Shifting diets and the rise of male-biased inequality on the Central Plains of China during Eastern Zhou

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Abstract

Farming domesticated millets, tending pigs, and hunting constituted the core of human subsistence strategies during Neolithic Yangshao (5000–2900 BC). Introduction of wheat and barley as well as the addition of domesticated herbivores during the Late Neolithic (2600–1900 BC) led to restructuring of ancient Chinese subsistence strategies. This study documents a dietary shift from indigenous millets to the newly introduced cereals in northern China during the Bronze Age Eastern Zhou Dynasty (771–221 BC) based on stable isotope analysis of human and animal bone samples. Our results show that this change affected females to a greater degree than males. We find that consumption of the newly introduced cereals was associated with less consumption of animal products and a higher rate of skeletal stress markers among females. We hypothesized that the observed separation of dietary signatures between males and females marks the rise of male-biased inequality in early China. We test this hypothesis by comparing Eastern Zhou human skeletal data with those from Neolithic Yangshao archaeological contexts. We find no evidence of male–female inequality in early farming communities. The presence of male-biased inequality in Eastern Zhou society is supported by increased body height difference between the sexes as well as the greater wealth of male burials.

Keywords: bioarchaeology; paleo diet; Yangshao; East Asia

Eastern Zhou (771–221 BC), the last preimperial dynasty, nominally ruled much of China before the unification of its vast territory by Qin Shi Huang. A system of ethical and philosophical thought that has permeated Chinese social life through much of its history developed during Eastern Zhou from the teachings of Confucius (551–479 BC). Teachings recorded by his followers as The Analects of Confucius laid the foundation for the principles of Chinese society and government as well as prescribed men’s behavior in great detail (1). In The Analects of Confucius (論語), Confucius mentions women only once, stating that “唯女子與小人爲難養也。近之則不孫，遠之則怨。[It is not pleasing to have to do with women/wives or petty men/servants]” (ref. 1, p. 219), apparently consigning women to oblivion (2, 3). It remains unclear whether this neglect of women in the teachings reflects that lower status for women was already institutionalized during Eastern Zhou, because few early historic sources define the position of women in China during the early dynasties (4).

The objective of this paper is to investigate whether the status of women changed during the Bronze Age (1700 to ‒221 BC) (5) compared with their status in Neolithic Yangshao (5000–2900 BC). After the end of Yangshao, introduction of new cereals and domesticated herbivores to northcentral China led to restructuring of indigenous Chinese subsistence strategies. Research in other parts of the world has shown that subsistence restructuring frequently affected the social status of women and parental investment in female offspring (6, 7). We hypothesize that subsistence change during the Bronze Age would have similarly affected the position of women in China. We use stable isotope analysis to test for dietary differences between men and women during Yangshao and Eastern Zhou. Skeletal analysis allows us to compare male and female health and infer inequality in parental investment. Finally, we compare the distribution of grave goods and elaboration in grave construction between male and female individuals. The Eastern Zhou Dynasty communities are represented by two recently excavated skeletal series from cemeteries associated with the Ancient City of Zhong Han: Changxingyuan and Xiyasi (8) (Fig. 1). Animal data were obtained from the Zhong Han-associated site of Tianlin. The skeletal materials from five Yangshao (5000–2900 BC) archaeological sites, including Jiangzhai, Shijia, Xipo, Guanjia, and Xishan (9–12), serve as the Neolithic reference for early farming communities of China’s Central Plains.

