, to the north of the Hanjiang River, was located in the Sui-Zao Corridor. It was excavated three times during 1959 and 1962. It covered three different periods, i.e., the Yangshao Culture (3500 BC to 3000 BC), the Qujialing Culture (3000 BC to 2600 BC), and the Shijiahe Culture (2600 BC to 2200 BC). Large quantities of archaeological remains with different cultural styles were found, suggesting that cultural interaction was very frequent during those three periods [12]. The findings of rice imprints and millet grains implied that both crops were cultivated. This site was excavated again due to the North-to-South Water Diversion Project. The human and pig bone samples in the present study came from this excavation [21].

2 Materials and methods

2.1 Sample selection

All samples came from the Qinglongquan site, which covered two periods, namely the Qujialing Period and the Shijiahe Period. A total of 57 bone samples were selected, including 29 human individuals and 28 pigs.

2.2 Collagen preparation

Collagen was extracted from the human and pig bone samples using the standard procedures outlined in Richards and Hedges [22]. Approximately 300–500 mg of bone was sampled and the surface contaminants were removed mechanically. The bone samples were demineralized in 0.5 mol/L HCl at 5°C and refreshed every 2 or 3 days until the bone samples were soft and no bubbles came out. Then, samples were rinsed in deionized water three times and gelatinized at 70°C in 0.001 mol/L HCl for 48 h. After that, the resulting solutions were first filtered to remove insoluble materials while they were hot, and then filtered again to remove contaminants lower than 30000 D by using Millipore Amicon Ultra-4 centrifugal filters. Finally, the residues were freeze-dried for 48 h to get the collagen. After the collagen was weighed, the collagen content ratio was calculated (the weight of the collagen was divided by the original weight of the bone sample).

2.3 Measurement and analysis

The contents of carbon and nitrogen of bone collagen were measured in a Thermo Finnigan Flash EA 1112 and the isotopic ratios were measured in a Thermo Finnigan DELTA plus XL isotope ratio mass spectrometer with respect to the V-PDB standard and the AIR standard, respectively. The analytical precisions of carbon and nitrogen isotope were 0.1‰ and 0.2‰, respectively.

In total, bone collagen was extracted from 39 out of 57 bone samples. The collagen content, C:N ratios, the contents of carbon and nitrogen in collagen, and $\delta^{13}C$ and $\delta^{15}N$ values of these 39 samples were shown in Table 1.

Previous studies showed that well-preserved collagen should have collagen content more than 5%，carbon and nitrogen contents from 15.3% to 47.0% and from 5.5% to 17.3%, respectively, and atomic C:N ratio within 2.9–3.6 [23–25]. The contaminated collagen samples were identified according to these standards. Although these samples had low collagen contents (averaging 2.8%±1.5%), which indicated that the majority of bone collagen had decomposed during the long-term burial, the other factors, such as carbon content (averaging 44.2%±0.5%), nitrogen content (averaging 16.1%±0.5%) and C:N ratio (averaging 3.2±0.1), matched the above standards very well. Therefore, all 39 bone collagen samples were considered as non-contami-

