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Isotopic perspectives ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$) of diet, social complexity, and animal husbandry during the proto-shang period (ca. 2000–1600 BC) of China

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Abstract

Objectives

To examine dietary patterns and animal husbandry practices and assess the links between human diet and sex, age, burial direction/position, and social status (as inferred by type of grave goods) during the transformative Proto-Shang (ca. 2000–1600 BC) period of China.

Materials and Methods

Stable isotope ratios of carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), and sulfur ($\delta^{34}S$) were analyzed from human ($n = 83$) and animal ($n = 36$) bone collagen at the site of Nancheng in Hebei Province, China.

Results

The Proto-Shang population consumed a predominately C_4 diet ($\delta^{13}C$ = −6.8 ± 0.4‰; $\delta^{15}N$ = 9.4 ± 0.6‰), but a single individual (M70) had a mixed C_3/C_4 diet ($\delta^{13}C$ = −14.9‰; $\delta^{15}N$ = 10.1‰). The $\delta^{34}S$ measurement of M70 (8.8‰) is similar to the local animals (8.2 ± 2.6‰) and the other members of the population (7.0 ± 0.8‰) suggesting this individual may not have been a migrant even though the burial direction (north-south) and position (flexed) was different than the majority of the graves in the cemetery.

Discussion

From comparison with the faunal bone collagen stable isotope results, the Nancheng population ate millets with varying levels of animal protein consumption focused primarily on pigs and possibly cattle and dogs, but sheep/goats, and deer were not eaten in significant amounts. Analysis of the isotopic results in relation to other contemporary sites such as Liuzhuang and Xinzhai show strikingly similar patterns, suggesting that the sheep/goats were likely raised mainly for their secondary products (e.g., wool). No link between diet and sex was found at the population level, but when the data were sorted by age and sex, the older males (>40 years old) were found to have significantly lower $\delta^{13}C$ values (−6.6 ± 0.3‰; n = 18) compared to the younger males (<40 years old) (−7.3 ± 0.5‰; n = 8). Further, no significant correlations between diet and burial direction/position or social status (based on the type of grave goods) were found at Nancheng, possibly indicating that the dietary social stratification of the later Shang and Zhou Dynasties had yet to be established in Chinese society at this time. Am J Phys Anthropol 160:433–445, 2016..

A formative yet enigmatic era in Chinese history is the Proto-Shang period (ca. 2000–1600 BC) which occurs between the end of the late Longshang Neolithic (ca. 2200–2000 BC) and the establishment of the Shang Dynasty (1600–1046 BC) or the earliest form of the “Chinese” state (XSZCP Group, **2000**). This transitional period marks a critical phase in the development of early Chinese civilization, with the formation of social systems and structures related to ritual, status, and wealth (Zhang, **1983**; King and Goldman, **1992**; SACH, **2009**; SACH et al., **2011**). The Proto-Shang people are believed to originate from north China, and were composed of a number of chiefdoms from different ethnic groups (Liu, **2004**; Wang, **2005**). The culture quickly grew and they expanded their influence southward to the Central Plains, where they were frequently engaged in warfare with the Xia ethnic group, finally conquering them and establishing the Shang Dynasty in 1600 BC (Zou, **1980**; Ding, **1988**; Li, **1989**; Huang, **2010**).

Over the last decades, many sites dating to the Proto-Shang culture were discovered in northern Henan Provence and southern Hebei Provence, and these greatly expanded our knowledge of the lifeways of these people (Zhu, **2007**; Zhang, **2008**; Wang, **2011**). Historical sources and archaeological evidence suggest a varied subsistence strategy for the Proto-Shang based on hunting, animal husbandry, and agriculture (Zhang, **2002**; Chen, **2007**; Zhu, **2007**; Hou et al. **2013, 2009**). However, despite an increased number of archaeological excavations, little direct research has explored the diet and social complexity of the Proto-Shang people. Hou et al. (**2013**) were the first to report human isotopic results from the Proto-Shang period site of Liuzhuang (Fig.

1a). Their results found the diet was based on millets, with the animal protein mainly derived from pigs, cattle, and dogs. In addition, Hou et al. (**2013**) examined dietary differences as related to age, sex, and burial type (pit, stone coffin, and wooden coffin) within the population, but no differences were found. While this is regarded as pioneering research, it was limited in scope by the small number of individuals studied (*n* = 21).

Figure 1.

Open Figure

(**a**) Map of mainland China showing the location of the Nancheng site in Hebei Province (shaded), the location of the Liuzhuang site in Henan Province, with an expanded section showing the locations of the Nancheng and Baicun sites in Ci County of Hebei Province. (**b**) Picture of burial M3 showing that the head was covered with a large scallop shell "蚌" (Pectinidae) that was possible part of a cowry "贝" (Cypraeidae) necklace. (**c**) Picture of typical pottery recovered from the burials.

Here we present the largest isotopic study of humans (*n* = 83) from a Proto-Shang site, the cemetery at Nancheng in Hebei Province (Fig. 1a–c). The focus of this research has multiple goals. The first is to reconstruct the subsistence patterns and animal husbandry practices of this population to determine if the type of animal protein consumed was mainly centered on certain species of domestic animals such as pigs and cattle (as found by Hou et al. **2013**), as opposed to other domestic animals (sheep/goats) and wild animals. The second is to assess if unique dietary patterns are linked to sex, age, and burial direction/position in the population. The third is to examine if dietary differences are linked to perceived social status, as inferred from the type of grave goods interred with the deceased (see below). This type of analysis can provide information about the mechanisms of possible social hierarchy in a prestate level society in China.

