Journal of Archaeological Science: Reports 67 (2025) 105350

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Breastfeeding, weaning, and dietary patterns in the east Qinghai-Tibet Plateau, China during Han and Jin Periods by stable isotope analysis

Qi Dai [a,b], Rongyu Fu [a,b], Ningkang Xie [c], Yi Si [d], Guanjin Liang [e], Xiaoyan Ren [e], Quanchao Zhang [a,b,*], Liangliang Hou [f,**]

[a] *Bioarchaeology Laboratory, Jilin University, Changchun 130012 Jilin, China*
[b] *School of Archaeology, Jilin University, Changchun 130012 Jilin, China*
[c] *Key Laboratory for Molecular Enzymology and Engineering of the Ministry of Education, School of Life Science, Jilin University, Changchun 130012 Jilin, China*
[d] *School of History and Culture, Henan University, Kaifeng 475000 Henan, China*
[e] *Qinghai Provincial Institute of Cultural Relics and Archaeology, Xining 810000 Qinghai, China*
[f] *College of Archaeology and Museology, Shanxi University, Taiyuan 030006 Shanxi, China*

ARTICLE INFO

Keywords:
Taojiazhai Cemetery
Eastern Qinghai-Tibet Plateau
Han and Jin Periods
Breastfeeding and weaning patterns
Stable Isotope analysis

ABSTRACT

Breastfeeding and weaning represent critical phases in infant growth and development, offering valuable insights into early life conditions and the nutritional status of ancient populations. These practices significantly influenced population health, fertility rates, and, by extension, the stability and development of social economies. In recent years, bioarchaeological research has increasingly focused extensively on breastfeeding and weaning practices in ancient populations. However, limited attention has been paid to such practices during Han and Jin periods in the eastern Qinghai-Tibet Plateau. This study investigates the dietary structure and breastfeeding-weaning patterns of the ancient inhabitants of the Taojiazhai Cemetery in Xining, Qinghai, dating to Han and Jin periods (approximately 206–352 CE). Stable isotope analysis was conducted on 8 skeletal samples and 98 sequential dentin samples. The results indicate that the Taojiazhai population's diet consisted of a mixture of C_3 and C_4 plants, with a predominant reliance on C_3 plants, supplemented by varying amounts of animal protein. Most residents were weaned between 2.6 and 3.5 years of age, with males generally weaned later than females. In terms of feeding strategies, males consumed slightly more animal protein and C_4 foods than females during the weaning period, and after weaning, showed a dietary pattern featuring greater intake of animal protein and C_3-based foods. When interpreted in conjunction with the subsistence economy, historical background, funerary objects, and paleopathology, these findings also shed light on the rise of male-biased inequality in access to dietary resources, patterns of daily life, and social hierarchy.

1. Introduction

Infancy is a crucial phase of individual growth and development, with profound implications for long-term health and socioeconomic outcomes (Li et al., 2020; Pellegrino et al., 2017; Wang et al., 2019). Existing research highlights the vital influence of early-life conditions on survival, physical growth, cognitive development, and future economic potential (National Research Council & Institute of Medicine Committee on Integrating the Science of Early Childhood Development, 2000; Tang et al., 2019). Among these factors, breastfeeding and weaning are central to determining early health and nutritional status. Breastfeeding not only provides optimal nutrition but also strengthens immune function, protects against pathogen-induced infections, and supports the development of a stable gut microbiota, thereby lowering the risks of gastrointestinal disorders and allergic diseases (Ananthakrishnan et al., 2018; Henrick et al., 2021; Ho et al., 2018; Laursen et al., 2021; Murphy et al., 2017; Pannaraj et al., 2017; Piovani et al., 2019; Van den Elsen et al., 2019; Vandenplas et al., 2020; Walsh et al., 2020). Additionally, breastfeeding has been associated with reduced prevalence of pneumonia, eczema, and asthma, as well as a decreased likelihood of long-term conditions such as obesity, diabetes, and cardiovascular diseases (Amanda K Debes, 2013; Chowdhury et al., 2015; Forbes et al., 2018;

* Corresponding author at: School of Archaeology, Jilin University, Changchun, Jilin, China.
** Corresponding author at: College of Archaeology and Museology, Shanxi University, Taiyuan, Shanxi, China.
E-mail addresses: py2000sdqy@sina.com (Q. Zhang), llhou@sxu.edu.cn (L. Hou).

https://doi.org/10.1016/j.jasrep.2025.105350
Received 14 January 2025; Received in revised form 3 August 2025; Accepted 5 August 2025
Available online 11 August 2025
2352-409X/

Frank R. Greer et al., 2019; Huang et al., 2019; Koletzko et al., 2019; McAllister et al., 2019; Rito et al., 2019; Yan et al., 2014). The World Health Organization (WHO) and the American Academy of Pediatrics (AAP) recommend exclusive breastfeeding for the first six months of life. After this period, the introduction of complementary foods alongside continued breastfeeding is advised, with breastfeeding ideally maintained for at least two years. This approach has been shown to lower the incidence of growth stunting, lower respiratory tract infections, severe diarrhea, otitis media, and obesity, contributing to improved health outcomes in early childhood and later life (Eidelman et al., 2012; Goldman, 2012).

Although numerous studies in modern medicine and nutrition have demonstrated the positive effects of breastfeeding and weaning on infant health and development, key questions remain largely unexplored in archaeological and paleoanthropological research, specifically, how infants were fed in ancient societies and when weaning occurred. Early Chinese texts contain scattered references to weaning age and dietary practices in traditional societies, but these records offer only preliminary clues for reconstructing historical infant feeding strategies. For example, *The Analects of Confucius* (論語) mentions that a child remains under parental care for three years before being weaned, representing one of the earliest references to extended breastfeeding and parental involvement in Chinese history (Yang, 2018). During the Tang Dynasty, the renowned physician Simiao Sun (孫思邈) detailed infant feeding strategies in his influential medical text *Prescriptions Worth a Thousand Pieces of Gold for Emergencies* (備急千金方). He recommended introducing thin gruel at six months and gradually transitioning to more substantial foods by the age of five. However, he cautioned against excessive indulgence, such as delaying the introduction of solid foods until two or three years of age, warning that it could weaken the spleen and stomach and lead to chronic health issues (Sun, 1998). These textual records highlight the importance of infant feeding in traditional Chinese society and offer cultural insights into historical child-rearing. However, their practical relevance and generalizability are limited by temporal and geographic constraints, especially in under-documented areas like the northeastern Tibetan Plateau.

In this context, stable isotope analysis provides a valuable method for reconstructing early-life diets, offering proxy data on breastfeeding, weaning timing, and dietary shifts where direct evidence is lacking. This study applies carbon and nitrogen isotope analysis to bones and teeth from Han and Jin periods burial site at Taojiazhai, Xining, Qinghai Province. Located in an agro-pastoral frontier, the cemetery serves as a key case for exploring infant feeding practices within a mixed subsistence economy. This study aims to elucidate the weaning strategies adopted by the ancient inhabitants of the northeastern Tibetan Plateau in historical times and contribute to a deeper understanding of the early life history of ancient northwestern China.

2. Breastfeeding and weaning patterns by stable isotope analysis

In the natural environment, plants are classified into C_3, C_4, and CAM types based on their photosynthetic pathways, each of which induces distinct carbon isotope fractionation effects. C_3 and C_4 plants represent the primary dietary sources for humans. C_3 plants are characterized by lower $\delta^{13}C$ values, with a mean of approximately −26.5 ‰, whereas C_4 plants exhibit higher $\delta^{13}C$ values, averaging −12.5 ‰ (Farquhar et al., 1989; Farquhar et al., 1982; Lee-Thorp, 2008; O'Leary, 1981). These isotopic differences serve as key indicators in dietary reconstructions. Following the "you are what you eat" principle, the isotopic composition of consumed plants is reflected in the tissues of consumers. In bone collagen, $\delta^{13}C$ values are typically enriched by around 5 ‰ compared to dietary inputs (Ambrose et al., 1993; Kohn, 1999). Furthermore, $\delta^{15}N$ values increase systematically with trophic level, showing an enrichment of approximately 3.0 ‰ to 5.0 ‰(Hedges, 2003). This pattern is widely utilized to infer trophic positions and dietary protein sources.

Since the 1980s, stable isotope analysis has become a widely used method to study weaning practices and infant feeding behaviors (Fogel et al., 1989; Fuller et al., 2006; Nitsch et al., 2011; Pezo-Lanfranco et al., 2018; Stantis et al., 2021; Tian et al., 2025; Väre & Nordfors, 2025). Studies have shown that the $\delta^{15}N$ values of infants exclusively breastfed are about 2 ‰ to 3 ‰ higher than those of their mothers. With the progress of weaning and the introduction of complementary foods, the $\delta^{15}N$ values decline and are consistent with the adult isotopic characteristics after complete weaning (Fuller et al., 2006; Tsutaya & Yoneda, 2015). The $\delta^{15}N$ isotope pattern is essential for delineating the timing and duration of breastfeeding and weaning in historical populations. At the same time, the $\delta^{13}C$ values of breastfed infants are generally 1 ‰ higher than the $\delta^{13}C$ values of their mothers during lactation (Fuller et al., 2003; Richards et al., 2002). After the introduction of complementary foods, the $\delta^{13}C$ values decline faster than $\delta^{15}N$ and reach adult levels in a relatively short period of time (Fuller et al., 2006). Therefore, the $\delta^{13}C$ value during breastfeeding is an important indicator for tracking the addition of complementary foods during infancy and its composition.

Differences in metabolic characteristics and remodeling rates between bone and dental tissues render them complementary proxies in stable isotope analysis for reconstructing dietary patterns and behaviors across life stages. Bone tissue remodels continuously, with turnover rates differing by type: trabecular bone (e.g., ribs) renews at about 10 % annually, reflecting diet over 2–5 years, while cortical bone (e.g., femur) remodels slower at 2.5 % per year, averaging diet over roughly ten years (Hedges et al., 2007; Parfitt, 2002; Seibel, 2003). Thus, bone collagen isotopes represent long-term dietary averages. In contrast, teeth, which do not remodel after mineralization, preserve isotopic signatures from formation, making them vital for reconstructing early-life diet and weaning patterns (Beaumont et al., 2014; Elamin & Liversidge, 2013). Permanent teeth develop from shortly after birth through adolescence, with specific teeth corresponding to distinct developmental stages, enabling precise chronological dietary analysis (AlQahtani et al., 2010; Beaumont & Montgomery, 2015; Hillson, 2014; Smith, 1991). Combining carbon and nitrogen isotope data from teeth and bones allows detailed reconstruction of dietary transitions from infancy to adulthood, offering critical insights into early feeding strategies and subsistence in ancient populations (Lei & Guo, 2022).