Table 1 Information of bone samples and isotopic data

Period	Species	Archaeological number a)	Collagen (%)	C (%)	N (%)	δ^{13}C (‰)	δ^{15}N (‰)	C:N
Qujialing	Human	M155	3.5	44.5	16.3	−15.3	9.9	3.2
		M190	4.6	43.8	16.5	−15.9	9.2	3.1
		M157E	2.2	44.0	16.6	−16.5	10.1	3.1
		M79	5.4	44.6	17.0	−14.1	6.8	3.1
		M184	2.0	43.9	16.2	−16.1	9.2	3.2
		M157W	6.2	44.6	16.8	−15.5	9.8	3.1
		M162	2.2	43.9	15.8	−16.7	9.9	3.2
	Pig	M162	0.9	43.3	15.4	−20.8	8.9	3.3
		H478	1.7	44.4	15.3	−17.5	7.8	3.4
		H667	2.7	44.6	16.1	−17.4	7.8	3.2
		M163B	0.9	43.7	16.3	−13.9	7.4	3.1
		H463A	3.8	44.3	15.6	−13.9	7.1	3.3
		H595	2.3	44.5	16.0	−13.4	7.9	3.3
		H463B	3.8	44.6	16.5	−11.7	7.5	3.2
Shijiahe	Human	M132	4.5	44.8	16.6	−12.9	8.5	3.2
		M69	0.9	44.6	16.6	−12.4	9.9	3.1
		M110A	5.4	45.1	16.4	−13.1	9.2	3.2
		M78	3.9	44.7	16.9	−14.7	8.2	3.1
		M67	3.0	43.9	15.8	−12.9	9.4	3.3
		M127	1.4	43.9	15.5	−13.7	8.2	3.3
		M187	3.6	44.0	15.9	−15.3	9.2	3.2
		M110B	0.3	44.0	16.7	−14.2	9.6	3.1
		M133	3.7	42.9	15.1	−14.6	6.6	3.3
		M139	2.2	43.6	16.0	−15.4	9.7	3.2
		M128	4.0	43.9	16.6	−13.6	8.9	3.1
		M145	4.5	43.6	16.6	−15.9	10.8	3.1
		M158	5.1	44.5	16.8	−14.0	9.5	3.1
		M124	3.1	43.6	16.2	−14.3	6.7	3.1
		M118	1.8	44.4	16.1	−15.7	9.2	3.2
		M98	1.6	44.0	15.9	−15.4	7.1	3.2
		M148	0.4	45.4	17.0	−13.0	10.4	3.1
	Pig	M148B	0.3	43.3	15.2	−12.0	7.6	3.3
		H590	1.6	44.1	15.4	−13.7	6.1	3.3
		H576	2.9	44.4	16.1	−16.3	4.7	3.2
		H579	2.0	43.8	15.2	−13.0	8.0	3.4
		H546B	2.3	44.6	16.2	−11.0	8.3	3.2
		H578	3.0	44.6	15.8	−13.2	8.2	3.3
Unknown	Pig	TS1A	2.7	43.9	15.8	−17.2	7.9	3.2
		TS1B	1.5	44.5	15.8	−18.5	8.0	3.3

a) Different individuals from the same tomb or ash-pit were marked by A and B. The M157 was a double burial tomb: M157E was the one in the east and M157W was the one in the west.

nated and suitable for stable isotope analysis.

SPSS 16.0 and Origin7.0 were used for statistical analysis.

3 Results and discussions

3.1 Human dietary reconstruction

All δ^{13}C and δ^{15}N data of human collagen samples are dispersed and shown in Figure 4. The range of δ^{13}C value is from −16.7‰ to −12.4‰, with a mean value of −14.6±1.3‰ (n=24), while the range of δ^{15}N value is from 6.6‰ to 10.8‰, with a mean value of 9.0±1.2‰ (n=24).

The coexistence of rice and millets found at the Qinglongquan site [12] suggested that both crops were consumed by ancient humans. Since rice is a typical C_3 plant while millets are C_4 plants, they have quite different δ^{13}C values. If humans consume the products made by different crops, the δ^{13}C values of their bone collagen will be quite different. Therefore, rice agriculture and millet agriculture, as well as the relative contributions of different foods to human and animal diets, could be revealed by stable isotope

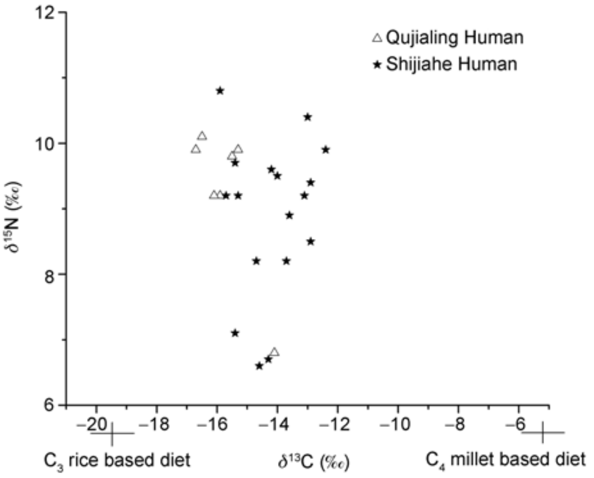

Figure 4 Plot of $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen of humans.

analysis of human and animal bone collagen [26].