Development of Indigenous Subsistence Strategies on the Central Plains of China

The Central Plains region, formed by deposits of the Yellow River and its tributaries, spans the fertile lands of Henan, southern Hebei, southern Shansi, and the western portion of Shandong as well as those of the Guanzhong Plain of the Wei River Valley in Shaanxi (Fig. 1). Two species of drought- and cold-resistant cereals collectively known as millets (Setaria italica and Panicum miliaceum) were first domesticated in the area by 8000 BC (13, 14) and persisted as principal crop plants through much of the history of the region (15–18). Remains of cabbage, grapes, poppy, rice, and acorns were also recovered from Yangshao sites, albeit in small quantities (18). Wheat (Triticum aestivum) and barley (Hordeum vulgare) were introduced into the area from the west sometime during the Late Neolithic (~2600–1900 BC) (19–21). However, the proportion of wheat and barley among the botanical remains was much lower than in later historical times (22). The remains of domesticated pigs, goats, and sheep were also ubiquitous in Yangshao cemeteries, and their proportion increased through time. The triarchal state. Analyzing human skeletal remains from early agricultural and later preimperial archaeological sites, we find no evidence of inequality between males and females in early farming communities. The observed differences between male and female skeletons from Eastern Zhou archaeological contexts allow us to infer a decline in female social status after the introduction of new crop plants and domesticated herbivores in preimperial China. The analysis reveals that male-biased inequality and subsistence change become intertwined with the rise of social complexity.

Significance

Male-biased inequality in Imperial China imposed strong limitations on the economic and intellectual contribution of women to the society and fostered male-biased resource distribution, because females were subordinated to the priorities of the patriarchal state. Analyzing human skeletal remains from early agricultural and later preimperial archaeological sites, we find no evidence of inequality between males and females in early farming communities. The observed differences between male and female skeletons from Eastern Zhou archaeological contexts allow us to infer a decline in female social status after the introduction of new crop plants and domesticated herbivores in preimperial China. The analysis reveals that male-biased inequality and subsistence change become intertwined with the rise of social complexity.
recovered from Late Neolithic and Bronze Age archaeological sites was persistently low compared with remains of indigenous millets (15, 22, 23). Domesticated soybeans (Glycine max) of the Leguminosae family also first appeared during the Late Neolithic and became more important over time (24). Historical records of the Han Dynasty (206 BC to AD 220) suggest that wheat, barley, and beans were initially regarded as coarse foods, provisioning the poor against famine (25). Only at the end of the Han Dynasty, when the development of hand mills and large water- and animal-powered mills allowed converting wheat into fine flour for noodle production, were these new cereals finally seen as valuable in the area (ref. 26, p. 461).

Faunal assemblages from Yangshao sites tend to be dominated by deer, domesticated pig, and dog bones (27–29). Domesticated cattle (Bos taurus) appeared on the Central Plains between 2500 and 2000 BC (30). Sheep also first appeared in the region during the Late Neolithic and were predominantly used for wool (31). Domesticated water buffalo (Bubalus bubalis) was introduced to China from South Asia as late as 1000 BC (32). Eastern Zhou faunal assemblages in our study area are dominated by the bones of domesticated animals. Pig remains were predominant followed by cattle, dog, horse, and sheep. Deer, fish, turtle, bird, and tiger bones were present in small quantities (33, 34).

**Stable Isotope Research**

The two stable isotopes of carbon, 12C and 13C, accumulate at different rates in plants using the C3 and C4 pathways of photosynthesis (35, 36). The overwhelming majority of plants follow the C3 pathway. The two millet species were the only C4 domesticates grown in Early China. The C4 pathway incorporates relatively more 13C into plant tissues, resulting in less negative δ13C isotopic signatures averaging around −12.5‰ as opposed to the −26.5‰ typical for C3 plants (37–39). Thus, consumption of millets can be detected by the stable isotope analysis of bone collagen, which preserves the isotopic composition of the diet plus an ~5‰ trophic-level enrichment.

Nitrogen isotopic composition (δ15N) for terrestrial food webs is a reliable indicator of animal product consumption (40). Because δ15N undergoes trophic-level enrichment of 2–6‰ with every step of the food chain (41, 42). In human communities where terrestrial diets are inferred from the geographic location and zooarchaeological evidence, higher δ15N values generally reflect greater proportions of animal products in the diet. Heavy reliance on legumes (e.g., beans) can potentially lower bone δ15N values. Legumes maintain colonies of nitrogen-fixing bacteria and hence, have δ15N values close to 0‰ (43).