ARCHAEOLOGICAL BACKGROUND

The Nancheng cemetery site is located on the northern side of the ancient Jian River near Handan City in Hebei Province (Fig. 1a). Excavations at Nancheng uncovered 116 burials dating from the late Longshan period to the Tang Dynasty (960 AD–1127 AD). However, the majority of the graves (*n* = 83) dated to the Proto-Shang period based on analysis of the recovered grave goods (see Fig. 1b,c). Nearly all the human remains were buried in an extended supine posture, except for M51 and M70 which were both buried in a flexed posture. In addition, all graves were placed in a west to east orientation, except for five burials (M46, M51, M70, M76, and M78) which were aligned north to south (Supporting Information Table S1). Sixty-percent of the burials had associated grave goods such as pottery, shells, and jade. In particular, three individuals (M3, M15, M87) were found with large scallop shells (*Pectinidae*) covering their faces, and some of these skeletons were associated with necklaces made of small sea snail shells (*Cypraeidae*) or cowries (Fig. 1b). These large scallop shells have a small hole drilled through their centers and are believed to have been centerpieces of necklaces that were used here as burial masks, possibly for high status or wealthy individuals in the community. A similar necklace (also containing a large scallop shell) was found with a female in tomb M7 at the late Neolithic Yueshi culture (ca. 1900–1600 BC) site of Xianrentai, located closer to the coast in Shangdong Province (Ren and Cui, 1998; Fang, 2010). These unique discoveries are rare for inland archaeological sites in China, and their association suggests these individuals were possible elites or migrants to the community.

STABLE ISOTOPE RATIO ANALYSIS AND PALAEODIET

Stable isotope ratio analysis is widely applied to reconstruct diet, animal husbandry strategies, health and nutrition, and social status in both modern and past populations (e.g., van der Merwe and Vogel, 1978; Schoeninger and DeNiro, 1984; Sealy et al., 1987; Richards et al., 1998; Fuller et al., 2004; Müldner and Richards, 2007; Choy et al., 2010; Bourbou et al., 2011; Commendador et al., 2013; Cui et al., 2015). Since body tissues are derived from the intake of food and water, isotopic ratios obtained from bone collagen reflect the average lifetime diet (including a significant portion from adolescence) of an individual or animal (Stenhouse and Baxter, 1979; Hedges et al., 2007). In general, carbon ($\delta^{13}C$) results permit detection of C_3 plants ($\delta^{13}C$ values between −20 and −34‰) and C_4 plants ($\delta^{13}C$ values between −9 and −16‰) in the diet (Smith and Epstein, 1971; DeNiro and Epstein, 1978; O'Leary, 1981; Nelson and Schwarcz, 1982). Nitrogen ($\delta^{15}N$) values are used to determine trophic level, since tissues, like bone, have a ~3–5‰ enrichment in $\delta^{15}N$ relative to diet (e.g., Schoeninger and DeNiro, 1984; Bocherens and Drucker, 2003; Hedges and Reynard, 2007; Reitsema, 2013). In addition, the combination of $\delta^{13}C$ and $\delta^{15}N$ measurements permits the identification of marine food consumption in archaeological populations (e.g., Richards and Hedges, 1999). In China, applications of these measurements have become vital for understanding the timeline for the introduction and spread of different forms of C_3 (rice, wheat, barley etc.) and C_4 (millets) cultigens to various regions (e.g., Pechenkina et al., 2005; Hu et al., 2008; Barton et al., 2009; Fu et al., 2010; Atahan et al., 2011a, 2011b; Lanehart et al., 2011; Liu et al., 2012; Atahan et al., 2014) and for reconstucting animal husbandry practices (e.g., Hu et al., 2009; Chen et al., 2012; Hou et al., 2013).

Sulfur ($\delta^{34}S$) analysis is a more recent addition to paleodiet studies. The source of sulfur in bone collagen is the essential amino acid methionine, and there is wide variation in plant values (−22 to +22‰) as a result of location and geology, with little isotopic fractionation between diet and consumer tissues (Krouse, 1980; Richards et al., 2001, 2003; Nehlich and Richards, 2009; Nehlich, 2015). Increased applications of sulfur measurements (combined with $\delta^{13}C$ and $\delta^{15}N$ results) have shown that $\delta^{34}S$ results are useful to determine origins or 'nonlocal' individuals in a population as well as freshwater and marine protein consumption (Nehlich and Richards, 2009; Nehlich, 2015). While studies were published for Pacific Island, European and Near Eastern sites (e.g., Craig et al., 2006; Privat et al., 2007; Nehlich et al., 2011; Nehlich et al., 2012; Kinaston et al., 2013; Sayle et al., 2013; Loesch et al., 2014), only a single application of $\delta^{34}S$ analysis was previously published for China (Hu et al., 2009), making the results presented here of particular importance to Chinese isotopic studies. For more in-depth discussion of these isotopic methods the reader is directed to the following comprehensive reviews (Schoeninger, 1995; Katzenberg, 2000; Lee-Thorp, 2008; Reitsema, 2013; Nehlich, 2015).