Previous studies showed that $\delta^{13}C$ values of modern millets and modern rice were −11.7‰ [27] and −26.1‰ [28], respectively. Thanks to the fossil-fuel effect (approximately 1.5‰ [29]), the $\delta^{13}C$ values of millets and rice in Neolithic Period should be −10.2‰ and −24.6‰, respectively. The enrichment of $\delta^{13}C$ value from food to bone collagen is approximately 5‰ [30]. However, the enrichment of $\delta^{13}C$ value between trophic level is so low (1.5‰) that it is always neglected. In this case, the $\delta^{13}C$ values of human bone collagen based on rice or millets purely would be around −19.6‰ or −5.2‰, respectively.

The range of $\delta^{13}C$ value of human bone collagen (−16.7‰– −12.4‰) indicates that human consumed both C_3 and C_4 food resources. If a simple mixing model is used, and −24.6‰ and −10.2‰ are assumed to stand for the $\delta^{13}C$ values of the two end-members of primitive rice and primitive millets, respectively, the contribution of different agriculture to human diets could be briefly calculated [31–34]. As a result, the range of the contribution to human diets from millets and/or animals that consume millets is approximately from 20.1% to 50.0% with a mean value of 34.5%±8.7% (n=24), suggesting that millets were not the primary food resources in human diets. In addition, different from that (−10.3‰±1.5‰, n=14) of the Jiangzhai site and the Shijia site [28] on the basis of millet agriculture mainly, and that (−20.1‰±0.2‰, n=19) of the Sanxingcun site [33] on the basis of rice agriculture in the Yangtze River valley, the mean $\delta^{13}C$ value (−14.6‰±1.3‰, n=24) of humans from the Qinglongquan site is similar to that (−14.3‰± 1.9‰, n=41) from the Gouwan site [18] in the Rice-Millet Blended Zone. This result is consistent with the rice-millet mixed agriculture at both the Qinglongquan site and the Gouwan site.

The enrichment of nitrogen isotope values between trophic levels is roughly from 3‰ to 5‰, which is rather different from that of the carbon isotopes [35]. Therefore, it is useful to determine the trophic level of human by this method. Generally, the range of $\delta^{15}N$ value of omnivores is between 7‰ and 9‰ while that of carnivores is over 9‰ [36], although these values may change somewhat in different environments. Published isotopic data showed that the $\delta^{15}N$ mean value of human bone collagen from the Gouwan site and from the Sanxingcun site was 8.3‰±1.1‰ (n=41) and 9.7‰±0.3‰ (n=19) respectively. The high $\delta^{15}N$ values at the Sanxingcun site strongly suggested that the proportion of meat resources in human diets was significantly high, probably from hunting and fishing. Overall, the $\delta^{15}N$ mean value of human bone collagen from the Qinglongquan site is 9.0‰±1.2‰ (n=24), slightly higher than that of the Gouwan site and lower than that of the Sanxingcun site. This finding suggests that the proportion of meat resources in human diets here was relatively high.

The range of human $\delta^{15}N$ value is quite broad, reflecting that different individuals had diverse protein resources. In general, all human samples could be classified into three groups based on the differences of the $\delta^{15}N$ values. The first group comprises 16 human bone collagen samples with $\delta^{15}N$ values higher than 9‰, with 6 samples from the Qujialing Period and 10 samples from the Shijiahe Period. The high nitrogen values of human bone collagen in this group indicate a significantly high contribution of meat to the protein resources. Fish was also probably consumed [37] as fishing tools and fish bones were presented here [12]. The second group, consisting of 5 individuals from the Shijiahe Period, has $\delta^{15}N$ values ranging from 7‰ to 9‰, which suggests that human individuals in this group were more dependent on plant foods compared with the first group. The third group with $\delta^{15}N$ values lower than 7‰ contains 1 and 2 samples from the Qujialing and the Shijiahe periods, respectively, suggesting that they relied mostly on the plant foods, probably from gathering or agriculture. Three facotrs are probably responsible for the human dietary variability at the Qinglongquan site. First of all, the Qinglongquan site is located in the Sui-Zao Corridor, where interactions between northern and southern China occurred frequently. Ancient humans might have some migrations here. Secondly, different persons might have different food choices. Thirdly, although no researches on paleoenvironment of the Qinglongquan site have been presented so far, this site now is near the Hanjiang River and at the foot of Yuqian Hill [12], and the biodiversity from complicated ecosystem could give ancient humans a diverse selection of food resources. In addition, the sulphur isotope analysis to be conducted in the future will give us more evidence about the human diets and migration [38].