Previous stable isotope studies on samples from the Central Plains and northeastern China confirm that millets served as the primary source of calories in the human diet from the beginning of Yangshao (9–12). Little stable isotope data are available for bone samples from dynamic China. There is no clear understanding as to when wheat, barley, and legumes began to contribute significantly to the human diet.

**Results**

**Dietary Differences Between Yangshao and Eastern Zhou.** We analyzed human bone samples from two Eastern Zhou sites (30 from Xiya and 16 from Changxin) as well as 23 samples from the Middle Yangshao site of Guanjuan. One Changxin sample and two Guanjuan samples were excluded from the analysis because of low collagen yield. Previously reported data from the Jiangzhai, Shijia, Xipo, and Xishan archaeological sites (n = 109) (9–12) were also included in the analysis (Fig. 2, Dataset S1, and SI Appendix, Table S1). Isotopic composition of the Eastern Zhou human bone collagen is significantly different from that of Yangshao samples for both δ13C values [median (Mdn) δ13C = −11.2 vs. −8.8‰, P = 5.5 × 10−12, Z = −6.5, exact Wilcoxon test (EWT), SD Eastern Zhou = 2.1‰, SD Yangshao = 1.4‰] and δ15N values [Mdn δ15N = 7.7 vs. 8.7‰, P = 0.003, Z = −2.93, EWT, SD Eastern Zhou = 1.0‰, SD Yangshao = 1.3‰]; 12 of 45 Eastern Zhou bone samples displayed more negative δ13C values than any of 130 Yangshao samples, indicating a mixed C3/C4 diet. Significant correlation between δ13C and δ15N values in the Eastern Zhou sample (Spearman’s correlation ρ = 0.61, P = 8.74 × 10−4) suggests that either consumption of C3 plants was associated with a lower proportion of animal products in the diet during Eastern Zhou or C3 and C4 staple cereals had different δ15N values.

**Sex Differences in Dietary Signatures During Eastern Zhou.** With the exception of Jiangzhai, no significant differences were observed between male and female δ13C and δ15N values within individual Yangshao sites (Fig. 2A and SI Appendix, Table S1) or for the Yangshao datasets overall (Mdn δ13C = −8.7 vs. −8.9‰ for males and females, respectively, P = 0.46, Z = −0.75, EWT, SDmales = 1.4‰, SDfemales = 1.2‰; Mdn δ15N = 8.8 vs. 8.5‰, respectively, P = 0.21, Z = −1.25, EWT, SDmales = 1.4‰, SDfemales = 1.3‰). For the Eastern Zhou sites, δ13C values of female skeletons were significantly more negative than those of males (Mdn = −13.5 vs. −9.9‰, P = 0.001, Z = −3.67, EWT, SDfemales = 2.0‰, SDmales = 1.6‰), indicating greater overall reliance on C3 plants for females. Eastern Zhou females also had lower δ15N values than males (Mdn = 7.5 vs. 8.5‰, P = 0.001, Z = −3.22, EWT, SDfemales = 0.9‰, SDmales = 0.8‰) (Fig. 2B).

Both Eastern Zhou males (Mdn Eastern Zhou = −9.9‰ vs. Mdn Yangshao = −8.7‰, P = 0.003, Z = −3.4) and females (Mdn Eastern Zhou = −13.5‰ vs. Mdn Yangshao = −8.9‰, P = 2 × 10−8, Z = −5.48) had more negative δ15N values than those of Yangshao individuals of the same sex (Fig. 2C and SI Appendix, Table S1). The magnitude of differences was considerably larger for females than for males [ΔMdn Eastern Zhou–Yangshao = 1.1‰, ΔMdn Eastern Zhou–Yangshao = 4.5‰ for males and females, respectively, P < 10−3, bootstrapping] (SI Appendix, Fig. S1B), suggesting that the dietary shift caused by inclusion of C3 staples affected females to a greater degree. With respect to δ15N values, no significant difference was observed between Eastern Zhou and Yangshao males (P = 0.12, Z = −1.16, EWT). Eastern Zhou females had lower δ15N values than their Yangshao counterparts (P = 0.001, Z = −3.08, EWT).