INVESTIGATING SOCIAL STATUS WITH ISOTOPIC

RATIOS: CONSIDERATIONS FOR CHINA

Isotopic measurements ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, etc.) are increasingly used to investigate relationships between diet and social hierarchy in archaeological populations (reviewed in Twiss, **2012**). In particular, the focus of many studies (e.g., Murray and Schoeninger, **1988**; Richards et al., **1998**; White, et al., **2001**; Privat et al., **2002**; Ambrose et al., **2003**; Le Huray and Schutkowski, **2005**; Kjellström et al., **2009**; Jørkov et al., **2010**; Yoder **2012**; Kinaston et al., **2013**; Quintelier et al., **2014**), was the use of $\delta^{15}N$ measurements to examine if there were differences in animal protein consumption (↑ $\delta^{15}N$ values ≈ ↑ animal protein consumption) between social classes based on grave goods, type of burial, burial location and direction, etc. Some notable examples include: increased consumption of marine foods by individuals interred in lead coffins or mausoleums vs. common graves at the Late Roman site of Poundbury, UK (Richards et al., **1998**), more animal protein and less maize in the diet of high status individuals vs. low status individuals at the Cahokia Mound 72 in Illinois, USA (Ambrose et al., **2003**), greater consumption of animal/dairy protein by males buried with iron swords, shields and/or spears vs. males buried without weaponry at the La Téne period site of Kutná Hor-Karlov, Czech Republic (Le Huray and Schutkowski, **2005**), increased consumption of high status foods, pork, chicken, sea turtle, and pelagic fish by wealthy individuals on the Polynesian outlier island of Taumako (Kinaston et al., **2013**), and more marine and animal protein in the diet of individuals found buried in the church (more expensive location) vs. those buried in the cloister garth (less expensive location) at the postmedieval Carmelite Friary at Aalst, Belgium (Quintelier et al., **2014**). These isotopic studies are valuable to bioarchaeological research since they provide an independent line of evidence for the dietary dimensions of social inequality which are often missing in the archaeological record. However, it is important to remember that dietary variations in these populations were complicated and likely determined by a variety of factors including: ideology, culture, social and biological status, etc. While diet can be used as a symbolic representation of social relations, it must be viewed together with the specific archaeological information and background of the site and time period, and one must be cautious when interpreting and reconstructing the relationships between dietary variation and social status (for reviews see, Danforth, **1999**; Curet and Pestle, **2010**).

In ancient China, complex and rigid systems of social organization and hierarchy were present in life and in death (e.g., Yu and Gao, **1978**; Song, **1994, 2010**; Dai, **2013**), but how and when these traditions were first established is not clear. Historical sources provide evidence that differences in diet were present between the nobility and the common people, and that meat was viewed as a luxury item for the nobility, wealthy, or elders of a family group that was generally reserved for special occasions such as festivals or banquets (Song, **1999**; Wang, **2007**). For example, Zuo Qiuming who lived from 502 to 422 BC, described in *Guoyu: History of Zhou Dynasty States*, how during the Zhou Dynasty that the king could eat everything, the rulers of small states could eat cattle, senior officials could eat sheep, middle officials could eat pig, lower officials could eat fish, and that the common people would mainly eat only vegetables (Zuo, **2015**). Further, the Chinese philosopher, Mencius (372–289 BC) wrote that the elders of the common people could wear silk and eat meat given their elevated social status in the community (Mencius, **2012**), and in *Liji: Book of Rites*, which describes the customs and traditions of the Zhou Dynasty, it discusses how the number of dishes served at a meal was determined by an individual's status and age, with higher status and older individuals having more dishes and greater dietary options (Dai, **2013**). In addition, social status in ancient China was also maintained in death through specific mortuary practices. Tomb size, quality and quantity of grave goods, human sacrifice, number and type of coffins, etc. were all strictly controlled based on the social standing and wealth of an individual (Qing, **2007**; Wu, **2012**). For example, during the Shang and Zhou Dynasties the combination and total number of bronze ritual vessels, *Ding* (used to cook or hold meat) and *Gui* (used to hold grains), buried with an individual was a sign of their social rank in the community (Yu and Gao, **1978**; Tang, **2004**; Wang, **2007**).

Despite these historical accounts of dietary differences linked to social status in ancient Chinese society, little isotopic research has been conducted on this topic (Ling et al., **2010**; Zhang et al, **2012**; Zhang et al, **2014**; Wang et al., **2014**) and none was directly focused on Proto-Shang sites. At Nancheng, archaeological evidence in the form of metallurgy, (potential) written inscriptions on oracle bones, and walled settlements suggests the Proto-Shang likely had some form of social complexity and hierarchy (Underhill, **1994**; Liu and Chen, **2003**; Ebrey et al., **2006**). In addition, the small bronze tools and weapons found at the sites of Jiangou, Beiyangtai, and Xiaquyuan indicate the development of complex technology, and the centralization of a trade specialization, which can be regarded as causal factors leading to social stratification (HPACH, **1979**; Pluciennik, **2005**). Even more impressive evidence is found in Proto-Shang burials in the form of different types and qualities of grave goods interred with the deceased, evidence that pronounced differences in wealth and status possibly existed in Proto-Shang society (HPICRA, **2003**).

Here at Nancheng, the large number of burials recovered with different types of grave goods permits an investigation of links between diet and social status. As little is known about how social status is reflected by grave goods during the Proto-Shang period, we decided to define individuals found with no grave goods as low status, individuals buried with only pottery (excluding type and number) as medium status, and individuals buried with jade, calcite, and shells (exotic items) as high status. While far from perfect, we believe these are reasonable classifications since during the following periods (Shang and Zhou Dynasties) the type and quality of graves goods are used as one of the markers to identify social status (IA CASS, **2003**). Given that after the Proto-Shang period, historical sources describe social status differences linked with the type and quantity of animal meat eaten, we hypothesize that the high status individuals at Nancheng might have elevated δ^{15}N values compared to the medium and low status individuals. In addition, as the elders of a community were revered and honored in ancient Chinese society and were described as having preferential diets with possibly more access to meat, we suspect that older individuals might have different isotopic results than younger individuals; including higher δ^{15}N values. Thus, this research can shed light on the origins of social hierarchy and complexity in relation to diet in ancient China.