Since 2017, research into breastfeeding and weaning practices among ancient populations in China has expanded significantly. Studies focusing on southern China, spanning the Late Neolithic to the Sui-Tang periods, suggest that diets in this region were predominantly based on C_3 plants, with supplemental intake of C_4 plants (Lee et al., 2020; Xia et al., 2018; Yi et al., 2021; Yi et al., 2018; Yi et al., 2024; Yi et al., 2019). Research from central China indicates that ancient populations typically weaned between 2.5 and 4 years of age, with early childhood diets rich in C_4 plants (Lei et al., 2023; Miller et al., 2020; Miller et al., 2023). Investigations into feeding strategies in northwestern China reveal a higher reliance on animal protein, with some nomadic groups continuing breastfeeding beyond 4 years of age (Cui et al., 2024; Cui et al., 2025; Dai, 2024; Dai et al., 2025; Wang, Fuller, et al., 2022; Wang, Wei, et al., 2022). Overall, the weaning age in ancient China commonly ranged from 2.5 to 4 years, with complementary foods varying according to geographic and economic subsistence patterns. However, limited research has been conducted on regions like Qinghai. Investigating the breastfeeding and weaning practices of ancient populations in the east Qinghai-Tibet Plateau would significantly advance our understanding of early life history and adaptive strategies of frontier populations in ancient China.

3. Materials and methods

3.1. The archaeological context

The Taojiazhai Cemetery is located in the northern suburbs of

Xining, at geographic coordinates 36°41.348′ N and 101°44.443′ E, with an altitude of 2,330 m (Fig. 1). The cemetery features a terrain that is higher in the west and lower in the east, with a relative elevation difference of approximately 15 m. Positioned east of the Beichuan River and west of the Xishan Mountains, the area is characterized by flat and expansive topography. The cemetery primarily comprises burial features dating from the Eastern Han to the Wei-Jin periods and is notable for its large scale and high burial density. Between March and November 2002, the Qinghai Provincial Institute of Cultural Relics and Archaeology conducted a rescue excavation at the cemetery, uncovering 47 tombs. These were primarily categorized as brick-chamber tombs and pit tombs. A total of 695 artifacts were recovered, including items made of pottery, bronze, iron, wood, bone, stone, jade, agate, amber, and precious metals such as gold and silver (Qinghai Provincial Institute of Cultural Relics and Archaeology, 2007). These findings provide critical material cultural evidence, offering insights into the historical and cultural development of the region during Han and Jin periods.

Sex and age analyses of the human remains from the Taojiazhai Cemetery reveal a lower mortality rate among juveniles and a higher mortality rate among middle-aged residents (36–55 years old) (Zhang, 2008). DNA analysis indicates genetic continuity between the Taojiazhai inhabitants, the ancient Lajia population, and the modern Qiang ethnic group, suggesting historical coexistence of the Qiang and Han peoples during Han and Jin periods (Li et al., 2017). Paleopathological studies identified a high prevalence of traumatic injuries within the population, likely linked to violent conflicts of the time. Additionally, a significant prevalence of dental caries was observed, closely associated with the development of the agricultural economy (Zhang, 2008). The dietary shift toward foods high in sugars and starches, resulting from agricultural advancements, likely contributed to the increased incidence of dental caries among the population.

Research on the archaeobotanical and zooarchaeological aspects of the Taojiazhai Cemetery remains limited, with interpretations of its subsistence economy largely based on historical textual sources (Gao, 2005). The Taojiazhai Cemetery, situated in the Huangshui Valley, is historically documented as a settlement area for the Qiang people. According to the *Book of Later Han: The Biography of Xiqiang* (後漢書·西羌傳), the Qiang had limited agricultural production, primarily relying on pastoralism, and were extensively involved in hunting various wild animals (地少五穀，以產牧為業，多禽獸，以射獵為事) (Ban, 1962). Additionally, a record from the fifth year of Yongyuan (永元五年) (93 CE) described a winter harvest of several thousand bushels of wheat (收麥數萬斛), indicating that wheat, along with barley, buckwheat, and foxtail millet, was widely cultivated in the region (Wang & Fan, 2013). Archaeological evidence further reveals a dietary transition in the Huangshui Valley between 2000 and 1000 BCE, shifting from a millet-based economy to one centered on wheat cultivation (Ma, 2013). These findings suggest that during Han and Jin periods, the residents of the Huangshui Valley adopted a mixed subsistence strategy, incorporating both agricultural and pastoral practices. Wheat and millet likely served as the primary crops, supplemented by animal-derived protein. Based on this evidence, it can be inferred that the weaning practices of the Taojiazhai population reflected this mixed agricultural-pastoralist economy, with complementary diets likely including C_3 plants (e.g., wheat), C_4 plants (e.g., millet), and animal protein. To evaluate this hypothesis, the present study will perform carbon and nitrogen stable isotope analysis on human remains from the Taojiazhai Cemetery. This analysis aims to provide a more detailed understanding of the weaning practices and dietary strategies of Han and Jin periods populations, contributing to broader discussions on subsistence strategies and early life histories of ancient communities in the region.

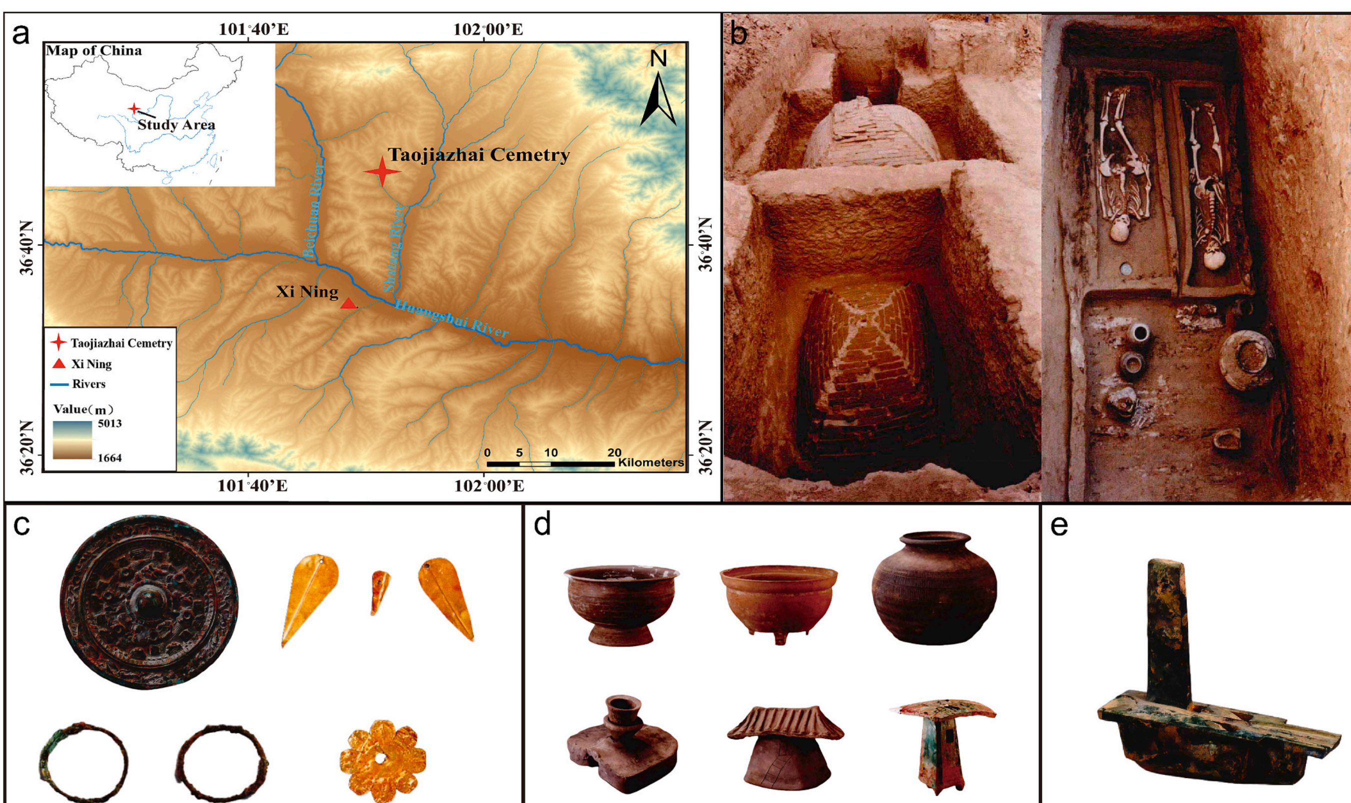

Fig. 1. **a.** Location Map of Taojiazhai Cemetery (Map generated using ArcGIS 10.2); **b.** External structure and internal burial characteristics of one of the tombs at the Taojiazhai Cemetery; **c.** Taojiazhai Cemetery funerary ornaments (a copper mirror, silver earrings, gold flower decorations, a gold leaf decoration); **d.** The pottery assemblage unearthed from the Taojiazhai Cemetery includes ceramic gui (ritual food containers), zun (wine vessels), jars, stoves, and granary models; **e.** A copper crossbow trigger buried in Taojiazhai Cemetery.

3.2. Sample selection and processing for stable isotopic analysis

The dental samples primarily consisted of first molars and canines, selected due to their importance in reflecting critical early life stages from birth to approximately 10 years of age. The first molars (M1) were generally prioritized, as they begin to form within the first few months after birth and are completed by around the age of 9–10 years. Canines were selected as secondary samples, given that they begin to form around 6 to 9 months of age and are completed by 13–14 years. For skeletal samples, ribs were the primary choice because their chemical composition undergoes complete replacement closer to the time of death, making them highly valuable for obtaining physiological data from the last few years of life. In the absence of rib bones, other long bones such as the femur and tibia were selected as secondary options. It is important to note that, with the exception of individual TJZ02, whose skeletal remains were poorly preserved and for whom only dental samples were available, both skeletal and dental samples were successfully obtained from the remaining eight residents. Detailed information regarding the sample set is provided in Table 1.

A total of 9 residents were sampled from the Taojiazhai Cemetery in Xining, Qinghai (4 females, 3 males, and 2 minors whose gender could not be determined using existing scientific methods), accounting for about 2.4 % of the total number of residents excavated in the cemetery (9/378). Although the sample size was small, the selection process was very strict, giving priority to residents with well-preserved teeth and bones, clear development stages, and complete archaeological background records. The gender and age composition of the selected residents varied, which to a certain extent reflected the basic structure of the cemetery population. Specifically, the sample included 1 adolescent (7–14 years old), 3 young adults (15–23 years old), 2 middle-aged (24–35 years old), and 3 adults (36–55 years old).

A total of nine dental samples were obtained, including eight first permanent molars and one canine. Samples were selected based on preservation quality, minimal dentin wear, and absence of pathological conditions. The first molar was preferred due to its early development shortly after birth and root apex closure around 9.5 years (±6 months) for maxillary molars and 10 years (±6 months) for mandibular molars. The canine was chosen as a secondary option, initiating development around six months of age and completing root formation by approximately 14.5 years (±6 months). For the two non-adults, only the second deciduous molar was sampled, as it begins forming during the perinatal period and completes root formation by about 3.5 years of age, making it the last deciduous molar to finish development (AlQahtani et al., 2010; Beaumont & Montgomery, 2015; Hillson, 2014; Lei & Guo, 2022). All adult residents who provided dental samples also had corresponding skeletal samples taken, with ribs as the preferred bone type; long bones were used when ribs were unavailable. Age and sex determinations were made using methods established by White and Zhu Hong. Detailed sample information is presented in Table 1.