**Eastern Zhou Animal Isotopic Data.** It is possible that significant correlation between δ13C and δ15N values in Eastern Zhou humans as well as male–female differences in δ15N values were caused by consumption of cereals with different δ15N values (i.e., legumes or cereals from fertilized fields). Alternatively, male–female differences in δ13C values could relate to consumption of animals with different feeding patterns. To evaluate the effects of field fertilization and animal product consumption on human isotopic values, animal bone samples from the Eastern Zhou sites of Changxin and Tianli, including those of domesticated pigs, dogs, sheep, and

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cattle, were analyzed (n = 17) (Fig. 2D and SI Appendix, Table S1). The results were compared with data on Yangshao pigs and dogs from Xipo that we reported previously (11, 12) and other published data (SI Appendix, Table S2).

Isotopic values of domesticated mono-gastric animals (i.e., pigs and dogs) tend to reflect the composition of household refuse and hence, were examined together. For Eastern Zhou, \( \delta^{15}N \) values of these animals were low (Mdn_{pig\_dog} = 6.5‰, n = 8, SD = 0.9‰), similar to those of Eastern Zhou females (\( P = 0.12, Z = -2.59, \) EWT) but significantly lower than those of Eastern Zhou males (\( P = 0.0008, Z = 3.17, \) EWT). The wide range of \( \delta^{13}C \) values for Eastern Zhou pigs and dogs (from -15.7 to -7.9‰) (Fig. 2D) suggests that the fodder of some mono-gastric animals included large proportions of C3 plants, whereas others were mostly fed millet. Unlike for Eastern Zhou humans, there was no significant correlation between the \( \delta^{13}C \) and \( \delta^{15}N \) values of Eastern Zhou monogastrics (\( r = 0.63, P = 0.09 \)), indicating that Eastern Zhou C3 and C4 cereals had similar \( \delta^{15}N \) values and could not contribute to the observed correlation between \( \delta^{13}C \) and \( \delta^{15}N \) values in humans. \( \delta^{13}C \) values of Eastern Zhou pigs and dogs were more negative than those of Yangshao monogastrics (Mdn = -12.6‰, n = 8 vs. Mdn = -7.4‰, n = 7, \( P = 2.6 \times 10^{-5}, Z = -4.05 \), EWT). No significant difference was found for \( \delta^{13}C \) values between Eastern Zhou monogastrics and Eastern Zhou human males and females (\( P = 0.22, Z = 0.75 \) and \( P = 0.08, Z = -1.36, \) respectively).

Sheep \( \delta^{13}C \) values (Mdn = -15.8‰, n = 6, SD = 2.1‰) were significantly more negative than those of Eastern Zhou human males (\( P = 0.003, Z = 2.75, \) EWT) but were not significantly more negative than those of females (\( P = 0.21, Z = 0.79, \) EWT). Because the \( \delta^{15}N \) values of Eastern Zhou females were significantly lower than those of sheep (\( P = 0.004, Z = -2.67, \) EWT), it is unlikely that consumption of lamb affected female isotopic values. Cattle \( \delta^{13}C \) values were considerably less negative than those of sheep (Mdn = -10.4‰, n = 3, SD = 2.3‰, \( P = 0.01, Z = 2.31, \) EWT), likely because millet hay and straw were used to support the cattle through the winter. Cattle \( \delta^{13}C \) values were less negative than those of Eastern Zhou females (\( P = 0.02, Z = 2.02, \) EWT) but were not significantly different from those of Eastern Zhou males (\( P = 0.26, Z = 0.63, \) EWT).

**Stable Isotope Values and Cranial Lesions.** Reduction in diet quality is often associated with the development of cranial lesions known as cribra orbitalia (CO) and porotic hyperostosis (PH) that represent an adaptive reaction of skeletal tissue to red bone marrow...
Differences between male and female postcranial measurements. (A) Comparison of femur and tibia maximal lengths between Yangshao and Eastern Zhou by sex. ANOVA followed by a posthoc Tukey’s test was used to analyze the difference in means. The P value for the Tukey’s test is shown. (B) KDEs of male–female differences for pooled Yangshao and Eastern Zhou samples. The male–female pairs were assembled by a random draw from within each pooled sample. The gray areas indicate the 95% confidence bands for equality of male–female KDEs.

