Human subsistence strategy at Liuzhuang site, Henan, China during the proto-Shang culture (~2000–1600 BC) by stable isotopic analysis

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\begin{abstract}
Since the discovery of the proto-Shang culture, created mostly by ancestors of the Shang clan from the late Neolithic Age to the early Shang period (~2000–1600 BC), the subsistence strategy and lifestyle of humans in China during their movement southwards have been a great focus. Chinese literature and archaeological findings suggest that the proto-Shang societies were composed of different cultural groups and had various subsistence strategies. For example, at the Liuzhuang site, three types of burials, i.e., stone coffin, wooden coffin and earthen shaft-pit, are found. The wooden coffin and earthen shaft-pit burials had been adopted locally in the Central Plains since the Neolithic Age while the stone coffin burials were usually used by people living in Northeast China and had never been found in the Central Plains before. In this study, stable carbon and nitrogen isotopic analyses were performed on human bones from the Liuzhuang site and animal bones from Zhangdeng site in Henan province, China to determine whether different social groups had various accesses to food resources and whether their dietary difference was related to inequality in social status. Humans have mean $\delta^{13}C$ and $\delta^{15}N$ values of $-7.6 \pm 0.6$ and $9.6 \pm 1.0$, respectively, which strongly indicates that humans rely primarily on C$_4$-based food. The main contribution of C$_4$-based food in their diet is from millet agriculture or animals that consume millet by-products. The isotopic spacing of carbon and nitrogen isotopic values between pigs and humans, between dogs and humans, and between cattle and humans, all imply that these animals were the main meat resources for humans. Surprisingly, the $\delta^{13}C$ values and $\delta^{15}N$ values of humans with different types of burials are quite close, indicating that they had equal access to food resources. This result suggests that the proto-Shang humans had adapted to the local subsistence strategy, and the local cultural factors in the Central Plains were very well integrated into proto-Shang culture.
\end{abstract}

1. Introduction

Due to rich written records and abundant archaeological discoveries related to the Shang Dynasty (1600–1046 BC), it has been widely accepted that the Shang Dynasty is an early state of ancient China (Chang, 2002; Zhu, 2007). Since the first important discovery of the Shang remains in central China in 1920s, intensive discussions have been made on the social and political organizations, subsistence strategy, and ritual ideology in the Shang societies (e.g., Chang, 1983, 2002). To better understand how the Shang clan came into being, more and more studies have turned to the precursor of the Shang Dynasty, proto-Shang culture (Li, 1989; Tsou, 1980).

The proto-Shang culture was defined as the culture created primarily by the Shang clan from the late Longshan period to the early Bronze Age (~2000–1600 BC) in the Central Plains of China (Li, 1989). Current researches indicate that the proto-Shang cultural remains were distributed mainly in northern Henan and southern Hebei along the east side of the Taihang Mountains (Hu...
and Wang, 2012; Wang and Hu, 2011) (Fig. 1). So far four variants of the proto-Shang culture have been suggested, including Baobei (Shen, 1991), Zhanghe (Tsou, 1980), Huiwei (Tsou, 1980) and Lutaigang (Wei, 1999). The distribution of each variant is illustrated in different colors in Fig. 1 (in the web version). According to studies of pottery typology, the dates of the Baobei and Zhanghe were earlier than that of Huiwei, which was followed successively by Lutaigang (Hu and Wang, 2012; Li, 1989; Tsou, 1980; Wang and Hu, 2011).

It is argued mostly by Chinese historians that the subsistence strategy of the proto-Shang societies from the emergence of the Shang clan to the setup of Shang Dynasty underwent a fundamental change, from nomadic to semi-nomadic and semi-agricultural, and then to completely agricultural (Wang, 2010; Zhu, 2007). For example, Ding (1988) proposed that the ancestors of the Shang people lived a completely nomadic life based on the records of literature, Taiping huanyuji, which described an animal herding scene. Later, they were gradually influenced by the agricultural practices in central China as they interacted more frequently with the farmers during their migration southwards. For instance, the early Chinese literature, i.e., Guanzi Qingzhongwu, recorded the setup of Zaoaao, a specific place for raising livestock. More importantly, the naming pattern of two famous chiefs, Hai and his grandson Shangjiawei, was adopted by the Heavenly-stem and Earthly-branch system, which was widely used for agricultural production in China in ancient times (Zhu, 2007). By 1600 BC when the Shang Dynasty was founded, agriculture was highly developed and flourishing, which can be inferred from the records of Mencius Tengwengong Xia and Shangshu Tangshi.