The preparation of tooth samples followed the methodology described by Czermak et al. (2020) and Lei and Guo (2022). Initially, the teeth were mechanically cleaned using air abrasion with aluminum oxide powder to remove surface debris at the Biological Archaeology Laboratory of Jilin University. The samples were then partially embedded in Herculite II, a high-strength gypsum-based molding material. Longitudinal sections (~1.5 mm thick) were obtained using a Buehler Isomet low-speed diamond saw at the Dinosaur Evolution Research Center of Jilin University. Each section underwent demineralization in 10 mL of 0.5-M HCl at 4 °C for approximately two weeks at the Biological Archaeology Laboratory of Jilin University. After demineralization, the sections were treated with 0.1 M NaOH for 30 min at room temperature, followed by treatment with 0.5-M HCl for one hour. Although the selected samples were macroscopically well-preserved, slight discoloration and lower collagen yields in some sections suggested potential organic contamination, possibly from humic acids in the burial environment. Therefore, the NaOH treatment was employed as a precautionary step to remove such contaminants, following the recommendations of Brock et al. (2010). This step was used selectively and with caution to minimize collagen loss, particularly given the small sample size. Between each reagent treatment, the sections were thoroughly rinsed with deionized water(Brock et al., 2010). Subsequently, the sections were rinsed three times with deionized water until they reached a neutral pH. Dentine samples were collected sequentially from the crown to the root apex using a 1-mm KAI medical biopsy punch with a plunger. The anatomical position of each dentine slice was then compared with tooth development stages, following the reference framework of AlQahtani et al. (2010). Dentine micro-samples were labeled based on their sequence and approximate developmental age. Finally, the micro-samples were freeze-dried to preserve the material in an undenatured state (supplementary Table 1). The detailed experimental procedures are illustrated in Fig. 2.

Due to the varying secretion rates of dentin during different developmental stages, including the crown, root, and apex, incremental growth is particularly slower at the cervical region. In this study, dentin was divided into three sections—crown, root, and apex—for sequential microdrilling sampling. Taking the mandibular first molar and canine as examples: The crown of the mandibular first molar has an average thickness of approximately 4–5 mm, and its formation is completed around 3.5 years of age. When sampled sequentially at 1 mm increments, each sample represents roughly 0.7–0.9 years of dentin growth. The root and apex have an average combined thickness of about 12–13 mm, with full development completed at 10 years of age. Sequential sampling at 2 mm increments results in each sample representing approximately 1 year of dentin growth. The crown of the mandibular canine has an average thickness of about 5 mm, with formation completed at around 5.5 years of age. Sequential sampling at 1 mm increments yields samples representing approximately 1.1 years of dentin growth. The root and apex, with an average combined thickness of approximately 18 mm, are fully developed by 13 years of age. Sampling at 2 mm increments results in each sample representing

Table 1
Stable carbon and nitrogen isotope values for the human bones from the Taojiazhai Cemetery.

Lab. ID	Location	Age	Sex	Funerary objects	Skeletal type	Collagen yield (%)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C (%)	N (%)	C/N
TJZ01	M2	35–40	Female	A copper tent hook	Rib	2.7	−16.6	11.9	41.0	15.0	3.2
TJZ02	M5	35–40	Male	A copper crossbow trigger, A rectangular copper ware, Copper Wu zhu coins, Bone ornaments	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TJZ03	M10	14–16	Female	N/A	Rib	4.6	−16.9	12.0	44.6	16.2	3.2
TJZ04	M10	12 ± 2.5	?	N/A	Rib	5.7	−16.8	12.1	44.7	16.3	3.2
TJZ05	M12	15±	Female	A copper ring	Rib	8.4	−17.4	11.9	43.5	16.0	3.2
TJZ06	M16	20–23	Female	N/A	Tibial	3.7	−17.5	10.7	47.4	17.2	3.2
TJZ07	M26	20–25	Male	A bronze helmet, A lead ring,	Rib	8.9	−16.9	12.1	41.3	14.9	3.2
TJZ08	M40	50–55	Male	A copper belt hook	Rib	4.2	−17.6	11.1	43.0	15.6	3.2
TJZ09	M63	10 ± 2.5	?	N/A	Fibula	5.3	−17.6	9.8	42.0	15.1	3.2

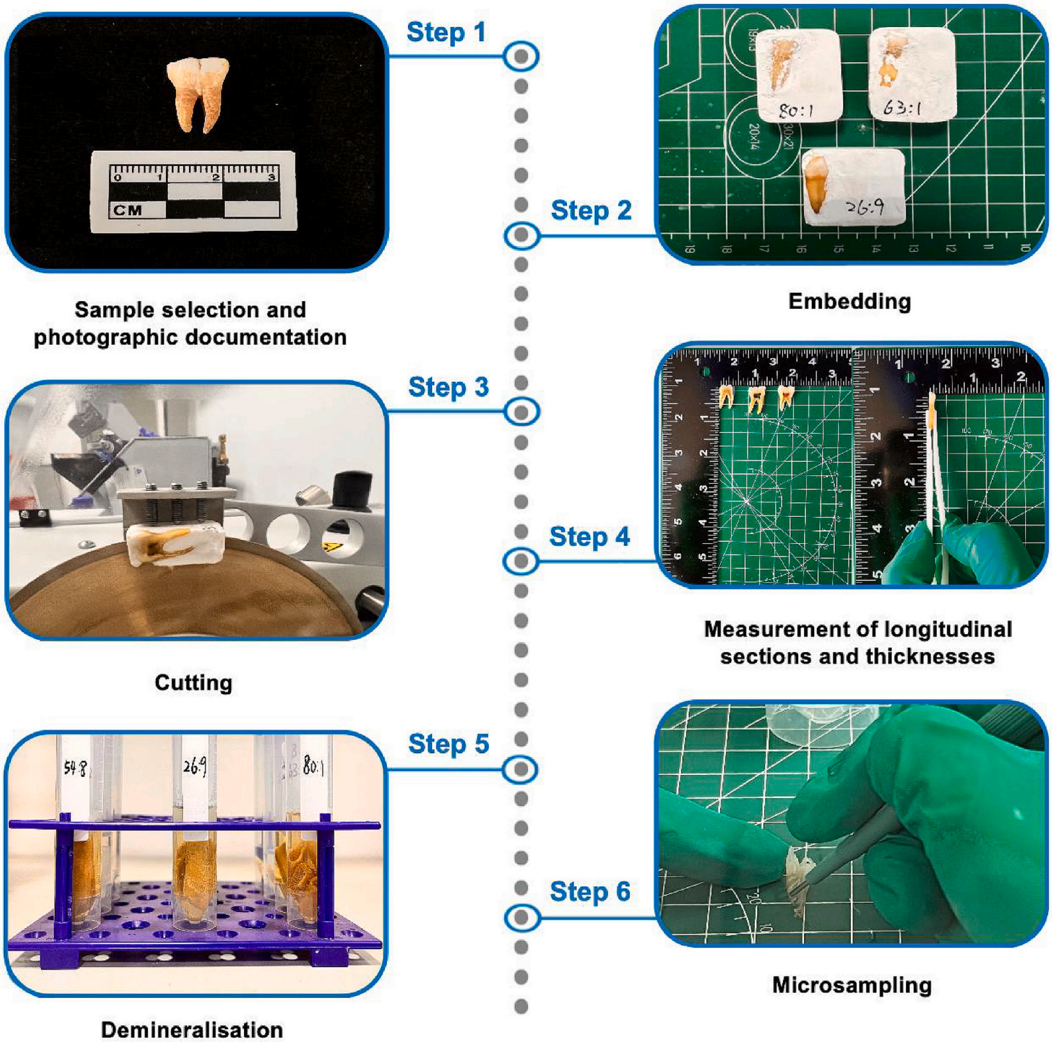

Fig. 2. Microsampling workflow.

approximately 0.9 years of dentin growth. The tooth sampling diagram is detailed in Fig. 3.

The bone sample preparation followed the collagen extraction protocol as described by Richards and Hedges (1999). Bones (~2 g) were cleaned by sonication and then demineralized in a 0.5-M HCl solution at below 5 °C until the bones were soft and bubble-free. The HCl

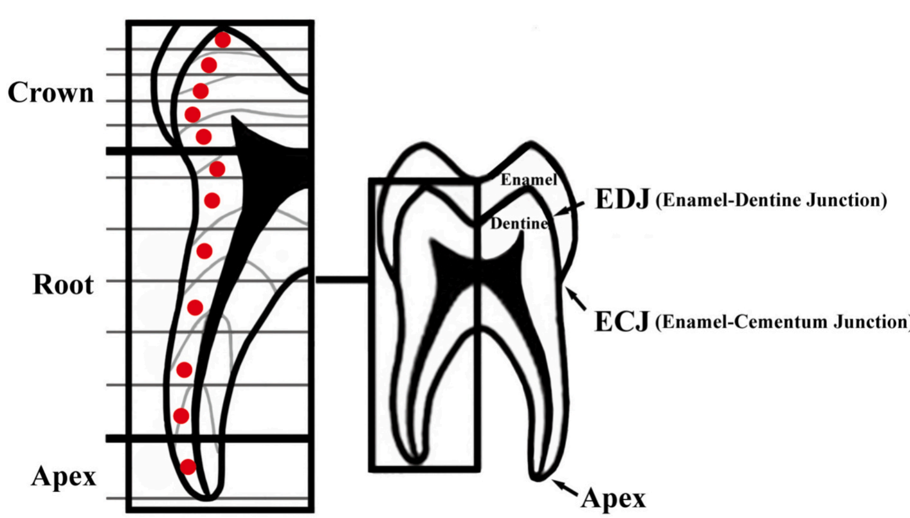

Fig. 3. Schematic diagram of continuous section sampling of crown, root and apex of mandibular first molar revised from Lei et al. (2023), the sampling methodology is informed by the anatomically sensitive dentine microsampling approach described in Czermak et al. (2020).

solution was changed every 2–3 days. To remove humic acid, the samples were rinsed with deionized water until they became neutral and then soaked in 0.125-M NaOH at room temperature for 20 h. After rinsing with deionized water, the samples were gelatinized in a pH3 HCl solution at 70 °C for 48 h. Finally, bone collagen was obtained by lyophilization after concentration and freezing. (Table 1).

3.3. Stable isotopic testing and analysis

Collagen samples were measured in an IsoPrime-100 IRMS coupled with an Elementary Pyro Cube elemental analyser at the test center of the Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences. The standard for measuring the content of C and N is sulfanilamide. IAEA-N-1 and USGS 24 were used to normalize N_2 (AIR as standard) and CO_2 (VPDB as standard) in steel bottles, respectively. After every 10 samples, we ran an in-house collagen sample standard ($\delta^{13}C = -14.7 \pm 0.1$ ‰, $\delta^{15}N = 6.9 \pm 0.2$ ‰) for adjustment. The analytical precision for $\delta^{13}C$ and $\delta^{15}N$ was ± 0.2 ‰. Each sample were measured in duplicates; the average value was taken, and a standard deviation of less than ± 0.1 ‰ was maintained. Test results were expressed as $\delta^{13}C$ (relative to VPDB) and $\delta^{15}N$ (relative to AIR).