Body Height Dimorphism. Yangshao burials differed primarily in the number and type of grave goods and generally displayed little heterogeneity of wealth (47). To examine whether grave goods distribution was affected by sex during Yangshao, we constructed mosaic plots for the Jiangzhai and Xipo burials. Because Shijia burials were

Funerary Context and Sex. Yangshao burials differed primarily in the number and type of grave goods and generally displayed little heterogeneity of wealth (47). To examine whether grave goods distribution was affected by sex during Yangshao, we constructed mosaic plots for the Jiangzhai and Xipo burials. Because Shijia burials were
all secondary collective graves, making it impossible to test the association between goods and individual skeletons, evidence from this site was excluded. At Guanjia, grave goods were limited to small personal adornments, such as hairpins and beads, and did not display any heterogeneity by sex ($\chi^2 = 0.27$, df = 1, $P = 0.60$). Grave goods distribution in relation to sex was similar overall at Jiangzhai and Xipo. In both sites, male burials with no grave goods were over-represented. Large quantities of pottery were often found in association with female skeletons (Fig. 5 A and B and Dataset S4). At Xipo, where jade rings and yue axes were present, female burials with multiple pots also tended to have jade objects (Fig. 5B).

Eastern Zhou burials ranged from simple graves to ostentatious multichambered constructions with outer and inner coffins and a plentitude of objects (48, 49). Mosaic plots (Fig. 5 C and D and SI Appendix, Fig. S3) show a male-biased distribution of grave goods and investment in burial construction in the Eastern Zhou burials. As is evident from the plot, burials without an outer coffin, with a single chamber, and with zero to one grave items were most frequently associated with female skeletons. When a female burial had an outer coffin, the number of grave goods in such a burial exceeded the expectation, suggesting that, in a few cases, females had attained preferential treatment after death. Burials with an outer coffin and multiple grave goods were overrepresented in association with male skeletons. Conversely, even when a male burial lacked an outer coffin, it still tended to have multiple chambers and multiple grave goods. Heterogeneity of grave goods by sex was further illustrated by the principal component analysis (SI Appendix, Fig. S4).

Discussion

Subsistence strategies of the human communities on China’s Central Plains experienced a considerable restructuring during the Late Neolithic and Bronze Age as wheat, barley, and legumes as well as ruminant domesticated animals entered the area and gained importance. Using stable isotope analysis in this study, we find evidence of a dietary shift toward C3 plants during Eastern Zhou. Even allowing for substantial variation in local Yangshao diets (Fig. 2A), Eastern Zhou isotopic values clearly indicate an increased contribution from C3 plants. At the same time, even the most negative $\delta^{13}C$ values for Eastern Zhou humans are higher than those typical of a strictly C3 diet-reliant population (for instance, at rice-growing Neolithic Jiahu, where $\delta^{13}C$ values averaged $-20.3^{\circ}\text{C}$) (50). This finding suggests that C4 plants and C4 plant-consuming animals constituted a considerable bulk of the human diet during Eastern Zhou.

We have shown that the position of women during Eastern Zhou was qualitatively different from that during Yangshao. The $\delta^{13}C$ and $\delta^{15}N$ values of Eastern Zhou females are significantly lower than those of males, suggesting a greater consumption of C3 plants combined with lesser access to animal products for females. Low $\delta^{15}N$ values of Eastern Zhou females could be also a consequence of a larger proportion of legumes in their diet. Multiple accounts dated to the Han Dynasty attest to wheat, barley, and beans initially being regarded as low status foods, provisioning the poor against famine (25). Consumption of domesticated animals with C3-derived $\delta^{13}C$ values by females during Eastern Zhou is unlikely to have driven these sex differences, because highly negative $\delta^{13}C$ values in females were coupled with low $\delta^{15}N$ values. The observed strong separation between male and female dietary signatures (Fig. 2B) suggests that meals were no longer shared at the household level during Eastern Zhou.