MATERIALS AND METHODS

The remains of 83 skeletons consisting of both adults and adolescents [10–15 years old] (no infants or children) were examined and classified by a team of physical anthropologists led by Dong Wei (an author on this paper) at the Research Centre for Chinese Frontier Archaeology at Jilin University (Supporting Information Table S1). Age estimation and sex determination for each individual (where possible) were determined by standard methods outlined by Ubelaker (**1999**) and White and Folken (**2000**). Specifically, sex was determined by pelvic sexual dimorphism and age was estimated by morphological changes of the pubic symphysis. Rib and long bone fragments from each skeleton were selected for collagen extraction and isotopic analysis. Since only two unidentified animal species were found at the Nancheng site, faunal remains (dogs (*Canis* *familaris*), cattle (*Bos Taurus*), pigs (*Sus domesticus*), sheep (*Ovi aries*) and goats (*Capra hircus*), deer (*Cervidae*), and sika deer (*Cervidae nippon*); total *n* = 34) were obtained from the nearby (< 3 km) contemporary site of Baicun and used as an isotopic baseline with which to compare the human results (Supporting Information Table S2). The identification of faunal species was conducted by the Institute of Archaeology, CASS in Beijing.

Bone collagen was extracted following the standard procedures detailed in Richards and Hedges (**1999**) with the addition of ultrafiltration (Brown et al., **1988**; Jørkov et al., **2007**). Approximately, 0.5–1.0 g of bone was cleaned by air abrasion and then demineralized in a 0.5M HCl solution at 4°C for 2 weeks, with the acid changed every 2 days. Samples were then gelatinized at 70°C in a pH = 3 solution for 48 hr. After purification with a 5 µm EZEE© filter, the solution was concentrated by Amicon© ultrafilters (<30 kDa), and then was frozen and freeze dried for 2 days. Approximately 0.5 mg of extracted collagen was weighed in duplicate for carbon and nitrogen analysis, using a Flash EA 2112 coupled to Thermo-Finnigan Delta XP isotope ratio mass spectrometer. Approximately, 10 mg collagen was required for sulfur analysis, and to each sample 1 mg of V_2O_5 was added to ensure complete combustion. The resulting gases SO and SO_2 were analyzed in an elemental analyzer (HeKaTech, Wegberg, Germany), which was coupled to a Delta V plus isotope ratio mass spectrometer (Thermo-Finnigan, Bremen, Germany). The inorganic international standards NBS127 (20.3‰), IAEA-S1 (−0.3‰), IAEA-S2 (21.5‰), and IAEA-SO-5 (0.5‰) and two organic standards NIST bovine liver 1577 b (7.5‰) and IVA protein casein (6.3‰) were analyzed daily. Isotopic results are presented as the ratio of the heavier isotope to the lighter isotope ($^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{34}S/^{32}S$) and reported as δ values in parts per 1,000 or "per mil" (‰) relative to internationally defined standards for $\delta^{13}C$ (VPDB), $\delta^{15}N$ (AIR) and $\delta^{34}S$ (VCDT). The analytical error for both $\delta^{13}C$ and $\delta^{15}N$ measurements was determined to be ±0.2‰ (1σ) or better, and ±0.5‰ for $\delta^{34}S$, based upon the reproducibility of isotopic measurements of internal and international standards.

RESULTS AND DISCUSSION

The isotopic results and sample information are presented in Supporting Information Tables S1 and S2. The majority of the humans (75 out of 83) and animals (31 out of 36) produced good quality collagen with C:N between 2.9 and 3.6 (DeNiro, **1985**; van Klinken, **1999**). However, we were only able to obtain enough collagen for $\delta^{34}S$ measurements from 20 humans and 12 animals, but this still reflects the largest number of $\delta^{34}S$ values published for a Chinese archaeological site to date. All the $\delta^{34}S$ results had C:S and N:S results within the acceptable limits (C:S ratio of 600 ± 300 and N:S ratio of 200 ± 100) (Nehlich and Richards, **2009**).

Faunal diet and animal husbandry practices at Nancheng

The carbon and nitrogen isotopic results of the fauna were variable with large ranges observed for both the $\delta^{13}C$ (−21.3 to −5.8‰) and $\delta^{15}N$ (2.8 to 8.3‰) values, and this is evidence of different diets and that different animal husbandry strategies were employed at the site (Fig. 2a). When the mean values were plotted, a strong linear correlation was found (R^2 = 0.89) for all species that spanned the range between C_3 and C_4 diets (Fig. 2b). In addition, the $\delta^{34}S$ results of the fauna are graphed in relation to the $\delta^{13}C$ (Fig. 3a) and $\delta^{15}N$ (Fig. 3b) values. Unfortunately, only 12 specimens produced enough collagen for $\delta^{34}S$ analysis, but interesting patterns were still detected. The $\delta^{34}S$ values ranged from 2.5 to 12.8‰, demonstrating significant amounts of variation in the bioavailable environmental sulfur and also suggesting variable animal husbandry strategies.

Figure 2.

Open Figure

(a) $\delta^{13}C$ and $\delta^{15}N$ animal results from the Nancheng and Baicun sites in Hebei Province, China. Note: Measurements ≥12‰ reflect a predominately C_4 diet, values between −12 to −18‰ indicate a mixed C_3/C_4 diet, and values ≤18 reflect a predominately C_3 diet in China (Pechenkina et al., **2005**; Barton et al., **2009**). (**b**) Human and the mean ± SD animal $\delta^{13}C$ and $\delta^{15}N$ results from the Nancheng and Baicun sites in Hebei Province, China. A strong linear correlation ($R^2 = 0.89$) in the mean animal results is observed between the C_3 and C_4 environments. Note: Measurements ≥12‰ reflect a predominately C_4 diet, values between −12 and −18‰ indicate a mixed C_3/C_4 diet, and values ≤18 reflect a predominately C_3 diet in China (Pechenkina et al., **2005**; Barton et al., **2009**).

Figure 3.

Open Figure

(a) Human and animal $\delta^{34}S$ and $\delta^{13}C$ results from the Nancheng and Baicun sites in Hebei Province, China. (**b**) Human and animal $\delta^{34}S$ and $\delta^{15}N$ results from the Nancheng and Baicun sites in Hebei Province, China.