Statistical analyses were performed using SPSS 25, RStudio 2023.12.0 + 369 was used for graphing.

3.4. Identification of bone and dentine contamination

The most important indicators of collagen contamination (Hedges, 2002) are the carbon and nitrogen contents of collagen and the C/N molar ratio. Modern sample collagen shows that the carbon and nitrogen contents are between 15.3 % and 47 %, and 5.5 % and 17.3 %, respectively (Ambrose, 1990). A C/N molar ratio between 2.9 and 3.6 (DeNiro, 1985), it indicates that the collagen is not contaminated. It can be seen from Table 1 and supplementary Table 1 that except for the TJZ07-8 sample, which did not extract collagen, the remaining 97 dentine samples and 8 bone samples were within the range of non-contaminated standard and can all be used.

3.5. AMS-^{14}C dating

To further refine the absolute chronology of the Taojiazhai Cemetery, a fibula from individual M63 (XTM63:1) was selected for radiocarbon dating.

The chronological framework of the article was established based on carbon-14 dating data from the Beta Laboratory, and calibrated using the OxCal program (Ramsey, 2017) from Oxford University, using IntCal 20.0 as the reference database (Reimer et al., 2020). The dating information is presented in Table 2.

4. Results and discussions

4.1. AMS-^{14}C date and isotopic results

The AMS-^{14}C dating results for the human bone sample (XTM63:1) is 1790 ± 30 a BP, (Table 2). After calibration using tree-ring data, the ages of the sample is estimated to be between 1744 cal. a BP ~ 1598 cal. a BP (with a confidence level of 95.4 %) (Fig. 4). Based on the calibrated radiocarbon date, in conjunction with the characteristics of the unearthed remains and funerary objects, a preliminary assessment suggests that the Taojiazhai cemetery dates to the late Eastern Han to Eastern Jin period.

4.2. Stable isotope analysis and dietary structure of the Taojiazhai Cemetery inhabitants

The stable isotope analysis presented in Table 1 indicates that the $\delta^{13}C$ values of bone collagen from the ancient residents at the Taojiazhai Cemetery range from −17.6 ‰ to −16.6 ‰ (mean ± SD value: −17.2 ± 0.4 ‰, n = 8). These values suggest a diet predominantly based on C_3 plants. The $\delta^{15}N$ values range from 9.8 ‰ to 12.1 ‰, (mean ± SD value: 11.5 ± 0.8 ‰, n = 8), indicating a significant contribution of animal protein to their diet.

In comparison, the $\delta^{13}C$ values of dentin collagen, as presented in supplementary Table 1, range from −18.7 ‰ to −9.8 ‰ (mean ± SD value: −16.9 ± 1.3 ‰, n = 97), This reflects a mixed dietary composition incorporating both C_3 and C_4 plants, though predominantly relying on C_3 resources. The broader range of $\delta^{13}C$ values in dentin suggests considerable dietary variability during childhood. Similarly, the $\delta^{15}N$ values of dentin range from 9.8 ‰ to 14.3 ‰ (mean ± SD value: 11.4 ± 0.9 ‰, n = 97), further supporting the substantial intake of animal protein in early life.

A comparative analysis of isotopic data from bone and dentin collagen reveals dietary shifts across different life stages. Bone collagen, which reflects dietary intake during later stages of life (mean ± SD value: $\delta^{13}C$ −17.1 ± 0.4 ‰, $\delta^{15}N$ 11.4 ± 0.8 ‰, n = 8), indicates a slightly higher reliance on C_3 plants and variable levels of animal protein consumption compared to dentin collagen, which captures childhood dietary patterns (mean ± SD value: $\delta^{13}C$ −16.9 ± 1.3 ‰, $\delta^{15}N$ 11.3 ± 0.9 ‰, n = 97). These findings are further illustrated in Fig. 5, where isotopic sequences from juvenile dentin (depicted as points) show partial overlap with the isotopic signatures of adult bone collagen (represented by dashed lines). The observed dietary transitions and their potential causes will be explored in greater detail in the subsequent discussion.

Isotopic evidence indicates that approximately 4,000 years ago, the diets of ancient populations in the Hehuang region and adjacent areas were primarily based on C_4 resources, most likely millet or animals raised on millet, with no isotopic signatures of C_3 plants detected (Ma et al., 2016). Around the turn of the Common Era, China entered a cooling phase, culminating in a pronounced cold period during the early fourth century CE (Fan & Ye, 2014; Ge et al., 2014; Zhu, 1972). Against this climatic backdrop, cultivation of cold- and drought-tolerant crops such as barley and spring wheat expanded in the Hehuang region (Li, 2009; Wu, 2014). Supporting evidence from macrobotanical remains and stable isotope data from the Han–Jin period reveals a mixed C_3/C_4 dietary pattern among local populations, with C_3 resources, either through direct consumption or indirectly via animal fodder, playing a predominant role. (Gao, 2024; Wang, 1995).

Historical texts such as *The Book of Later Han: The Biography of Xiqiang* (後漢書·西羌傳) and *The Book of Han: The Biography of Zhaochongguo* (漢書·趙充國傳), document that by the first century BCE, the Qiang people of Qinghai had already begun cultivating wheat (Gao, 2005; Wang, 2012). These lines of evidence suggest that this period witnessed a major agricultural transition, from a millet-dominated system to one increasingly centered on wheat and barley, reflecting a broader adaptive response to changing environmental and socio-

Table 2
AMS-^{14}C dating data of the human bone from the Taojiazhai Cemetery (using OxCal V4.4. (Ramsey, 2017), and the IntCal 20 calibration curve (Reimer et al., 2020)).

Lab ID.	Sample No.	Material	Radiocarbon date (a B.P.)	Calibrated date (95.4 % confidence) (cal. a B.P.)
Beta-673884	XTM63:1	Human Fibula	1790 ± 30	1744–1598

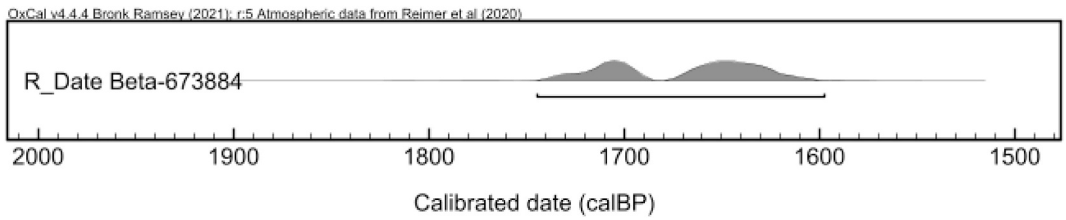

Fig. 4. Chronological distribution of radiocarbon data of the human bone at the Taojiazhai Cemetery.

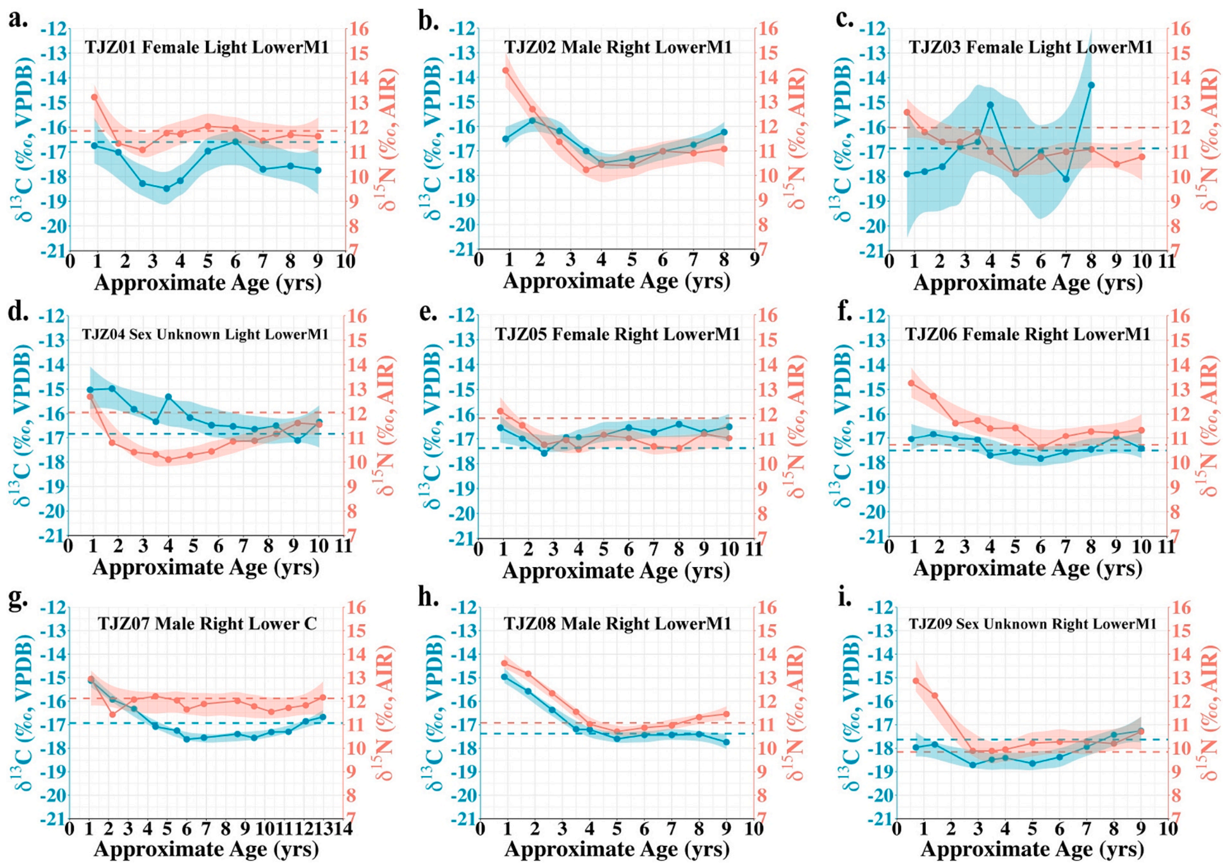

Fig. 5. Plots of dentin sequence and skeletal carbon and nitrogen stable isotope values shift with age in adult individuals from the Taojiazhai Cemetery.

political conditions (Ma et al., 2016). The introduction of domesticated cattle, sheep, and goats around 4,000 years ago further facilitated the emergence of agro-pastoral economies in the Hehuang region.

Among Han–Jin residents in the area, elevated $\delta^{15}N$ values point to the importance of animal protein in the diet, indicating a substantial reliance on meat consumption (Gao, 2024). This interpretation is corroborated by the frequent presence of sacrificed livestock, particularly sheep and cattle, in the burials at the Taojiazhai cemetery (Zhang & Li, 2018). Historical accounts also describe how, during repeated Han–Qiang military conflicts, the Han army routinely captured tens of thousands of livestock following major battles, with vivid descriptions such as "captives filled the roads; cattle and sheep blanketed the mountains" (降虜載路, 牛羊滿山), attesting to the advanced pastoral economy of the time. Collectively, these findings suggest that Taojiazhai inhabitants during Han and Jin periods adopted a mixed subsistence strategy combining agriculture and animal husbandry. With the continued implementation of migration and military-agricultural colonization (tuntian) policies by the Central Plains dynasties in the Hexi-Huangshui (Hehuang) region, the area underwent increasing levels of sinicization under the sustained influence of agrarian culture. As a result, agriculture-based subsistence strategies became widely established. Funerary objects unearthed from the Taojiazhai cemetery, such as granaries and stoves—symbols of a sedentary agricultural society—further underscore the central role of agricultural production in local socio-economic life during Han and Jin periods (Qinghai Provincial Institute of Cultural Relics and Archaeology, 2015). Collectively, these lines of evidence suggest that while animal husbandry remained well-developed, agriculture also held a prominent position in the subsistence economy of the Taojiazhai community in this period.