In addition, more and more evidence on the subsistence strategy can be seen from the artifacts and archaeological contexts unearthed in proto-Shang sites from northern Henan and southern Hebei (Fig. 1). Archaeological artifacts, such as stone tools used for hunting and fishing, were found from early proto-Shang sites mostly located in northern Hebei like the Yabazhuang site (CPAMHP and CPAMCC, 1992), supporting the idea that the early proto-Shang societies lived a nomadic life. At sites during the Early to Middle
To answer the above questions, stable carbon and nitrogen isotopic analyses of human skeletal remains from the LZS as well as animal bones from the Zhangdeng site (ZDS) (Hou et al., 2009) were undertaken to explore the similarities or dissimilarities in subsistence strategy among people from this region. This comparative study will allow us to not only explore the differences in human diets and subsistence strategy but it will also help to clarify the relationship between the social organization, burial practices, and social identity of the proto-Shang people at the LZS.

2. Materials and methods

2.1. Materials

Thirty-two human bones from the LZS were selected for stable isotope analysis. Since animal bones from the LZS are currently not available, 49 animal bones including pigs, dogs, cattle and sheep/goats were sampled from the ZDS (Hou et al., 2009), contemporary to and near the LZS. The exact location of LZS and ZDS is illustrated in Fig. 1. More details about the human skeletons and animal bones can be seen in Tables 1 and 2.

2.2. Collagen extraction

Collagen was extracted from the human and animal bone samples based on a slightly modified version of the protocol outlined by Jay and Richards (2006). Bone samples weighing 2–3 g were mechanically cleaned to remove outer and inner contaminants. The bone samples were then demineralized in 0.5 mol/L HCl at 4 °C. The liquid was refreshed every 2 days until the samples turned soft and no bubbles came out. Then the residues were washed by deionized water until neutral, rinsed in 0.125 mol/L

Table 1

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<th>Type</th>
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<th>Age</th>
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<th>Wt. %N</th>
<th>C:N</th>
<th>CollS</th>
<th>δ¹³C v/c</th>
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</table>

Note: wt% C and wt% N are of collagen; A — Earthen shaft-pit burial; B — Simple stone coffin burial; C — Wooden coffin burial; M — male; F — female; ? — sex not known or age not known; the italic means the samples has been contaminated, italicized C:N data indicate unusable data.
NaOH for 20 h at 4 °C, and finally washed by deionized water again. Afterward, the remains were rinsed in 0.001 mol/L HCl, gelatinized at 70 °C for 48 h, and filtered. Then the residues were freeze-dried for 48 h to get the collagen. Finally, the collagen content was calculated through the dried collagen weight divided by the bone sample weight (Tables 1 and 2).

2.3. Measurement of C and N contents and their stable isotope ratios

The contents of C, N and the C, N stable isotope ratios of collagen were measured in an Isoprime 100 IRMS coupled with Elementary Vario at the Measuring Center of the Institute of Agricultural Environment and Substantial Development, Chinese Academy of Agricultural Sciences. The standard for measuring the content of C, N is Sulfanilamide. IEAE-N-1 and USGS 24 were used as standards to normalize N2 (AIR as standard) and CO2 (PDB as standard) in steel bottles respectively. In addition, after every 10 samples, a standard laboratory made collagen with a δ13C value of −14.7 ± 0.2‰ and a δ15N value of 6.8 ± 0.2‰ was inserted into the sample list for calibration. The precision of carbon and nitrogen isotope ratios is ±0.2‰ and ±0.2‰ respectively. Stable isotopic data are shown in Tables 1 and 2 too.

Generally speaking, the collagen contents of all samples are very low (0.1%–7.2%), with an average of 2.0%, which is much lower than the average (about 20%) of modern bones (Ambrose et al., 1997). In addition, the amount of C (2.8%–44.4%) and N (0.5%–16.1%) in collagen is also lower than that found in modern collagen (C: 41%; N: 15%) (Ambrose, 1990), indicating that the majority of bone collagen had been decomposed to some extents during its long-term burial. However, the atomic ratios of C to N in collagen ranged from 2.3 to 3.6 (DeNiro, 1985), so the samples can still be considered well-preserved for stable isotopic analysis. In this study, 11 samples (LZ58, LZ56, LZ57, LZ59, LZ513, LZ516, LZ518, LZ520, LZ527, LZ528 and LZ531) were excluded for further analysis due to their abnormal C:N atomic ratios (Tables 1 and 2).