The two dogs had an average value of −8.0‰ for $\delta^{13}C$, 7.3‰ for $\delta^{15}N$, and 7.5‰ for $\delta^{34}S$. The carbon results suggest a predominately C_4 diet of millets. The high nitrogen values are near but below the humans suggesting a diet with a possible inclusion of human refuse. The sulfur values are nearly identical to the humans which also supports the likelihood of overlapping diets (Fig. 3a,b), and this is a common finding for isotopic studies from north China (e.g., Chen et al., **2012**; Si, **2013**) as well as other parts of the world (reviewed by Guiry, **2012**). Comparing our dog results with those of Hou et al. (**2013**) from Liuzhuang also finds very similar patterns (Fig. 4a), and this is further evidence in support of our conclusions.

Figure 4.

Open Figure

(a) Plot of the animal $\delta^{13}C$ and $\delta^{15}N$ results of Hou et al. (**2013**) with the animal $\delta^{13}C$

and δ^{15}N results from the Baicun site in Hebei Province, China. (**b**) Comparing the human δ^{13}C and δ^{15}N results of Hou et al. (**2013**) with the human and mean ± SD animal δ^{13}C and δ^{15}N results from the Nancheng and Baicun sites in Hebei Province, China. The similarities in the isotopic results between the two sites suggest that pigs were the primary source of dietary animal protein during the Proto-Shang period. However, note the three individuals with significantly different mixed C_3/C_4 diets that could suggest consumption of more sheep/goats and/or that they were migrants from other communities.

Pigs (*n* = 3) also had a predominately C_4 diet based on millets (mean ± SD; δ^{13}C = −7.0 ± 0.4‰), and this agrees with previous results from North China (e.g., Pechenkina et al., **2005**; Chen et al., **2012**; Dai et al., in press). Their mean ± sd δ^{15}N value of 7.8 ± 0.4‰ is the highest of all the species studied (Fig. 2b), and these results combined with the carbon measurements suggests the pigs were kept in close proximity to the humans and likely consumed human leftovers and/or waste (feces). Only two pigs were measured for δ^{34}S (average value 7.6‰), and these were found to plot with the humans (Fig. 3a,b). Nearly identical isotopic patterns are observed for the pigs at Nancheng and Liuzhuang (Fig. 4a), and this reinforces the findings of Hou et al. (**2013**) that pigs during the Proto-Shang period were fed a relatively homogenous diet of mainly millet and human byproducts.

All cattle (*n* = 5) display a predominately C_4 diet (mean ± SD; δ^{13}C = −8.3 ± 1.8‰) with δ^{15}N values (mean ± SD; 7.3 ± 1.0‰) similar to the dogs and pigs. This suggests cattle were possibly fed in a similar manner as the dogs and pigs and were possibly kept close to the habitation site. In addition, our cattle measurements cluster with the isotopic results from Liuzhuang (Hou et al., **2013**), and this is further evidence reinforcing this interpretation of shared animal husbandry strategies for Proto-Shang cattle, pigs, and dogs. However, four of the cows were analyzed for δ^{34}S values (mean ± SD; δ^{34}S = 5.9 ± 3.4‰), and two groups were found; one with high δ^{34}S values (8.6‰ and 9.0‰) and one with low δ^{34}S values (2.5 and 3.3‰). The two cows with the high results plot just above the pigs in terms of δ^{34}S (Fig. 3a,b) which is suggestive of a similar diet but with a greater component of C_3 plants in the diet. Further, these two cows have quite high δ^{15}N values which could be evidence they consumed plants fertilized with manure (e.g., Commisso and Nelson, **2006, 2007**; Bogaard et al., **2007**; Szpak, **2014**), but additional isotopic research on plants from the site is necessary to confirm this. In contrast, the two cows with the low δ^{34}S values are very different than the other animals, and this suggests they were fed or foddered in a distinct location in relation to the site or possibly coming from an entirely different site. Additional δ^{34}S measurements on a larger number of cattle combined with other isotopic techniques such as hydrogen (e.g., Topalov et al., **2013**) or strontium (e.g., Viner et al., **2010**) are ongoing, and will provide more information on this in the future. Still, these results demonstrate the added benefit of combining sulfur with carbon and nitrogen stable isotope measurements to glean more information about animal husbandry practices.

The sheep/goats (*n* = 13) show a wide range of δ^{13}C (−16.4 to −6.4‰; mean ± SD = −12.1 ± 2.6‰) and δ^{15}N (5.1 to 8.3‰; mean ± SD = 6.2 ± 1.1‰) values (Fig. 2a,b). Three sheep/goats were analyzed for δ^{34}S and had a mean ± SD of 7.3 ± 0.9‰. The sheep/goats had predominately C_4 or mixed C_3/C_4 diets, and this suggests they were allowed to roam and graze at different locations near the site (Fig. 2a,b). However, a single sheep/goat (δ^{13}C = −6.4‰; δ^{15}N = 8.3‰) had a highly ^{13}C-enriched δ^{13}C value that plots close to the pigs, suggesting this individual was likely cared for in or near the settlement and fed with significant amounts of millet. When the sheep/goats from the Liuzhuang site (Hou et al., **2013**) are plotted with our results (Fig. 4a), the same general pattern emerges confirming that the sheep/goats had a wide dietary diversity in terms of C_3 and C_4 plant resources, and this is additional evidence they could freely graze on or near sites during the Proto-Shang period.