Stable isotope data from the Taojiazhai cemetery (dentine: $\delta^{13}C$ − 16.9 ± 1.3 ‰, $\delta^{15}N$ 11.3 ± 0.9 ‰; bone collagen: $\delta^{13}C$ − 17.1 ± 0.4 ‰, $\delta^{15}N$ 11.4 ± 0.8 ‰) reflect a dietary regime incorporating both C_3 (e.g., wheat and barley) and C_4 (e.g., millet) plants, along with animal-derived products. These results indicate a mixed diet comprising cereals and animal-based foods, including mutton, beef, and possibly dairy products.

4.3. Weaning patterns of residents

Fig. 5a–i illustrates age-related variations in carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes in the dentin of nine residents from the Taojiazhai Cemetery in Qinghai, which offers insights into dietary transitions during early life and later stages.

As shown in Fig. 5 and Fig. 6a, the δ^{15}N values for the nine residents exhibit a gradual decline starting at approximately 0.9 years of age, reaching their lowest levels around 3.5 years before beginning to rise again. This trend indicates that most residents completed weaning between 2.6 and 3.5 years, with a few, such as TJZ03 and TJZ08, completing the process later, beyond 4 years of age.

Weaning completion ages were further analyzed by sex, and the respective mean ages were calculated. Males completed weaning at an average age of approximately 4 years, while females completed the process at an average age of 3.5 years, indicating that males were weaned later than females. As shown in supplementary Table 1 and Fig. 6b, slight differences in δ^{13}C values were observed between the sexes during the weaning period. Stable isotope data from dentin sequences of male ($n = 3$) and female ($n = 4$) residents from the Taojiazhai cemetery were also analyzed. Given the small sample size and non-normal distribution of the data, as indicated by the Shapiro-Wilk test and histograms, the non-parametric Mann-Whitney *U* test was employed. Results reveal a statistically significant difference in δ^{13}C values between sexes during the weaning period. Females exhibited lower δ^{13}C values (mean: -17.1 ± 0.7 ‰) than males (-16.3 ± 0.8 ‰), a difference that was statistically significant (Mann-Whitney *U* test: $p = 0.014 < 0.05$). This suggests that females consumed more C_3-based foods than males or residents of undetermined sex. Conversely, the higher δ^{13}C values in males point to a greater intake of C_4-based resources during the weaning period. In contrast, δ^{15}N values showed no statistically significant difference between sexes during the same period. The mean δ^{15}N value for females was 11.6 ± 0.8 ‰, compared to 12.4 ± 0.9 ‰ for males (Mann-Whitney *U* test: $p = 0.553 > 0.05$), suggesting only a slight, non-significant trend toward higher animal protein intake among males.

In summary, the weaning patterns of the Taojiazhai population during Han and Jin periods reveal distinct sex-based differences. Males completed weaning later than females and consumed complementary diets with relatively higher proportions of C_4-based foods and animal protein. Females, on the other hand, had diets richer in C_3-based foods. The potential cultural, economic, and ecological factors influencing these sex-based differences are discussed in the following section.

4.4. Causes of differences in weaning patterns and dietary structures

As shown in Fig. 6b, the average weaning age for males at the Taojiazhai cemetery was slightly later than that of females, as evidenced by the later age at which males reached their lowest δ^{15}N values. During the weaning period, males exhibited higher δ^{13}C values than females, indicating a greater reliance on C_4-based foods. After weaning, females displayed slightly higher δ^{13}C values (-16.6 ± 2.0 ‰) than males (-17.2 ± 0.4 ‰), although this difference was not statistically significant (Mann-Whitney *U* test: $p = 0.723 > 0.05$). This suggests that males may have consumed marginally more C_3-derived foods post-weaning. Males, however, exhibited slightly elevated δ^{15}N values (11.5 ± 0.6 ‰) relative to females (11.2 ± 0.4 ‰), again with no statistically significant difference (Mann-Whitney *U* test: $p = 0.069 > 0.05$), indicating a modestly greater intake of animal protein among males. The differences observed in weaning patterns and dietary composition between males and females may be influenced by the following factors:

Firstly, historical and archaeological evidence indicates that the Taojiazhai region was incorporated into the Han Empire's commandery-county administrative system during the Western Han period. The subsequent influx of Han migrants from the Central Plains facilitated deep cultural integration with the indigenous Qiang populations, and by the late Eastern Han, Qiang culture had largely assimilated into Han traditions (Cui et al., 1999; Wang & Wang, 2007; Zhang, 2008). Alongside political and economic restructuring, Han migration

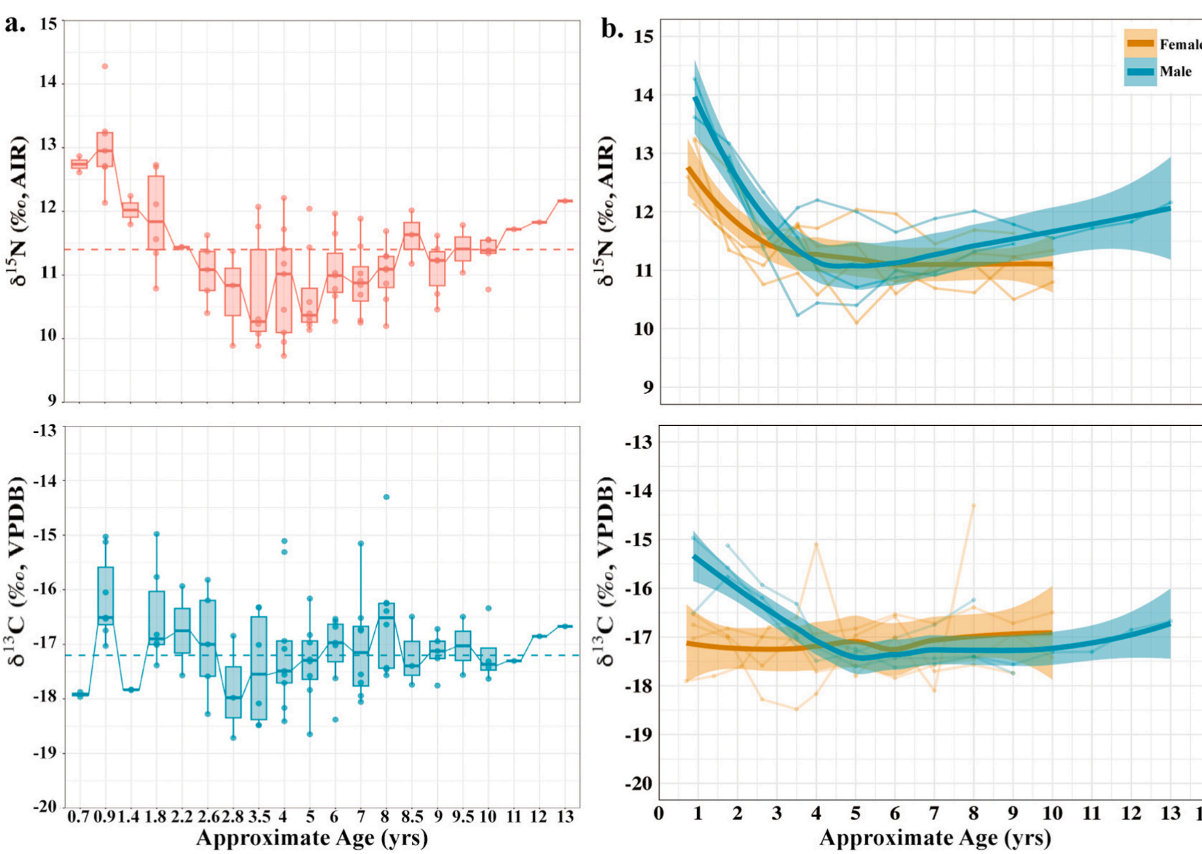

Fig. 6. **a.** Trends of overall δ^{13}C and δ^{15}N of Taojiazhai residents with age of residents in Taojiazhai Cemetery **b.** Trends of δ^{13}C and δ^{15}N with age for different genders of ancestors in Taojiazhai Cemetery.

introduced Confucian ideological systems, particularly patriarchal and lineage-based norms. Concepts such as "ruler over subject, father over son, and husband over wife" (君爲臣綱,父爲子綱,夫爲妻綱), which underscored male dominance within both family and society (Gao & Gao, 2002), together with ideas expressed in the *Taiping Jing* (太平經) from the Eastern Han period: "Since the world lost the Way, women have often been despised and even killed by rebels"(天下失道以來, 多賤女子, 而反賊殺之) (Gao & Li, 1998), reflect a deeply gendered social hierarchy that increasingly favored men. Within this socio-cultural framework, men's dominance in both familial and public spheres became progressively entrenched, while women's autonomy and economic rights were increasingly curtailed, leading to a gradual institutionalization of gender inequality. This hierarchical gender order is also reflected in the funerary objects at Taojiazhai: as shown in Table 1, male residents were generally buried with a greater quantity and wider variety of funerary objects, such as copper belt hooks, crossbow triggers, helmets, and rings made of bronze or lead, while most females had no funerary objects or only a single copper ring or a copper tent hook. This disparity suggests that men held higher social status and occupied more diverse social roles. Within this sociocultural context, male infants may have received more familial resources and care in early life, including extended breastfeeding to bolster immunity and reduce mortality risks. Contemporary biomedical research has shown that male infants are generally more vulnerable to illness and early mortality, and prolonged breastfeeding can significantly improve survival outcomes (American Academy of Pediatrics, 2012; Ananthakrishnan et al., 2018; Rito et al., 2019). This hypothesis is supported by stable isotope analysis from the Taojiazhai cemetery, which indicates that during the weaning period, male residents were weaned later than females on average, as evidenced by higher δ^{15}N values (12.4 ± 0.9 ‰ for males vs. 11.6 ± 0.8 ‰ for females), providing empirical support for gender-based differences in early-life feeding practices. Further support for the hypothesis that male infants received preferential weaning diets comes from historical medical texts and modern nutritional studies concerning millet consumption. The *Compendium of Materia Medica* (本草綱目) records that "Seven days after birth, millet porridge is used to assist the digestive spirit and promote gastrointestinal function; the millet is ground and cooked into a sweet porridge, and fed to the infant in small amounts daily." (嬰孩初生七日,助穀神以導達腸胃, 研粟米煮粥如飴, 每日哺少許) (Li, 2021). Similarly, the *Classified Materia Medica* (證類本草) notes that "Millet is ground and cooked into porridge, thin as milk, and administered daily to infants with swollen tongues as nourishment." (研粟米煮粥飲, 濃薄如乳, 每日研與小兒重舌, 用粟哺之) (Tang, 1993). These accounts suggest that millet was commonly used in traditional childcare not only as a staple supplementary food during early weaning, but also for its warming nature, soft texture, and ease of digestion, which made it suitable for therapeutic purposes. Contemporary nutritional research confirms that millet is rich in protein, dietary fiber, iron, and B vitamins, making it particularly beneficial for weaning infants, individuals recovering from illness, and manual laborers (Oladejo et al., 2020). Stable isotope analysis from the Taojiazhai cemetery reveals that male infants exhibited significantly higher δ^{13}C values (−16.3 ± 0.8 ‰) than female infants (−17.1 ± 0.7 ‰) during the weaning period (Mann–Whitney *U* test, $p = 0.014 < 0.05$). This indicates that male infants may have consumed more supplementary foods dominated by millet (a C_4 crop) during weaning, reflecting sex-based differences in early-life feeding practices.