3.2 Pig dietary reconstruction

Figure 5 presents the scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values of

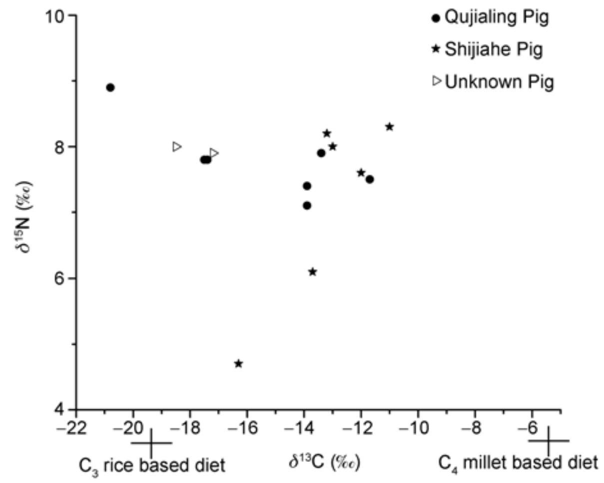

Figure 5 Plot of δ^{13}C and δ^{15}N values of bone collagen of pigs.

pig bone collagen samples. It shows that M162 sample with the lowest δ^{13}C value (−20.8‰) and the highest δ^{15}N value (8.9‰) is quite abnormal, which suggests that this individual should be based on quite different food resources from other pigs. Morphological identification of the pig by Dr. Laura Niven in the Max-Planck Institute for Evolutionary Anthropology indicated that it was an adult pig, which suggested that it might be extraneous. Moreover, H576 sample with normal δ^{13}C value (−16.3‰) has the lowest δ^{15}N value (4.7‰), which is much lower than the human δ^{15}N value range (9.0‰±1.2‰). This individual could be a wild boar since it seemed to have little relation with humans. Morphological research of pig bones from burials at this site also suggested that most of them were domestic pigs with some wild boars [39]. Obviously, M162 and H576 samples should be excluded if livestock managements based on the rice-millet mixed agricultural system is discussed.

The δ^{13}C values of the other pigs range from −18.5‰ to −11.0‰, with a mean value of −14.3‰±2.5‰ (n=13), while the δ^{15}N values range from 6.1‰ to 8.3‰, with a mean value of 7.7‰±0.6‰ (n=13). Similar to humans, the δ^{13}C values of most pigs indicate that the pigs' diets were full of C_3 and C_4 foods, probably from rice and millet by-products [40]. Furthermore, millet-based foods contribute 36.8%±17.2% to pig diets, which suggests that millets were still a minor component in pig diets. The mean δ^{15}N value of pigs is 1.3‰ negative compared to that of the humans, indicating that these pigs had a close relation with humans, and consumed large quantities of human food residues [41].

3.3 Correlation analysis of δ^{13}C and δ^{15}N values of humans and pigs

Recent researches have suggested that the carbon isotope mainly came from the overall dietary resource, whereas the nitrogen isotope represented the animal protein resource. Correlation analysis of δ^{13}C and δ^{15}N values could give further information about human and pig diets.

In the Qujialing Period, all carbon and nitrogen stable isotopic data of humans show a significant negative correlation (r=−0.806, P=0.029<0.05, n=7). However, M79 with the lowest δ^{15}N data (6.8‰) has a strong impact on the correlation analysis. There is no correlation at all if this value is taken out (r=−0.142, P=0.789>0.05, n=6). There is also no correlation between δ^{13}C and δ^{15}N data of pigs without M162 (r=−0.439, P=0.384>0.05, n=6).

In the Shijiahe Period, there is no correlation between δ^{13}C and δ^{15}N data of humans (r=−0.118, P=0.653>0.05, n=17). It is the same for δ^{13}C and δ^{15}N data of pigs if H576 is excluded (r=0.578, P=0.308>0.05, n=5).

Generally, there are no correlations between δ^{13}C and δ^{15}N values of humans and pigs. These results suggest that plant foods contributed significantly in both human and pig diets, which may be related to highly developed rice-millet mixed agriculture at that time.

3.4 Human and pig dietary change between periods

On the basis of the above analysis and in combination with the archaeological evidence, both C_3 (including rice) and C_4 (mainly millets) foods were consumed by humans and pigs in either the Qujialing Period or the Shijiahe Period, which indicates that ancient people at the Qinglongquan site cultivated both rice and millets. Comparison of the carbon and nitrogen stable isotopic data of humans and pigs in different periods may help us explore whether the rice-millet mixed agriculture changed significantly between the two periods [33].