The deer (*n* = 5) have the lowest $\delta^{13}C$ (mean ± SD; −20.8 ± 0.5‰) and $\delta^{15}N$ (mean ± SD; 3.4 ± 0.5‰) values, evidence they consumed exclusive C_3 diets and likely grazed in a closed forested habitat due to the canopy effect (France, **1996**; Vera, **2000**; Drucker et al., **2008**). For $\delta^{34}S$, only a single deer could be analyzed, and it produced the highest result (12.8‰) which is a clear outlier from the other animals (Fig. 3a,b). This supports the carbon and nitrogen isotopic evidence that the deer lived in a unique ecological habitat that was distinct from the domestic animals. In addition a single sika deer was analyzed, and it had distinctly different $\delta^{13}C$ (−16.2‰) and $\delta^{15}N$ (5.0‰) values which indicates it consumed a mixed C_3/C_4 diet, and thus likely lived closer to the site and grazed on the millet fields or was possibly kept as a pet. Deer with similar ^{13}C-enriched $\delta^{13}C$ values were also found at the contemporary site of Xinzhai in Henan Provence, and were thought to have been possibly raised for the purposes of hunting by the elites of the society (Dai et al., in press).

Human diet at Nancheng

The human carbon and nitrogen results in relation to the mean values of the animals are plotted in Figure 2b. The $\delta^{13}C$ values for 74 of the 75 individuals (excluding M70) have a narrow range between −8.3 and −5.8‰ (mean ± SD; −6.8 ± 0.4‰). This reflects a diet predominately based on terrestrial C_4 plants and/or animals that fed on C_4 plants. These results agree with the archaeobotanical evidence from phytoliths, pollen, and plant floatation research as well as the historical references from oracle bone scripts that mention millets [foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum milaceum*)] as the dominant crops in the north of China from the Neolithic to the Three Dynasties: Xia, Shang, Zhou (Keightley, **1978**; Zhang et al., **2003**; Crawford et al., **2005**; Pechenkina et al., **2005**; Zhao, **2005**; Crawford, **2006**; Chen, **2007**; Lee et al., **2007**; Wang et al., **2010**). Therefore, the human diet C_4 signature at Nancheng was certainly derived from the consumption of these species of millets. Comparing our results with those of Hou et al. (**2013**) from the contemporary site of Liuzhuang (Fig. 4b) reveals a nearly identical pattern of millet consumption, evidence that the Proto-Shang clan adopted the dietary traditions of the Central Plains area when they migrated from north China. The exception to this is individual M70, whom consumed a mixed C_3/C_4 diet ($\delta^{13}C$ = −14.9‰).

The human $\delta^{15}N$ values ranged from 7.9 to 11.1‰, with a mean ± SD of 9.4 ± 0.6‰. In addition, the $\delta^{34}S$ results ranged from 5.5 to 8.8‰ (mean ± SD; 7.0 ± 0.8‰), but only 20 individuals produced enough collagen for analysis. Examining Figure 2b, it is clear that pigs were the dominant source of animal protein for the Nancheng population since the humans plot directly above them (mean human-pig isotopic spacing = 0.2‰ for $\delta^{13}C$ and 1.6‰ for $\delta^{15}N$) although it is possible that cattle (mean human-cow isotopic spacing = 1.5‰ for $\delta^{13}C$ and 2.1‰ for $\delta^{15}N$) and dogs (mean human-dog isotopic spacing = 1.2‰ for $\delta^{13}C$ and 2.1‰ for $\delta^{15}N$) were also consumed to some extent. The variability in human $\delta^{15}N$ (3.2‰) represents approximately one trophic level indicating there were different degrees of domestic animal protein consumption in the population. Some individuals with low $\delta^{15}N$ values between ~8 and 9‰, likely had a mostly plant based diet of millet, since the $\delta^{15}N$ values are nearly identical or slightly elevated compared to the pigs, cows, and dogs. In contrast, individuals with high $\delta^{15}N$ values such as M28 (11.1‰), consumed a significant amount of protein mainly from pigs.

The $\delta^{34}S$ results are further support the humans mainly consumed pigs and some cows (Fig. 3a,b). However, a pair of cattle with lower $\delta^{34}S$ values compared to the other domestic animals and humans was unexpectedly found. Given that the trophic level shift for sulfur isotope ratios is about −1‰ (Nehlich, **2015**), human $\delta^{34}S$ values should be slightly lower than the animals they consumed. Therefore, these $\delta^{34}S$ results suggest that some cattle might not have contributed any significant amounts of protein to the regular diets of the humans. Thus, it is possible these cattle with low $\delta^{34}S$ values were obtained from a foreign area and might have been used more for labor rather than consumed.

Interestingly, the isotopic results from both the Nancheng and Liuzhuang sites (Hou et al. **2013**) suggest that humans did not consume sheep/goats in significant quantities compared to pigs (Fig. 4b). The exception to this at Nancheng was sample M70, since it appears that the diet of this individual was based on sheep/goats or that he/she was a possible migrant to the site (see below). If the sheep/goats did not act as dietary staples, then this is possible evidence they were kept for their secondary products such as wool. Unfortunately, no detailed zooarchaeological analysis has been conducted at Nancheng which could provide more information on this possibility. However, this finding is not without precedent during this time period in China. At the relatively contemporary late Neolithic/Early Bronze Age sites of Taosi, Xinzhai, and Erlitou, an analysis of the mortality profiles of the sheep and goats determined that the kill-off patterns were strongly suggestive of herding strategies related to maximize wool production (Dai et al., **2014**; Li et al., **2014**). Further, an isotopic study focused on animal husbandry practices at Xinzhai confirmed that the human diet was centered on pigs and cattle and that sheep were mainly exploited for wool (Dai et al., in press).

Like the sheep/goats, the large isotopic spacing for carbon (14.0‰), nitrogen (6.0‰), and sulfur (5.8‰) for the deer strongly suggests that they were not a major source of animal protein for the human population at Nancheng (Figs. 2b and 3a,b). Similar isotopic patterns were observed at the contemporary site of Xinzhai (Dai et al., in press), and at the somewhat earlier Late Longshan period (2200–1900 BC) site of Wadian (Chen et al., in press). Dai et al. (in press) proposed that the deer at Xinzhai might have been preferentially hunted for making tools and weapons given the large number of deer bone artifact recovered at the site, and this could also have been the case at Nancheng.