Secondly, from the perspective of mortuary assemblages and paleopathological evidence, Table 1 reveals that most male residents in the Taojiazhai cemetery were buried with offensive and defensive items such as copper crossbow triggers and copper helmets, suggesting their engagement in high-risk activities like military service or frontier defense during their lifetimes. In contrast, female burial goods were fewer and primarily consisted of domestic items such as rings, implying a more household-centered role for women. This interpretation is supported by historical texts. According to *The Book of Han: The Biography of Zhaochongguo* (漢書·趙充國傳), "when the Qiang harvested wheat, they had already separated from their wives and children; few soldiers remained at the border, and the people could not cultivate the fields" (羌人當獲麥, 已遠其妻子, 邊兵少, 民守保不得田作) (Wang, 2013). This passage underscores the strategic importance of wheat cultivation in the region while reflecting the dominant role of men in agricultural production and frontier defense. The phrase "separated from their wives and children" implies that women remained at home, whereas men undertook both harvest labor during critical agricultural periods and military responsibilities in times of frequent border conflict (Wang, 2013). During the mid to late Eastern Han period, as the central government intensified its control over western frontier regions, large-scale military campaigns and forced migrations disrupted local social structures, compelling men to engage more often in physically demanding labor related to warfare and settlement (Xiao & Li, 2021; Zhu, 2015). Paleopathological analysis corroborates this interpretation. High incidences of trauma and degenerative lesions among residents buried at Taojiazhai indicate widespread exposure to strenuous labor and violent encounters. Fractures accounted for 79.17 % of all traumatic injuries, with the skull, ribs, and scapula being the most affected regions—locations typically associated with trunk impact or force (Zhang, 2008). Males comprised 65 % of all residents with fractures, while females accounted for 35 %. Similarly, males represented 62 % of residents with degenerative joint disease. These lesions were primarily located in the upper limb joints, vertebrae, scapulae, and metatarsals, pointing to frequent engagement in activities requiring upper limb use, trunk loading, and prolonged standing or walking(Zhang, 2008). Against this social and labor backdrop, post-weaning dietary structures also display gendered differences. Stable isotope data show that male residents had slightly higher δ^{15}N values (11.5 ± 0.6 ‰) compared to females (11.2 ± 0.4 ‰), indicating greater consumption of animal protein. This pattern likely reflects the elevated energy and protein demands associated with high-intensity labor, military duties, and agricultural work (Hawley & Leckey, 2015). The correlation between a protein-rich diet and the higher incidence of skeletal stress and trauma in males suggests greater physiological burdens and exposure to physical risk. Furthermore, post-weaning δ^{13}C values for males (−17.2 ± 0.4 ‰) were slightly lower than those for females (−16.6 ± 2.0 ‰), implying a greater intake of C_3 plant-based foods. Given historical accounts linking male labor to the harvest of wheat and other C_3 crops, it is plausible that, following weaning, males increasingly participated in both agricultural and military spheres. This dual role not only intensified their physical workload but also influenced their distinct dietary profile, characterized by higher consumption of C_3 plants and animal-derived nutrients.

In summary, the stable isotope data from the Taojiazhai cemetery, combined with grave goods, paleopathological characteristics, and historical records, indicate that under the continuous influence of Han culture and the restructuring of frontier societies, gender-based disparities in nutritional and social resource allocation gradually emerged in Han and Jin periods in the Hehuang region. Males, owing to their roles in agricultural production and military defense—both high-risk and physically demanding activities—held relatively greater familial and societal authority and privileges. From early childhood, they received prolonged breastfeeding and nutritionally richer supplementary foods primarily based on millet. Following weaning, their diet included higher consumption of animal protein and C_3 crops, likely reflecting increased energetic and nutritional demands associated with adult responsibilities such as military service and labor-intensive farming. In contrast, females, constrained primarily to domestic duties and occupying a relatively lower social status, experienced earlier weaning and had more limited access to high-quality nutritional resources. These multi-source lines of evidence collectively reveal a profound linkage between gendered child-rearing strategies and labor division in frontier societies, further illustrating the institutionalization of gender hierarchies within early social structures.

4.5. Limitations

This study integrates stable isotope analysis with historical, environmental, and bioarchaeological data to examine breastfeeding and weaning practices and explore sex-based dietary differentiation among Taojiazhai residents. Nonetheless, several limitations remain. First, the relatively small sample size constrains the statistical robustness of weaning age estimates and intersex dietary comparisons. Second, while the isotopic data provide meaningful insights into dietary composition and early-life feeding strategies, interpretation is hampered by the absence of contemporaneous plant and animal baseline values, which limits the precision of dietary source identification.

5. Conclusions

This study employs carbon and nitrogen stable isotope analysis to investigate weaning patterns among residents buried at the Taojiazhai Cemetery on the eastern Qinghai-Tibet Plateau during Han and Jin periods, with a particular focus on sex-based differences in dietary structure and weaning practices. The results indicate that the dietary structure of the Taojiazhai residents comprised a mixture of C_3 and C_4 plants, with a gradual predominance of C_3 plants as age increasing, accompanied by a moderate intake of animal protein. Most residents completed weaning between the ages of 2.6 and 3.5 years. Notably, sex-based differences were observed: males, on average, weaned at approximately 4 years of age and exhibited higher consumption of C_4 plants and animal protein in their supplementary diets, whereas females typically weaned around 3.5 years and consumed more C_3 plants and less animal protein. After weaning, males continued to consume higher proportions of C_3 plants and animal protein than females. In light of the subsistence economy and historical context of Han and Jin periods in the Hehuang region, as well as the quantity and quality of grave goods and skeletal pathological evidence from the Taojiazhai cemetery, these dietary and weaning differences are likely related to social status, household resource allocation, and gendered divisions of labor. By reconstructing early-life dietary trajectories, this study offers valuable insights into the lived experiences of past populations in the agricultural-pastoral transition zone of the eastern Qinghai-Tibet Plateau, contributing to a deeper understanding of sociocultural organization during this period.

CRediT authorship contribution statement

Qi Dai: Writing – original draft, Visualization, Investigation, Data curation, Conceptualization. **Rongyu Fu:** Investigation, Formal analysis, Conceptualization. **Ningkang Xie:** Methodology, Investigation, Formal analysis. **Yi Si:** Supervision, Methodology, Conceptualization. **Guanjin Liang:** Resources, Investigation. **Xiaoyan Ren:** Resources, Methodology, Investigation. **Quanchao Zhang:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition. **Liangliang Hou:** Writing – review & editing, Validation, Supervision, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This study was supported by The National Social Science Fund of China Major Historical Issues Research Project of History Research of China 2023 Major Bidding Project-A bioarchaeological perspective on early cross-cultural exchange in the Eurasian steppe (Grant No.23VLS007), The National Social Science Fund of China Project-A comprehensive physical anthropological analysis of Bronze to Early Iron Age populations in the eastern Eurasian steppe (Grant No.23VRC034), and The Jilin University "Chinese Modernization and New Form of Human Civilization" Philosophy and Social Science innovation team project (Grant No.2023QNTD12).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2025.105350.

Data availability

Data will be made available on request.

References

AlQahtani, S.J., Hector, M.P., Liversidge, H.M., 2010. Brief communication: The London atlas of human tooth development and eruption. Am. J. Phys. Anthropol. 142 (3), 481–490. https://doi.org/10.1002/ajpa.21258.

Amanda K Debes, A. K., Neff Walker,Karen Edmond,Luke C Mullany, 2013. Time to initiation of breastfeeding and neonatal mortality and morbidity: a systematic review. BMC Public Health 13(S19). doi: 10.1186/1471-2458-13-S3-S19.

Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. J. Archaeol. Sci. 17 (4), 431–451. https://doi.org/10.1016/0305-4403(90)90007-R.

Ambrose, S.H., Norr, L., Lambert, J.B., Grupe, G., 1993. Effect of Diet Quality and Composition on the Isotopic Composition of Respiratory CO2, Bone Collagen, Bioapatite, and Soft Tissues. In: Lambert, J.B., Grupe, G. (Eds.), Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, Berlin, pp. 121–155.

American Academy of Pediatrics, 2012. Breastfeeding and the use of human milk. Pediatrics, 129(3), e827-841. doi: 10.1542/peds.2011-3552.

Ananthakrishnan, A.N., Bernstein, C.N., Iliopoulos, D., Macpherson, A., Neurath, M.F., Ali, R.A.R., Vavricka, S.R., Fiocchi, C., 2018. Environmental triggers in IBD: a review of progress and evidence. Nat. Rev. Gastroenterol. Hepatol. 15 (1), 39–49. https://doi.org/10.1038/nrgastro.2017.136.

Ban, G., 1962. Biography of Zhao Chongguo Xin Qingji (in Chinese). in: Yan, S., editor. The Book of Han. Shanghai: Zhonghua Book Company. pp. 2986.

Beaumont, J., Gledhill, A., Montgomery, J., 2014. Isotope analysis of incremental human dentine: towards higher temporal resolution. Bulletin of the Internationa Association for Palaeodontology 8 (2), 212–223.

Beaumont, J., Montgomery, J., 2015. Oral histories: a simple method of assigning chronological age to isotopic values from human dentine collagen. Ann. Hum. Biol. 42 (4), 407–414. https://doi.org/10.3109/03014460.2015.1045027.

Brock, F., Higham, T., Ditchfield, P., Ramsey, C.B., 2010. Current Pretreatment Methods for AMS Radiocarbon Dating at the Oxford Radiocarbon Accelerator Unit (Orau). Radiocarbon 52 (1), 103–112. https://doi.org/10.1017/S0033822200045069.

Chowdhury, R., Sinha, B., Sankar, M.J., Taneja, S., Bhandari, N., Rollins, N., Bahl, R., Martines, J., 2015. Breastfeeding and maternal health outcomes: a systematic review and meta-analysis. Acta Paediatr. 104 (467), 96–113. https://doi.org/10.1111/apa.13102.

Cui, M., Shang, X., Ding, Y., Li, Y., 2024. Breatfeeding and weaning patterns among agro-pastoralists: New evidence of dentine isotopes in Northwest China during Bronze Age. J. Archaeol. Sci. Rep. 56. https://doi.org/10.1016/j.jasrep.2024.104523.