Figure 6 shows the standard deviation plot of δ^{13}C and δ^{15}N values of human and pig bone collagen samples in different periods, after excluding the abnormal values. It indicates that the δ^{13}C values of humans and pigs in the Qujialing Period are quite different from those in the Shijiahe Period, but the δ^{15}N values are nearly the same. Furthermore, independent T-test analysis shows that the δ^{13}C values of humans are significantly different (t=−3.286, P=0.003<0.05), whereas the values of pigs have no difference (P=0.104>0.05). In addition, the comparison of δ^{15}N values of humans and pigs in two periods are not significantly different (P=0.482>0.05 for humans, and P=0.887>0.05 for pigs, respectively). These results suggest that the human diets, especially plant food resources, were significantly different between these two periods.

As shown in Figure 6, the mean δ^{13}C values of both humans and pigs are more positive in the Qujialing Period compared to those of the Shijiahe Period. In the Qujialing Period, millet agriculture contributed 26.9% to human diets and 34.5% to pig diets, respectively. In the Shijiahe Period, both proportions raised nearly 10% (37.6% for humans and

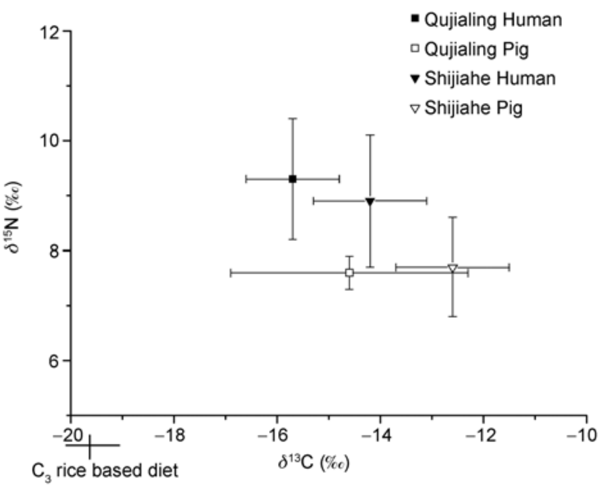

Figure 6 Standard deviation plot of $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen of humans and pigs.

48.8% for pigs, respectively). Clearly, this dietary shift reflected the enhanced influence of millet agriculture on both human lifestyle and livestock managements through time.

Compared with the $\delta^{13}C$ values of humans and pigs in the same period, there was no significant difference in the Qujialing Period (P=0.317>0.05), whilst there was significant difference in the Shijiahe Period (t=−2.863, P=0.010<0.05). It seems that the proportion of C_4 plants was higher in animal diets than in human diets, suggesting that ancient humans were more likely to feed pigs with millet by-products rather than rice, especially in the Shijiahe Period. The reason for this is still unclear and further investigation is needed.

3.5 Relationship among dietary changes of humans and pigs, paleoenvironmental change, and cultural interactions

As discussed previously, human and pig diets changed obviously from the Qujialing Period to the Shijiahe Period, which suggested that ancient people had different preferences to rice and millets in different periods. Why did ancient humans prefer different crops in different periods? Did it have any relationship with the paleoenvironmental change and cultural interactions?

Paleoenvironmental changes in the middle reach of the Yangtze River in the Neolithic Period [42, 43] suggested that the environment varied from the Qujialing Period to the Shijiahe Period. From the late stage of the Daxi Period to the early stage of the Qujialing Period, the climate was relatively cold and arid. It was getting comparatively warm and humid from the late stage of the Qujialing Period to the early stage of the Shijiahe Period. Then, it became cold and arid again since the middle stage of the Shijiahe Period. In addition, the archaeological research in this region showed that the Qujialing Culture expanded northwards strongly around 5000 BP [44, 45]. A large area in northern China such as the Nanyang Basin and some parts in Shaanxi Province were under the influence of the Qujialing Culture. The Qinglongquan site was definitely in the Qujialing Culture circle when this southern culture spread into the Nanyang Basin via the Sui-Zao Corridor. However, the situation was completely reversed in the Shijiahe Period. A northern culture, namely the Longshan Culture in the Central Plains, began to vigorously expand and infiltrate to the middle reach of the Yangtze River, especially in the late stage of the Shijiahe Period [46]. Research by Gao Chongwen [20] indicated that the cultural style was completely changed in the Shijiahe Culture area, which could be identified by several cultural factors, such as the type, surface ornamentation, color, and production technology of pottery. In the late stage of the Shijiahe Period, the cultural style here was more like northern culture rather than southern culture, which may be caused by the interruption of a new cultural system from the north. Obviously, when the Longshan Culture spread to the south, the Hanjiang River and the Sui-Zao Corridor should be the main routes. And the Qinglongquan site of the area may be influenced by the northern culture to some extent.