Linking diet with sex and age at Nancheng

To examine the possibility of sex related dietary variation, the $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ results of the confirmed males and females were compared in Table 1. A one-way ANOVA test found no significant differences for the $\delta^{13}C$ and $\delta^{15}N$ values, but did find a significant difference between the $\delta^{34}S$ results of the males and females (Table 1). Given the small number of individuals, particularly females, that were measured for $\delta^{34}S$, we believe it is premature to equate any substantial meaning to this finding at the moment. However, the results are intriguing and suggest a possible important area of future research whereby some females might have traveled from different areas to Nancheng or had slightly different diets compared to the males. The fact that the males and the females of the overall population did not show significant differences in their $\delta^{13}C$ and $\delta^{15}N$ values suggests the possibility that they had relatively equal access to food.

Table 1. Mean ± SD isotopic results classified by sex

	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{34}S$ (‰)
Male	−6.8 ± 0.5 (*N* = 27)	9.4 ± 0.6 (*N* = 27)	6.7 ± 0.7 (*N* = 9)
Female	−7.0 ± 0.2 (*N* = 12)	9.4 ± 0.7 (*N* = 12)	7.6 ± 0.6 (*N* = 4)

The results of a one-way ANOVA tests found no significant differences between the males and females for the $\delta^{13}C$ ($P = 0.41$) and $\delta^{15}N$ ($P = 0.93$) values, but did find a significant difference for the $\delta^{34}S$ ($P = 0.03$) results

The isotopic results were also compared by age group in Figure 5a. A one-way ANOVA test found no significant differences in the $\delta^{15}N$ values, but the $\delta^{13}C$ values of the individuals aged between 40–50 years old were found to be significantly elevated compared to the younger age groups (Table 2). In addition, when these results were further classified by sex between younger (less than 40 years old) and older (greater than 40 years of age) individuals, significant differences in $\delta^{13}C$ values were found for the males (one-way ANOVA, $P < 0.001$), but not for the females (one-way ANOVA, $P = 0.706$) (Fig. 5b). This finding that older males have elevated $\delta^{13}C$ values (mean ± SD, −7.3 ± 0.5‰) compared to the younger males (mean ± SD, −6.6 ± 0.3‰) could possibly be the result of their elevated status within the community where they were allowed or given a more variable diet, possibly more beef since the cattle have lower $\delta^{13}C$ values than the normal dietary staple of the pigs (Fig. 2b). This possibility would be in agreement with the historical texts written during later periods. However, we must caution that this is speculative, and we find no evidence that the older individuals, males or females, were consuming more animal protein in their diets compared to the younger members of the population. It is also entirely possible that these differences in $\delta^{13}C$ values have nothing to do with status and might reflect division of labor where the older males at Nancheng consumed a slightly different diet of more C_3 based foods from activities such as gathering wild plants or catching small game around the settlement site. Whatever the reason, it is difficult to determine or further speculate on a more precise cause for these isotopic differences between the young and old males, but we believe this is an area of important future research for Proto-Shang sites.

Figure 5.

Open Figure

(a) Human $\delta^{13}C$ and $\delta^{15}N$ results plotted in relation to the estimated age from the site of Nancheng, Hebei Province, China. No significant differences are observed in the $\delta^{15}N$ values, but individuals aged between 40 and 50 years old were found to be significantly elevated in $\delta^{13}C$ compared to the younger age group (Table 2). (**b**) Human $\delta^{13}C$ and $\delta^{15}N$ results plotted in relation to sex and sorted by younger (less than 40 years old) and older (greater than 40 years of age) individuals at the site of

Nancheng, Hebei Province, China. Significant differences in δ^{13}C values were found between the younger and older males (one-way ANOVA, $P < 0.001$), but not between the younger and older females (one-way ANOVA, $P = 0.706$).

Table 2. One-way ANOVA test comparing the 40–50-year-old humans with the individuals from the other age groups from Nancheng

Age groups	*N*	Mean δ^{13}C (‰)	Standard deviation	*P* value	Mean δ^{15}N (‰)	Standard deviation	*P* value
>20 years old	10	−6.7	0.4	**0.017**	9.4	0.5	0.49
20-30 years old	17	−6.7	0.4	**0.005**	9.4	0.8	0.37
30-40 years old	12	−6.7	0.3	**0.008**	9.5	0.5	0.40
40-50 years old	13	−7.2	0.6	–	9.4	0.3	–
Older than 50 years	3	−6.8	0.2	0.219	9.1	0.7	1.03

P values which are significant are in bold.

Linking diet, burial customs, and social status at Nancheng

Here we examine the possibility that individual dietary differences might be related to social status as inferred by the burial customs at the Nancheng site. Burial customs and the type and quality of graves goods can reveal important characteristics about a past culture including customs, religion, and status (Service, **1975**; Brown, **1981**; Danforth, **1999**; Scarre, **2005**; Curet and Pestle, **2010**). At Nancheng, the majority of the burials analyzed ($n = 70$) were oriented from west to east in a supine position, but five graves were aligned in a north to south direction (M46, M51, M70, M76, and M78), and two of these individuals (M51, M70) were the only ones to be buried in a flexed position (Supporting Information Table S1). These results are plotted in Figure 6, and it can be seen that there are no differences between the groups buried either west to east or north to south in the supine position. However, the two individuals that were buried in a flexed position have the lowest δ^{13}C values and standout from the rest of the population at Nancheng.

Figure 6.

Open Figure

Human δ^{13}C and δ^{15}N results plotted in relation to burial direction and position at Nancheng, Hebei Province, China.