Cui, M., Shang, X., Ma, J., Yang, Y., 2025. Isotope analysis of aristocratic dietary and lifestyles in Northwest China during the Eastern Zhou period. npj. Heritage Science 13 (1), 267. https://doi.org/10.1038/s40494-025-01843-3.

Cui, Y., Zhang, D., Du, C., 1999. Qinghai during the Han Dynasty (in Chinese). In: General History of Qinghai. Qinghai People's Publishing House, Xining, pp. 10–21.

Czermak, A., Fernandez-Crespo, T., Ditchfield, P.W., Lee-Thorp, J.A., 2020. A guide for an anatomically sensitive dentine microsampling and age-alignment approach for human teeth isotopic sequences. Am. J. Phys. Anthropol. 173 (4), 776–783. https://doi.org/10.1002/ajpa.24126.

Dai, Q., 2024. A Research on Breastfeeding and Weaning practices of Ancient People in the Jiayi Cemetery, Turpan, Xinjiang from Stable Isotopic Perspective (in Chinese). A Master Paper in Jilin University, Changchun.

Dai, Q., Wang, A., Wang, L., Wang, L., Zhang, Q., Hou, L., 2025. Diet of ancient Turban population from northwestern China illustrated by isotopic analysis of human teeth and bones. npj. Heritage Science 13 (1), 142. https://doi.org/10.1038/s40494-025-01696-w.

DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317 (6040), 806–809. https://doi.org/10.1038/317806a0.

Eidelman, A.I., Schanler, R.J., Johnston, M., Landers, S., Noble, L., Szucs, K., Viehmann, L., 2012. Breastfeeding and the use of human milk. Pediatrics 129 (3), e827–e841. https://doi.org/10.1542/peds.2011-3552.

Elamin, F., Liversidge, H.M., 2013. Malnutrition has no effect on the timing of human tooth formation. PLoS One 8 (8), e72274. https://doi.org/10.1371/journal.pone.0072274.

Fan, Q., Ye, W., 2014. Impact of Climate Change on Ancient Chinese Population in Historical Times (in Chinese). J. Anhui Agric. Sci. 42 (09), 2833–2836. https://doi.org/10.13989/j.cnki.0517-6611.2014.09.098.

Farquhar, G.D., Hubick, K.T., Condon, A.G., Richards, R.A., 1989. Carbon Isotope Fractionation and Plant Water-Use Efficiency. In: Rundel, P.W., Ehleringer, J.R., Nagy, K.A. (Eds.), Stable Isotopes in Ecological Research. Springer, New York, pp. 21–40.

Farquhar, G.D., O'Leary, M., Berry, J.A., 1982. On the Relationship Between Carbon Isotope Discrimination and the Intercellular Carbon Dioxide Concentration in Leaves. Funct. Plant Biol. 9 (2), 121–137. https://doi.org/10.1071/PP9820121.

Fogel, M.L., Tuross, N., Owsley, D., 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. In: Carnegie Institution of Washington Yearbook. Geophysical Laboratory, Washington, pp. 111–117.

Forbes, J. D., Azad, M. B., Vehling, L., Tun, H. M., Konya, T. B., Guttman, D. S., Field, C. J., Lefebvre, D., Sears, M. R., Becker, A. B., Mandhane, P. J., Turvey, S. E., Moraes, T. J., Subbarao, P., Scott, J. A., Kozyrskyj, A. L., & Canadian Healthy Infant Longitudinal Development Study, I., 2018. Association of Exposure to Formula in the Hospital and Subsequent Infant Feeding Practices With Gut Microbiota and Risk of Overweight in the First Year of Life. JAMA Pediatr, 172(7), e181161. https://doi.org/10.1001/jamapediatrics.2018.1161.

Greer, F.R., Sicherer, S.H., Wesley Burks, A., 2019. The Effects of Early Nutritional Interventions on the Development of Atopic Disease in Infants and Children: The Role of Maternal Dietary Restriction, Breastfeeding, Hydrolyzed Formulas, and Timing of Introduction of Allergenic Complementary Foods. Pediatrics 143 (4). https://doi.org/10.1542/peds.2019-0281.

Fuller, B.T., Fuller, J.L., Harris, D.A., Hedges, R.E., 2006. Detection of breastfeeding and weaning in modern human infants with carbon and nitrogen stable isotope ratios. Am. J. Phys. Anthropol. 129 (2), 279–293. https://doi.org/10.1002/ajpa.20249.

Fuller, B.T., Richards, M.P., Mays, S.A., 2003. Stable carbon and nitrogen isotope variations in tooth dentine serial sections from Wharram Percy. J. Archaeol. Sci. 30 (12), 1673–1684. https://doi.org/10.1016/s0305-4403(03)00073-6.

Gao, G., 2024. A Study on the Human Skeletal Remains of Han-Jin Dynasty from Yangjiazhai cemetery in Datong County, Qinghai Province (in Chinese). Changchun: A Ph.D Paper in Jilin University.

Gao, K., Li, P., 1998. On the Sexual Disproportion of the Population in Ancient China (in Chinese). Journal of Historical Science(3), 106–113.

Gao, L., Gao, X., 2002. The Comprehensive Book of Zhu Zi. In: General Theory of Zhu Xi's Studies (in Chinese). Xiamen University Press, Xiamen, p. 113.

Gao, Z., 2005. The Origin and Development of Ancient Agriculture in Qinghai Area (in Chinese). Qinghai Journal of Ethnology 16 (3), 109–112. https://doi.org/10.3969/j.issn.1005-5681.2005.03.025.

Ge, Q., Zheng, J., Hao, Z., Zhang, X., Fang, X., Wang, H., Yan, J., 2014. New progress in climate change research in China over the past 2000 years (in Chinese). Acta Geograph. Sin. 69 (09), 1248–1258. https://doi.org/10.11821/dlxb201409001.

Goldman, A.S., 2012. Evolution of immune functions of the mammary gland and protection of the infant. Breastfeed. Med. 7 (3), 132–142. https://doi.org/10.1089/bfm.2012.0025.

Hawley, J.A., Leckey, J.J., 2015. Carbohydrate Dependence During Prolonged, Intense Endurance Exercise. Sports Med. 45 Suppl 1(Suppl 1), S5–S. https://doi.org/10.1007/s40279-015-0400-1.

Hedges, R.E., Clement, J.G., Thomas, C.D., O'Connell, T., C., 2007. Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. Am. J. Phys. Anthropol. 133 (2), 808–816. https://doi.org/10.1002/ajpa.20598.

Hedges, R.E.M., 2002. Bone diagenesis: an overview of processes. Archaeometry 44 (3), 319–328. https://doi.org/10.1111/1475-4754.00064.

Hedges, R.E.M., 2003. On bone collagen—apatite-carbonate isotopic relationships. Int. J. Osteoarchaeol. 13 (1–2), 66–79. https://doi.org/10.1002/oa.660.

Henrick, B.M., Rodriguez, L., Lakshmikanth, T., Pou, C., Henckel, E., Arzoomand, A., Olin, A., Wang, J., Mikes, J., Tan, Z., Chen, Y., Ehrlich, A.M., Bernhardsson, A.K., Mugabo, C.H., Ambrosiani, Y., Gustafsson, A., Chew, S., Brown, H.K., Prambs, J., Bohlin, K., Mitchell, R.D., Underwood, M.A., Smilowitz, J.T., German, J.B., Frese, S. A., Brodin, P., 2021. Bifidobacteria-mediated immune system imprinting early in life. Cell 184 (15), 3884–3898 e3811. https://doi.org/10.1016/j.cell.2021.05.030.

Hillson, S., 2014. Building dental development sequences. In: Tooth Development in Human Evolution and Bioarchaeology. Cambridge University Press, Cambridge, pp. 112–148.

Ho, N.T., Li, F., Lee-Sarwar, K.A., Tun, H.M., Brown, B.P., Pannaraj, P.S., Bender, J.M., Azad, M.B., Thompson, A.L., Weiss, S.T., Azcarate-Peril, M.A., Litonjua, A.A., Kozyrskyj, A.L., Jaspan, H.B., Aldrovandi, G.M., Kuhn, L., 2018. Meta-analysis of effects of exclusive breastfeeding on infant gut microbiota across populations. Nat. Commun. 9 (1), 4169. https://doi.org/10.1038/s41467-018-06473-x.

Huang, K., Yang, T., Xu, J., Yang, L., Zhao, J., Zhang, X., Bai, C., Kang, J., Ran, P., Shen, H., Wen, F., Chen, Y., Sun, T., Shan, G., Lin, Y., Xu, G., Wu, S., Wang, C., Wang, R., Shi, Z., Xu, Y., Ye, X., Song, Y., Wang, Q., Zhou, Y., Li, W., Ding, L., Wan, C., Yao, W., Guo, Y., Xiao, F., Lu, Y., Peng, X., Zhang, B., Xiao, D., Wang, Z., Chen, Z., Bu, X., Zhang, H., Zhang, X., An, L., Zhang, S., Zhu, J., Cao, Z., Zhan, Q., Yang, Y., Liang, L., Tong, X., Dai, H., Cao, B., Wu, T., Chung, K. F., He, J., Wang, C., & China Pulmonary Health Study, G., 2019. Prevalence, risk factors, and management of asthma in China: a national cross-sectional study. Lancet, 394(10196), 407-418. https://doi.org/10.1016/S0140-6736(19)31147-X.

Kohn, M.J., 1999. You Are What You Eat. Science 283 (5400), 335–336. https://doi.org/10.1126/science.283.5400.335.

Koletzko, B., Godfrey, K. M., Poston, L., Szajewska, H., van Goudoever, J. B., de Waard, M., Brands, B., Grivell, R. M., Deussen, A. R., Dodd, J. M., Patro-Golab, B., Zalewski, B. M., & EarlyNutrition Project Systematic Review, G., 2019. Nutrition During Pregnancy, Lactation and Early Childhood and its Implications for Maternal and Long-Term Child Health: The Early Nutrition Project Recommendations. Ann Nutr Metab, 74(2), 93-106. https://doi.org/10.1159/000496471.

Laursen, M.F., Sakanaka, M., von Burg, N., Morbe, U., Andersen, D., Moll, J.M., Pekmez, C.T., Rivollier, A., Michaelsen, K.F., Molgaard, C., Lind, M.V., Dragsted, L. O., Katayama, T., Frandsen, H.L., Vinggaard, A.M., Bahl, M.I., Brix, S., Agace, W., Licht, T.R., Roager, H.M., 2021. Bifidobacterium species associated with breastfeeding produce aromatic lactic acids in the infant gut. Nat. Microbiol. 6 (11), 1367–1382. https://doi.org/10.1038/s41564-021-00970-4.

Lee, C.Y., Lin, K.C., Chen, J., Czermak, A., 2020. Dietary history of two human individuals at the Yingpanshan site, Sichuan Province, revealed by carbon and nitrogen isotope analysis of serial samples of dentinal collagen. Int. J. Osteoarchaeol. 30 (4), 565–574. https://doi.org/10.1002/oa.2871.