By reconstructing the ancient human and pig diets at the Qinglongquan site, we can conclude that rice-millet mixed agriculture took place here within two periods. And the proportion of rice and millets in the diets had apparently changed. Rice was widely cultivated and became a primary food resource in the Qujialing Period when the climate was warm and humid and cultures in southern China had infiltrated northwards simultaneously. However, during the middle stage of the Shijiahe Period, millet agriculture was enhanced when the climate was cold and arid, and the northern culture expanded southwards. Overall, C_3 food (probably rice) always played a significant role in human diets, which indicated that rice agriculture was the first choice of the ancient human here.

The stable isotope analysis of the Gouwan site [18] and the Qinglongquan site reveals that in the Rice-Millet Blended Zone rice agriculture from southern China was dominant, while millet agriculture contributed as a minor food resource in human diets. From the Yangshao Period to the Qujialing Period and to the Shijiahe Period, the human diets changed correspondingly, indicating the options of planting rice or millet always matched the climatic changes and cultural interactions here. Therefore, conducting analysis of human and pig diets in different cultural periods could help us better understand the paleoenvironmental change and cultural interactions.

4 Conclusions

The analysis of $\delta^{13}C$ and $\delta^{15}N$ values of human and pig bones from the Qinglongquan site indicates that:

(1) Overall, humans and pigs had a mixed C_3 (including

rice) and C_4 (almost certainly millets) diet in which C_3 food was primary, while millets were minor. The mean $\delta^{15}N$ value (9.0‰±1.2‰, n=24) and the broad range of human $\delta^{15}N$ values indicate that animal resources played a significant role in human diets and varied greatly. The $\delta^{13}C$ values of pigs are similar to those of humans whilst the mean $\delta^{15}N$ value is 1.3‰ less than that of humans, which suggests that pigs had a close relationship with humans. Pigs probably consumed a similar food resource to humans, including human food residues.

(2) The $\delta^{13}C$ and $\delta^{15}N$ values of humans and pigs show that there are no correlations between them, which suggests that humans and pigs here depended on plant foods due to highly developed rice-millet mixed agriculture at that time.

(3) From the Qujialing Period to the Shijiahe Period, the diets of humans and pigs both changed. The proportion of millet agriculture was enhanced by nearly 10% in their diets, which indicated that millets were more important for both human lifestyle and livestock managements in the Shijiahe Period.

(4) The dietary change of humans and pigs matched the paleoenvironmental change and cultural interactions at that time. When the climate was warm and humid, and southern culture was expanding northwards simultaneously, rice was widely cultivated. When it was cold and arid, and northern culture was expanding southwards, millets agriculture was more enhanced.

Although a stable carbon and nitrogen isotope analysis was conducted for ancient human and pig bone samples from the Qinglongquan site, which covered two phases, namely the Qujialing Culture and the Shijiahe Culture, and their diets and dietary change were discussed here, we only did a preliminary exploration in the present study. Because of the lack of samples from the Yangshao Period and from other animal species, the dietary change within the whole period remains unclear. In addition, the relationship among rice-millet mixed agriculture, paleoenvironment, and cultural interactions was quite complicated. Additional work on these questions is necessary.

We are indebted to the Deputy Director Li Taoyuan of the Hubei Provincial Institute of Cultural Relics and Archaeology, and Song Guoding, Yang Yimin, and Ma Ying from the Department of Scientific History and Archaeometry, School of the Humanities, Graduate University of Chinese Academy of Sciences for their kindly help. We also express our gratitude to the anonymous reviewers for their valuable comments. This study was supported by the Knowledge Innovation Project of Chinese Academy of Sciences (Grant No. KJCX3.SYW.N12), National Natural Science Foundation of China (Grant No. 40702003), Partner group program of Max Plank Institute and Chinese Academy of Sciences (Grant No. KACX1-YW-0830), and Relics Preservation Project of South-to-North Water Diversion.