Comparing our results to those of Hou et al. (**2013**) from Liuzhuang, similarities emerge, as three individuals are also seen with lower $\delta^{13}C$ values and variable $\delta^{15}N$ values (Fig. 4b); although M51 now overlaps with the main body of both populations. With these different diets and unique burial positions, it is possible that these two individuals were migrants to this Proto-Shang community. As a potential test of this hypothesis, we measured the bone collagen of M70 for $\delta^{34}S$ (M51 did not yield enough additional collagen for $\delta^{34}S$ analysis). However, the $\delta^{34}S$ result of M70 (while the highest, 8.8‰) was near the other humans (Fig. 3a,b) and within the range of the domestic animals (8.2 ± 2.6‰). This suggests that this individual was a local resident rather than an immigrant to the community, but it is possible that he/she was an immigrant from an area with a similar geological $\delta^{34}S$ signature as the Nancheng site. Unfortunately, as there is no sex or age information for M70, and as no grave goods were found, it is difficult to speculate on why these differences are observed. Whatever, the reason, it is clear that M70 was a unique individual to this community, and this evidence combined with the isotopic outliers and different type of burial customs (stone coffin, wooden coffin, earthen shaft pit) at Liuzhuang (Hou et al. **2013**), provide support to the theory that the Proto-Shang people were a collection of different groups or chiefdoms with different subsistence strategies rather than a single political or ethnic group (Zhu, **2007**; Wang, **2011**). Additional work is required using different isotopic measurements (oxygen, hydrogen, strontium, etc.) combined with ancient DNA analysis to determine if these observed outliers found at Nancheng and Liuzhuang represent local or migrant individuals, and this is an area of active research.

In order to investigate the relationship between diet and status, individuals were divided into three groups based on the type of grave goods recovered: high status (jade, calcite, shells; $n = 8$), medium status (only pottery; $n = 28$), and low status (no grave goods; $n = 39$) (Fig. 7). High status individuals such as M3 and M15, buried with shells and jade, were hypothesized to have more animal protein in their diets compared to the low status individuals based on the accounts of historical sources from later periods (see above). However, the data do not support this hypothesis as a one way ANOVA test found no significant differences between the $\delta^{13}C$ ($P = 0.463$) or the $\delta^{15}N$ ($P = 0.913$) results, suggesting that dietary variations were not related to wealth (as determined by the type of grave goods) and social status during the Proto-Shang period at Nancheng. In fact the highest $\delta^{15}N$ value (11.1‰) was found for M28, an adult male buried without grave goods. This finding (or lack thereof) is still important to Chinese history as it is possible evidence that the dietary differences associated with social hierarchy during the Shang and Zhou Dynasties had yet to be established during the Proto-Shang period.

Figure 7.

Open Figure

Human $\delta^{13}C$ and $\delta^{15}N$ results plotted in relation to status based on the type of associated grave goods recovered from the burials at Nancheng, Hebei Province, China. A one-way ANOVA test found no significant differences between the $\delta^{13}C$ ($P = 0.463$) or the $\delta^{15}N$ ($P = 0.913$) results, suggesting that dietary variations were not related to wealth (as determined by the type of grave goods).

While diet was not linked to status using grave goods, it is noteworthy that the low status individuals presented a broader range of $\delta^{13}C$ (−7.1 ± 1.4‰) and $\delta^{15}N$ values (9.4 ± 0.7‰) compared to the high ($\delta^{13}C$ = -6.7 ± 0.3‰; $\delta^{15}N$ = 9.5 ± 0.3‰) and medium status ($\delta^{13}C$ = −6.9 ± 0.4‰; $\delta^{15}N$ = 9.4 ± 0.4‰) individuals (Fig. 7). Similar trends have also been observed at other sites. For instance, at Wetwang Slack in East Yorkshire, UK, Jay and Richards (**2006**) found no distinctions between status and diet, but the $\delta^{15}N$ values of the "poor" (i.e., the group marked as "no barrow and no grave goods") showed a larger range than the "wealthy" (such as the "chariot burials" and the "barrows and grave goods") group. We interpret the narrow isotopic ranges observed for the high and medium status individuals at Nancheng as possibly reflecting more stable access to food resources and a more shared or similar subsistence pattern, whereas, the low status individuals might have had a more varied diet depending on their different means of livelihood.

CONCLUSIONS

Here we used a trio of isotopic measurements to examine dietary patterns at the Proto-Shang cemetery site of Nancheng and used these results to investigate social status and complexity as well as animal husbandry practices. The majority of the population had a C_4 diet based on millets, but a single individual (M70) was found to have a mixed C_3/C_4 diet. The $\delta^{34}S$ analysis of M70 determined this individual was unlikely a migrant even though his/her burial orientation (north-south) and position (flexed) was different from the majority of burials identified during excavation at the site. A large range of human $\delta^{15}N$ results suggest that animal protein consumption was variable, but that it was centered on pigs and cattle and possibly dogs. The sheep/goats were not consumed in great amounts and were likely kept for their secondary products (e.g., wool), and this finding is similar to the isotopic results of Liuzhuang (Hou et al. **2013**) and other sites from this period in north China. The exception to this was the M70 individual whom possibly had a diet based more on sheep/goats. While there was great diversity in the type and quality of grave goods recovered from the burials, no dietary differences were found to correlate with perceived social status. Also no link between diet and sex was found at the population level, but when the data were sorted by age and sex, the older males (> 40 years old) were found to have significantly lower $\delta^{13}C$ values compared to the younger males (< 40 years old). Thus, it appears that while the entire society as a whole likely had equal access to the dietary items of the community, older males were possibly given or allowed to eat more diverse diets such as cattle. However, the dietary social stratification discussed in the historical texts about the later Shang and Zhou periods is not observed at Nancheng which is possible evidence that these traditions had yet to be formally established during the Proto-Shang period. This study highlights the value of combining $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ measurements to examine diet, individual locality, social complexity, and animal husbandry patterns, and we hope it will spur additional research on Chinese archaeological collections.

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Article Information

Supporting Information

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