Note: wt% C and wt% N are of collagen.
3. Results and discussions

3.1. Animal diets

Fig. 2 presents the scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values in bone collagen extracted from animals (cattle, sheep/goats, pigs and dogs) at the ZDS. For convenience, the animals are divided into two groups for further discussion, i.e., herbivore (cattle and sheep/goat), and omnivore (pig) or carnivore (dog).

In Fig. 2, the $\delta^{13}C$ values of all cattle except one (C6) range from $-12.3^{\text{per mille}}$ to $-6.2^{\text{per mille}}$ with an average of $-9.0 \pm 2.1^{\text{per mille}} (n = 12)$, implying that they mainly ate C4 plants. The $\delta^{15}N$ values of cattle have a quite wide range ($5.3^{\text{per mille}}$ to $8.7^{\text{per mille}}$) with an average of $6.8 \pm 1.2^{\text{per mille}} (n = 12)$. However, the outlier, C6, has a much lower $\delta^{15}C$ value ($-18.9^{\text{per mille}}$) and $\delta^{15}N$ value ($4.0^{\text{per mille}}$) than the others, implying that it had a diet with more $^{15}N$-deficient C3 plants. The range of $\delta^{13}C$ values of sheep/goats ($-21.4^{\text{per mille}}$ to $-10.7^{\text{per mille}}$) is much wider than that of cattle, indicating that they had more diverse plant resources. All sheep/goats except S12 have $\delta^{15}N$ values ranging from $5.8^{\text{per mille}}$ to $8.7^{\text{per mille}}$ S12, however, has an abnormally high $\delta^{15}N$ value ($10.2^{\text{per mille}}$), which might be influenced greatly by the milk consumption effect (Balasse and Tresset, 2002; Makarewicz and Tuross, 2006; Ogrinc and Budja, 2005) or water stress (Ambrose, 1991; Pearson et al., 2007; Thompson et al., 2008).

As Fig. 2 shows, the $\delta^{13}C$ values of all pigs except one (P6) are quite close and range from $-9.2^{\text{per mille}}$ to $-6.4^{\text{per mille}}$ with a mean of $-7.5 \pm 1.0^{\text{per mille}} (n = 18)$, implying that they mainly consumed C4-based foods. As omnivores, the pigs have the mean $\delta^{15}N$ value of $7.7 \pm 0.5^{\text{per mille}} (n = 19)$. Compared to others, the $\delta^{13}C$ value ($-11.2^{\text{per mille}}$) of P6 is much lower, indicating that its diet included more C3 based foods. Although dogs are generally considered carnivores, in this study their average $\delta^{13}C$ and $\delta^{15}N$ values are $-7.6 \pm 0.9^{\text{per mille}} (n = 4)$ and $7.3 \pm 0.5^{\text{per mille}} (n = 4)$, respectively, similar to those of the pigs, which implies that the dogs might be fed by the same food.

3.2. Human diets

Fig. 3 presents the scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen of humans from LZS as well as an error bar plot of those of animals from the ZDS (A – Earthen shaft-pit burial, B – Simple stone coffin burial, C – Wooden coffin burial).

The isotopic spacing of the mean $\delta^{15}N$ values of pigs, dogs and cattle are closer to that of humans than to that of other animals. The isotopic spacing of $\delta^{13}C$ mean value between pigs and humans, dogs and humans, cattle and humans, is $-0.1^{\text{per mille}}$, $0^{\text{per mille}}$, and $1.4^{\text{per mille}}$, respectively. Obviously, they are all not beyond the range of the C isotopic enrichment (1$^{\text{per mille}}$–1.5$^{\text{per mille}}$) in one trophic level (Ambrose and Norr, 1993; Hedges and Reynard, 2007). Meanwhile, the small isotopic spacing of $\delta^{15}N$ mean value between pigs and humans ($2.0^{\text{per mille}}$), dogs and humans ($2.3^{\text{per mille}}$), cattle and humans ($2.8^{\text{per mille}}$) does not exceed the range of the N isotopic enrichment ($3^{\text{per mille}}$–$5^{\text{per mille}}$) in one trophic level (Ambrose and Norr, 1993; Hedges and Reynard, 2007) either. Based on the above, it is obvious that the main animal protein in human diets may come from pigs, dogs, and cattle.

However, the relationship between sheep/goats and humans is very different. As Fig. 3 shows, the isotopic spacing of the mean $\delta^{13}C$ value between sheep/goats and humans is as large as 7.8$^{\text{per mille}}$, which is much higher than the range of the C isotopic enrichment (1$^{\text{per mille}}$–1.5$^{\text{per mille}}$) in one trophic level (Ambrose and Norr, 1993; Hedges and Reynard, 2007). It seems that humans did not like to consume the meat from sheep/goats. So what was the purpose of raising sheep/goats? Were they used for wool? Were they milked? To better answer these questions, more work should be done to reveal the role that sheep/goats played in human society.