It is also plausible that the observed separation of dietary signatures between sexes reflects the culturally prescribed dietary preferences of males and females. However, our analysis shows that highly negative $\delta^{13}C$ values were associated with PH and CO, cranial lesions linked to poor juvenile health (Fig. 3). The association between diet and health shown by this analysis is likely indirect. Weaning girls onto cereal grain and limiting their access to other foods through childhood, which has been noted in some contemporary patriarchal societies (51), would lead to increased female morbidity. Increased male–female body height dimorphism and observed depression of female bone dimensions during Eastern Zhou compared with Yangshao also suggest that parental investment during the Bronze Age shifted in favor of sons (Fig. 4).

Adult body height, albeit genetically controlled, is highly sensitive to the stresses of childhood (52). Male-biased parental investment, especially in groups where females contribute little economically, has been shown to result in increased differences between male and female adult body heights in past and present populations (53, 54).

Diminished social status of women during Eastern Zhou relative to that during Yangshao was also evident in the distribution of burial wealth. At the Yangshao sites of Xipo and Jiangzhai, a disproportionally larger number of male burials contained no grave goods (Fig. 5 A and B). Given that the ties of the living to the deceased largely determine funerary treatment (55), this finding implies that a Yangshao female from those sites may have had a more substantial kinship network at the place of her death than a male. Eastern Zhou burials exhibit a clear male bias for the distribution of grave goods and investment in grave construction (Fig. 5 C and D). Although skeletal identified sex is not equivalent to the sociocultural categories of gender, bioarchaeological findings have strong implications for sociocultural changes related to gender roles and gender inequality (56). Together with male-biased distribution of grave goods, the observed dietary, health, and metric differences between male and female skeletons provide a robust body of evidence for an inference of emergent male-biased inequality during the Bronze Age in Early China.

Fig. 5. Mosaic plots illustrating the distribution of grave goods and burial construction. The sizes of tiles correspond to the numbers of cases that fall within each category. Categories with no cases are marked by thin lines. Sex refers to the skeletally assessed sex of the skeleton in the burial, chambers refers to the number of funerary chambers, outer coffin refers to the presence of an outer coffin, number of items refers to the number of grave goods in a burial, teeth and bones and animal bones refer to the numbers of isolated animal bones and/or teeth in a grave. The heat map indicates deviation from the null hypothesis that all parameters of the funerary context are distributed evenly: dark blue, category is overrepresented; pink, category is underrepresented. A and B Distribution of items of different materials in the Jiangzhai and Xipo burials. C Distribution of items of different materials in the Eastern Zhou burials (Yixiai and Changxinyuan combined). D) Grave construction parameters in the Eastern Zhou sites (Yixiai and Changxinyuan combined).
Materials and Methods
A comprehensive description of the archaeological contexts of skeletal collections that were used in this study as well as a detailed description of methods are provided in SI Appendix. Collagen extraction and stable isotope analysis were carried out to the protocol described in ref. 19. Similar analyses, including sex assessment, identification of pathological lesions, and bone measurements, were carried out according to the protocol described in ref. 58. Maximal lengths of the humerus, femur, and tibia were used as proxies for adult body height. We also included vertical diameter of the humerus head, maximum diameter of the femur head, and femur epicondylar breadth because these measurements correlate with body height. Given the fragmentary nature of the skeleton collections examined, these measurements were selected based on availability of representative epiphyses.

EWTs were used for pairwise comparison of continuous variables. Kruskal–Wallis tests with posthoc Dunn’s tests and ANOVA with posthoc Tukey’s tests were used for multigroup comparisons. Bootstrapping with 10,000 resampling was used to evaluate differences between time period δ13C and δ15N value differences. KDE comparisons of principal component analysis of logistic regressions, and ROC analyses of skeletal measurements and stable isotope data were performed in R using the sm, FactoMineR, rms, and pROC packages.

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22. Songtao Chen (Shandong University) collected the stable carbon and nitrogen isotope data were performed in R using the sm, FactoMineR, rms, and pROC packages.