1 Wang X G, Xu X. A discussion on the rice-millet blended zone in the Neolithic Age (in Chinese). Agricul Histor China, 2003, 22: 3–9
2 Chen W H. Source and development of primitive agriculture of China (in Chinese). Agricul Archaeol, 2005, (1): 8–15
3 Chen B Z, Zhang J Z, Lü H Y. Discovery of rice phytoliths in the Neolithic site at Jiahu of Henan Province and its significance. Chin Sci Bull, l995, 40: 1186–1191
4 Crawford W G, Cheng X X, Wang J H, et al. The carbonized rice of Houli Culture discoverd at Yuezhuang site in Changqing, Jinan city, Shandong (in Chinese). Orient Archaeol, 2006, 3: 247–250
5 Huaxian Archaeological Excavation Group of the Reservoirs on the Yellow River Excavation Team. A brief reporton of the excavation at Liuzizhen site in Huaxian County, Shaanxi (in Chinese). Archaeology, 1959, (2): 71–75
6 Liu G E, Xiang A Q. Discussion on the prehistorical south rice-north millet blended zone and its genesis (in Chinese). Agricul Archeol, 2005, (1): 115–122
7 Xie W. Agricultural remains in the ash from the Anban site (in Chinese). In: Archaeology Major in the School of the Northwest University College of Cultural Relics and Archaeology, ed. Archaeological Excavation Reports on the Ancient Site Fu Feng An Ban. Beijing: Science Press, 2000. 286–289
8 Wang Z L, Wu J A. Phytolith analysis of the Yuchisi site and economic traits of prehistoric agriculture (in Chinese). Archaeology, 1998, (4) :87–93
9 The Museum of Zhenzhou. An excavation report at Dahecun site in Zhengzhou city (in Chinese). Acta Archaeol Sin, 1979, (3): 301–375
10 The Henan Group of the Archaeological Team, The Office for Programme of the Works in the Changjiang River Valley. An excavation report at Huanglianshu site in Xichuan city, Henan (in Chinese). Huaxia Archaeol, 1990, (3): 1–69
11 Institute of Archaeology, Chinese Academy of Social Sciences. Excavations of the Diaolongbei Site in Zaoyang City (in Chinese). Beijing: Science Press, 2006. 345–346
12 Institute of Archaeology, Chinese Academy of Social Sciences. Qinglongquan and Dasi (in Chinese). Beijing: Science Press, 1991. 201–205
13 Hu Y W, Ambrose S H, Wang C S. Stable isotopic analysis on ancient human bones in Jiahu site. Sci China Ser D-Earth Sci, 2007, 50: 563–570
14 Hu Y W, Yang X M, Wang C S. Review on ancientdiet (in Chinese). In: Wang C S, Zuo J, eds. Collection of Essays in Archaeological Sciences (the second volume). Hefei: University of Science and Technology of China, 2000. 51–58
15 Vogel J C, van der Merwe N J. Isotopic evidence for early maize cultivation in New York State. Am Antiquity, 1977, 42: 238–242
16 Barton L, Newsome S D, Chen F H, et al. Agricultural origins and the isotopic identity of domestication in northern China. Proc Natl Acad Sci USA, 2009, 106: 5523–5528
17 Hu Y, Wang S, Luan F, et al. Stable isotope analysis of humans from Xiaojingshan site: Implications for understanding the origin of millet agriculture in China. J Archaeol Sci, 2008, 35: 2960–2965
18 Fu Q M, Jin S A, Hu Y W, et al. Agricultural development and palaeodietary study of Gouwan site, Xichuan, Henan. Chin Sci Bull, 2010, 55: 614–620
19 Abrantes K, Sheaves M. Food web structure in a near-pristine mangrove area of the Australian Wet Tropics. Estuar Coast Shelf Sci, 2009, 82: 597–607
20 Ma B C, Yang L. Tentative study on cultural communication among Hubei, Henan and Shaanxi during the Late Neolithic Age (in Chinese). Jianghan Archaeol, 2007, (2): 42–51
21 Zhu J Y. Great achievements in the archaeological excavation of the Qinglongquan site according to the divert water from the south to the north project (in Chinese). China Cultural Relics News, 2006, 12: 15
22 Richards M P, Hedges R E M. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic Humans at sites along the Atlantic Coast of Europe. J Archaeol Sci, 1999, 26: 717–722
23 Hedges R E M. Bone diagenesis: An overview of processes. Archaeometry, 2002, 44: 319–328