One outlier, LZS30 (Table 1), has the lowest $\delta^{13}C$ ($-15.1^{\text{per mille}}$) and $\delta^{15}N$ ($6.8^{\text{per mille}}$) values among the humans sampled, indicating that large quantities of C3 plants were part of her diet. The highest $\delta^{15}N$ value ($14.3^{\text{per mille}}$) is found in the human LZS14, the other outlier, which suggests that the largest proportion of animal protein or aquatic resources was his or her diet. Moreover, the comparison with C and N isotopic data of the animals will give greater clarity to what was the type of animal resources in their diet.

The isotopic spacing of the mean $\delta^{15}N$ value ($7.5^{\text{per mille}}$; $6.8^{\text{per mille}}$; $6.8^{\text{per mille}}$; $7^{\text{per mille}}$) between the above-mentioned domestic animals suggesting that the humans at LZS mainly ate C4 based foods. The mean $\delta^{15}N$ value of these people is $9.6 \pm 1.0^{\text{per mille}} (n = 19)$, indicating that their food contained high amounts of animal protein. Therefore, the high $\delta^{13}C$ and $\delta^{15}N$ values of these people (Fig. 3) strongly indicate that high amounts of C4-based animal protein were consumed by the proto-Shang people.
(cattle; sheep/goats; pigs; dogs) and LZS14 is much higher than the range of N isotopic enrichment (3\(^{\circ}\) to 5\(^{\circ}\)) in one trophic level (Ambrose and Norr, 1993; Hedges and Reynard, 2007), indicating that the human LZS14 did not consume meat from these domestic animals, but probably did consume meat from aquatic resources (Richards et al., 2005). An alternative interpretation is that the individual may have come from a more arid area, which can cause abnormality of N metabolism (Ambrose, 1991; Pearson et al., 2007; Thompson et al., 2008). The low \(\delta^{15}N\) (−15.1\(^{\circ}\)) and \(\delta^{15}N\) (6.8\(^{\circ}\)) values of LZS30 suggest that the individual ate primarily C3 plant foods, quite different from the other humans tested. Therefore, these two outliers might be immigrants rather than local residents.

### 3.3. Dietary difference among humans

Previous work shows that the study of dietary difference in humans can provide valuable clues to understanding the equality/inequality of human social status (e.g., Ambrose et al., 2003; Jay and Richards, 2006; Jarkov et al., 2010; Linderholm et al., 2008; Richards et al., 1998). Statistical analysis of carbon and nitrogen isotopic values of humans with different ages and sexes suggest that humans shared similar foods no matter what age or gender they were. Thus, more focus was put toward determining dietary variation of humans with different burial styles. A standard deviation plot of \(\delta^{13}C\) and \(\delta^{15}N\) values of humans with three types of different burials is drawn in Fig. 4, excluding the two outliers (LZS14 and LZS30).

Generally speaking, human isotopic values in Fig. 4 are quite close no matter to which burial they belonged. A represents stone coffin burials, B represents wooden coffin burials, and C represents earthen shaft-pit burials (Fig. 4). The mean \(\delta^{13}C\) values of A (−7.6 ± 0.6\(^{\circ}\), n = 10), B (−7.8 ± 0.4\(^{\circ}\), n = 4) and C (−7.6 ± 0.8\(^{\circ}\), n = 5) are almost the same. The mean \(\delta^{15}N\) values of A (9.7 ± 1.0\(^{\circ}\), n = 10), B (9.9 ± 0.7\(^{\circ}\), n = 4), and C (\(\delta^{15}N\) = 9.2 ± 1.2\(^{\circ}\), n = 5) are also very similar. Moreover, the independent t-test statistical analyses of the mean \(\delta^{13}C\) values (A vs B is \(t\) = 0.380, \(P > 0.05\)) and the mean \(\delta^{15}N\) values (A vs B is \(t\) = −0.331, \(P > 0.05\)) show that there was no significant difference in diet, suggesting that humans had similar access to the different types of food, even though they may have belonged to different clans.

### 3.4. Human subsistence strategy and animal management during proto-Shang culture period

Carbon isotopic analysis of palaeosol in North China indicates that C3 plants were dominant during the Holocene (Liu et al., 2011). C4 plants are rare in North China, and are mainly composed of the Gramineae and Chenopodiaceae (Liu et al., 2011). The only C4 plant used as a cultigen used in North China is millet (Barton et al., 2009; Hu et al., 2008; Liu et al., 2011).

The domestication of foxtail millet (Setaria italica) and broomcorn millet (Panicum milaceum) in North China can be traced back to 11,000 years ago (Yang et al., 2012), and millets, including foxtail millet and broomcorn millet, have been cultivated extensively since the Yangshao culture (~5000–3000 BC) (Hu et al., 2008; You, 2008; Zhao, 2005a). Afterward, other crops, such as rice, wheat, soybean, and hemp appeared, but millets still played a great role in the human diet from the Longshan culture (~2350–1950 BC) to the three dynasties (Xia, Shang, and Zhou) (Chen, 2007; Zhao, 2005b). During the proto-Shang culture, many millet remains have also been found by flotation at the LZS (Wang et al., 2010) and the ZDS (Liu, 2010).

Previous study shows that the \(\delta^{13}C\) values of modern millet are about −11.7\(^{\circ}\) (McGovern et al., 2004). Talking into account the fossil-fuel effect (approximately 1.5\(^{\circ}\)) (Marino and McElroy, 1991), the \(\delta^{13}C\) values of millets in the prehistory should be around −13.2\(^{\circ}\). The \(\delta^{13}C\) values of human or animals consuming 100% millet products would be around −7.2\(^{\circ}\) if the enrichment in bone collagen of \(\delta^{13}C\) value (5\(^{\circ}\)) or so from foods (DeNiro and Epstein, 1978) is considered.

The very high \(\delta^{13}C\) values of pigs (−7.5 ± 1.0\(^{\circ}\), n = 18) and dogs (−7.6 ± 0.9\(^{\circ}\), n = 4) suggest that they fed large amount of millet by-products or human leftovers. Since cattle are large herbivores, their high \(\delta^{13}C\) values (−9.0 ± 2.1\(^{\circ}\), n = 12) suggest that cattle were fed more millet by-products such as the stem, stalk, leaves, etc. However, the \(\delta^{13}C\) values of sheep/goats (−15.4 ± 2.8\(^{\circ}\), n = 18) are substantially lower, indicating that they relied more on wild C3 plants. In this study, humans are all of high \(\delta^{13}C\) values (−7.6 ± 0.6\(^{\circ}\), n = 19), indicating that their food came mainly from the contribution of millet agriculture or animals consuming millet by-products.

Just as mentioned in the introduction, the earthen shaft-pit burials and the wooden coffin burials were the traditional burial forms found in the Central Plains (Ye, 1994), while stone coffin burials were popularized in Northeast China, and also appeared in the adjacent areas, such as northern Hebei province (Zhang, 2002; Zhou, 2006). Stone coffin burials were only found in LZS during the time of the proto-Shang culture (Zhou, 2006). However, most of the stone coffin burials were more simplified than before (HPICRA, 2007, 2010; Zhao and Han, 2006), indicating that this archaeological culture shrank and adapted when it moved southwards. Most importantly, the artifacts in the stone coffin burials were similar to those found in the other two types of burials. Moreover, the stable carbon and nitrogen isotopic analyses of human bones show that all humans had quite similar dietary patterns no matter what type of burial they had. Therefore, based on the above discussions, we can conclude that the proto-Shang clan adapted to local cultural and agricultural systems very quickly during the migration from north to south, although some original cultural factors were retained. Obviously the adaptation to local culture and environment, and the integration of local people help to make the proto-Shang culture more vigorous and creative, which might have played an active role in the establishment of the Shang Dynasty.
4. Conclusion

The mean δ13C and δ15N values (−7.6 ± 0.6‰; 9.6 ± 1.0‰, n = 19) of humans at the LZS except for the two outliers (LZS14, LZS30) suggest that human diets were mainly comprised of C4-based food, coming from the contribution of millets or animals consuming millet by-products. Based on the isotopic spacing between humans and animals (dogs, pigs, cattle, sheep/goats), we found that dogs, pigs, and cattle were humans’ main animal protein resources but sheep/goats were not. Although humans were found in three types of burials, their diets were quite similar. This finding, in combination with the archaeological context, suggests that the proto-Shang humans had adapted to the local culture and environment in the Central Plains very well, and that they had integrated local cultural factors.

Finally, we suggest that a major cause of the integration of local or exotic culture by the proto-Shang clan might be human migration, as humans LZS14 and LZS30 in this study may have been immigrants. To better understand where they came from, other isotope analyses, such as sulfur, hydrogen, strontium, and oxygen, are under way.

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