24 Ambrose S H. Preparation and characterisation of bone and tooth collagen for stable isotope analysis. J Archaeol Sci , 1990, 17: 431–451
25 DeNiro M J. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature, 1985, 317: 806–809
26 Bocherens H, Drucker D. Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: Case studies from recent and ancient terrestrial ecosystems. Int J Osteoarchaeol, 2003, 13: 46–53
27 McGovern P E, Zhang J, Zhang Z, et al. Fermented beverages of pre- and protohistoric China. Proc Natl Acad Sci USA, 2004, 101: 17593–17598
28 Pechenkina E A, Ambrose S H, Ma X L, et al. Reconstructing northern Chinese Neolithic subsistence practices by isotopic analysis. J Archaeol Sci , 2005, 32: 1176–1189
29 Marino B D, McElroy M B. Isotopic composition of atmospheric CO_2 inferred from carbon in C_4 plant cellulose. Nature, 1991, 349: 127–131
30 DeNiro M J, Epstein S. Influence of diet on the distribution of carbon isotopes in animals. Geochim Cosmochim Acta, 1978, 42: 495–506
31 Schwarcz H P. Some theoretical aspects of isotope paleodite studies. J Archaeol Sci, 1991, 18: 261–275
32 Emery K F, Wright L E, Schwarcz H. Isotopic analysis of ancient deer bone: Biotic stability in Collapse Period Maya Land-use. J Archaeol Sci, 2000, 27: 537–550
33 Hu Y W, Wang G F, Cui Y P, et al. Palaeodietary study of Sanxingcun site, Jintan, Jiangsu. Chin Sci Bull, 2007, 52: 660–664
34 Zhang X L, Wang J X, Xian Z Q, et al. Studies on ancient human diet (in Chinese). Archaeology, 2003, (2): 62–75
35 Hedges R E M, Reynard L M. Nitrogen isotopes and the trophic level of humans in archaeology. J Archaeol Sci, 2007, 34: 1240–1251
36 Ambrose S H. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. J Archaeol Sci, 1991, 18: 293–317
37 Richards M P, Schulting R J, Hedges R E M. Sharp shift in diet at onset of Neolithic. Nature, 2003, 425: 366
38 Fornander E, Eriksson G, Lidén K. Wild at heart: Approaching Pitted Ware identity, economy and cosmology through stable isotopes in skeletal material from the Neolithic site Korsnäs in Eastern Central Sweden. J Anthropol Archaeol, 2008, 27: 281–297
39 Luo Y B, Tao Y, Zhu J Y, et al. Preliminary observation of pig-bones burials in the Qinglongquan Site (in Chinese). Jianghan Archaeol, 2009, (3): 58–65
40 Hu Y W, Luan F S, Wang S G, et al. Preliminary attempt to distinguish the domesticated pigs from wild boars by the methods of carbon and nitrogen stable isotope analysis. Sci China Ser D-Earth Sci, 2009, 52: 85–92
41 Guan L, Hu Y W, Tang Z W, et al. Stable isotopic analysis on *Sus* bones from the Wanfabozi site, Tonghua, Jilin. Chin Sci Bull, 2007, 52: 3393–3396
42 Guo L X. Genealogy of Late Neolithic Cultures in Middle Yangtze River Region (in Chinese). J Chin Histor Geogr, 2004, 19: 5–16
43 Shi Y F, Kong Z C, Wang S M. The climatic fluctuation and important events of Holocene Megathermal in China (in Chinese). Sci China Ser B, 1992, 22: 1300–1308
44 Fan L. The discussion on the Qinglongquan second pattern of the Qujialing Culture (in Chinese). Archaeology, 1998, (11): 76–89
45 Sun G Q. The Dawenkou Culture and the Qujialing Culture in Henan Province (in Chinese). Cultural Relics Central China, 2000, (2): 22–28
46 Wang H X. The exogenic actions for the origin and development of the Shijiahe Culture (in Chinese). In: Chinese Society of Archaeology, ed. Papers of the Ninth Annual Conference of the Chinese Archaeological Society. Beijing: Cultural Relics Publishing House, 1997. 151–160