Lee-Thorp, J.A., 2008. On Isotopes and Old Bones. Archaeometry 50 (6), 925–950. https://doi.org/10.1111/j.1475-4754.2008.00441.x.

Lei, S., Gu, W., Wu, Q., Xin, Y., Guo, Y., 2023. Early childhood nurturing strategies in groups of the Yellow River's middle reaches from the late Yangshao culture (3500–2800 BCE): A stable isotope perspective. Int. J. Osteoarchaeol. 33 (5), 920–937. https://doi.org/10.1002/oa.3254.

Lei, S., Guo, Y., 2022. Human tooth and diet from a bioarcheological perspective (in Chinese). Acta Anthropologica Sinica 41 (3), 501–513. https://doi.org/10.16359/j.1000-3193/AAS.2021.0057.

Li, J., Zeng, W., Zhang, Y., Ko, A.M., Li, C., Zhu, H., Fu, Q., Zhou, H., 2017. Ancient DNA reveals genetic connections between early Di-Qiang and Han Chinese. BMC Evol. Biol. 17 (1), 239. https://doi.org/10.1186/s12862-017-1082-0.

Li, S., 2021. Millet (in Chinese). in: Zhao, S. & Zhao, H., editor. Compendium of Materia Medica. Shanghai: Zhonghua Book Company. pp. 1082.

Li, W., 2009. A study on the agricultural economy and society in North ern Dynasties in the view of the climate (in Chinese). Wuhan: A Ph.D Paper in Central China Normal University.

Li, X., Zhang, L., Liu, J., 2020. Analysis on the effects of child health care intervention on early growth, intelligence and motor development in infants and young children (in Chinese). Shanxi Medical Journal 49 (4), 382–384.

Ma, M., 2013. Human dietary changes and agriculture developments in the Hehuang and contiguous regions in the second millennium BC-Stable isotopic evidence (in Chinese). A Ph.D Paper in Lanzhou University, Lanzhou.

Ma, M., Dong, G., Jia, X., Wang, H., Cui, Y., Chen, F., 2016. Dietary shift after 3600 cal yr BP and its influencing factors in northwestern China: Evidence from stable isotopes. Quat. Sci. Rev. 145, 57–70. https://doi.org/10.1016/j.quascirev.2016.05.041.

McAllister, D.A., Liu, L., Shi, T., Chu, Y., Reed, C., Burrows, J., Adeloye, D., Rudan, I., Black, R.E., Campbell, H., Nair, H., 2019. Global, regional, and national estimates of pneumonia morbidity and mortality in children younger than 5 years between 2000 and 2015: a systematic analysis. Lancet Glob. Health 7 (1), e47–e57. https://doi.org/10.1016/S2214-109X(18)30408-X.

Miller, M.J., Dong, Y., Pechenkina, K., Fan, W., Halcrow, S.E., 2020. Raising girls and boys in early China: Stable isotope data reveal sex differences in weaning and childhood diets during the eastern Zhou era. Am. J. Phys. Anthropol. 172 (4), 567–585. https://doi.org/10.1002/ajpa.24033.

Miller, M.J., Halcrow, S.E., Yang, B., Dong, Y., Pechenkina, K., Fan, W., 2023. Gender across Generations: Childhood Food Practices as Socialization Processes in Ancient China. Bioarchaeology International 8 (1–2), 63–84. https://doi.org/10.5744/bi.2022.0030.

Murphy, K., Curley, D., O'Callaghan, T.F., O'Shea, C.A., Dempsey, E.M., O'Toole, P.W., Ross, R.P., Ryan, C.A., Stanton, C., 2017. The Composition of Human Milk and Infant Faecal Microbiota Over the First Three Months of Life: A Pilot Study. Sci. Rep. 7, 40597. https://doi.org/10.1038/srep40597.

National Research Council, & Institute of Medicine Committee on Integrating the Science of Early Childhood Development, 2000. From Neurons to Neighborhoods: The Science of Early Childhood Development. in: Shonkoff, J. P. & Phillips, D. A. (eds.), The Nature and Tasks of Early Development. Washington (DC): National Academies Press (US). pp. 90-219.

Nitsch, E.K., Humphrey, L.T., Hedges, R.E., 2011. Using stable isotope analysis to examine the effect of economic change on breastfeeding practices in Spitalfields, London. UK. Am J Phys Anthropol 146 (4), 619–628. https://doi.org/10.1002/ajpa.21623.

O'Leary, M.H., 1981. Carbon isotope fractionation in plants. Phytochemistry 20 (4), 553–567. https://doi.org/10.1016/0031-9422(81)85134-5.

Oladejo, A.A., Obiegbuna, J.E., Ishiwu, C.N., Abah, C.R., 2020. Nutritional Composition, Functional Properties and Food Applications of Millet Grains. Asian Food Science Journal 14 (2), 9–19. https://doi.org/10.9734/afsj/2020/v14i230124.

Pannaraj, P.S., Li, F., Cerini, C., Bender, J.M., Yang, S., Rollie, A., Adisetiyo, H., Zabih, S., Lincez, P.J., Bittinger, K., Bailey, A., Bushman, F.D., Sleasman, J.W., Aldrovandi, G. M., 2017. Association Between Breast Milk Bacterial Communities and Establishment and Development of the Infant Gut Microbiome. JAMA Pediatr. 171 (7), 647–654. https://doi.org/10.1001/jamapediatrics.2017.0378.

Parfitt, A.M., 2002. Misconceptions (2): turnover is always higher in cancellous than in cortical bone. Bone 30 (6), 807–809. https://doi.org/10.1016/S8756-3282(02)00735-4.

Pellegrino, D.M.S., Chacon, J.M.F., Blanes, L., Ferreira, L.M., 2017. Prevalence and incidence of pressure injuries in pediatric hospitals in the city of São Paulo, SP. Brazil. J Tissue Viability 26 (4), 241–245. https://doi.org/10.1016/j.jtv.2017.07.001.

Pezo-Lanfranco, L., DeBlasis, P., Eggers, S., 2018. Weaning process and subadult diets in a monumental Brazilian shellmound. J. Archaeol. Sci. Rep. 22, 452–469. https://doi.org/10.1016/j.jasrep.2018.04.025.

Piovani, D., Danese, S., Peyrin-Biroulet, L., Nikolopoulos, G.K., Lytras, T., Bonovas, S., 2019. Environmental Risk Factors for Inflammatory Bowel Diseases: An Umbrella Review of Meta-analyses. Gastroenterology 157 (3), 647–659 e644. https://doi.org/10.1053/j.gastro.2019.04.016.

Qinghai Provincial Institute of Cultural Relics and Archaeology, 2007. Brief Report on the Excavation of the Han Tomb in Taojiazhai (in Chinese). in: Department of Cultural Relics and Museology in Nanjing Normal University (eds.), Asia Antiquity (Dongya Guwu). Beijing: Cultural Relics Press. pp. 311-350.

Qinghai Provincial Institute of Cultural Relics and Archaeology, 2015. The Excavation of the Tombs of the Han Dynasty at Taojiazhai Village in Xining, Qinghai. Wenwu (Cultural Relics)(09), 39-48+31. https://doi.org/10.13619/j.cnki.cn11-1532/k.2015.09.002.

Ramsey, C.B., 2017. Methods for Summarizing Radiocarbon Datasets. Radiocarbon 59 (6), 1809–1833. https://doi.org/10.1017/RDC.2017.108.

Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). Radiocarbon 62 (4), 725–757. https://doi.org/10.1017/RDC.2020.41.

Richards, M., Hedges, R., 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. J. Archaeol. Sci. 26 (6), 717–722. https://doi.org/10.1006/jasc.1998.0387.

Richards, M.P., Mays, S., Fuller, B.T., 2002. Stable carbon and nitrogen isotope values of bone and teeth reflect weaning age at the Medieval Wharram Percy site, Yorkshire. UK. Am J Phys Anthropol 119 (3), 205–210. https://doi.org/10.1002/ajpa.10124.

Rito, A.I., Buoncristiano, M., Spinelli, A., Salanave, B., Kunesova, M., Hejgaard, T., Garcia Solano, M., Fijalkowska, A., Sturua, L., Hyska, J., Kelleher, C., Duleva, V., Music Milanovic, S., Farrugia Sant'Angelo, V., Abdrakhmanova, S., Kujundzic, E., Peterkova, V., Gualtieri, A., Pudule, I., Petrauskiene, A., Tanrygulyyeva, M., Sherali, R., Huidumac-Petrescu, C., Williams, J., Ahrens, W., Breda, J., 2019. Association between Characteristics at Birth, Breastfeeding and Obesity in 22 Countries: The WHO European Childhood Obesity Surveillance Initiative - COSI 2015/2017. Obes. Facts 12 (2), 226–243. https://doi.org/10.1159/000500425.

Seibel, M.J., 2003. Biochemical markers of bone remodeling. Endocrinol. Metab. Clin. North Am. 32(1), 83–113, vi–vii. https://doi.org/10.1016/s0889-8529(02)00077-4.

Smith, B.H., 1991. Standards of human tooth formation and dental age assessment. In: Kelley, M.A., Larsen, C.S. (Eds.), Advances in Dental Anthropology. Wiley-Liss Inc, New York, pp. 143–168.

Stantis, C., Buckley, H.R., Commendador, A., Dudgeon, J.V., 2021. Expanding on incremental dentin methodology to investigate childhood and infant feeding practices on Taumako (southeast Solomon Islands). J. Archaeol. Sci. 126. https://doi.org/10.1016/j.jas.2020.105294.

Sun, S., 1998. In: Prescriptions Worth a Thousand Pieces of Gold for Emergencies (in Chinese). People's Medical Publishing House, Beijing, p. 89.

Tang, L., Luo, X., Li, Y., Nie, J., Yang, J., Liu, H., 2019. An Empirical Study on the Status and Determinants of Infant and Toddler Feeding Practices in Poor Rural Areas of China (in Chinese). Journal of East China Normal University(Educational Sciences) 37 (3). https://doi.org/10.16382/j.cnki.1000-5560.2019.03.007.

Tang, S., 1993. Millet. In: Classified materia medica (in Chinese). Huaxia Publishing House, Beijing, p. pp..

Tian, H., Olivé-Busom, J., Czermak, A., Schulting, R.J., 2025. Sequential dentine δ13C and δ15N analysis of Islamic burials from medieval Al-Andalus. J. Archaeol. Sci. Rep. 62, 104958. https://doi.org/10.1016/j.jasrep.2024.104958.

Tsutaya, T., Yoneda, M., 2015. Reconstruction of breastfeeding and weaning practices using stable isotope and trace element analyses: A review. Am. J. PhysAnthropol 156 (Suppl 59), 2–21. https://doi.org/10.1002/ajpa.22657.

Van den Elsen, L.W.J., Garssen, J., Burcelin, R., Verhasselt, V., 2019. Shaping the Gut Microbiota by Breastfeeding: The Gateway to Allergy Prevention? Front. Pediatr. 7, 47. https://doi.org/10.3389/fped.2019.00047.

Vandenplas, Y., Carnielli, V.P., Ksiazyk, J., Luna, M.S., Migacheva, N., Mosselmans, J.M., Picaud, J.C., Possner, M., Singhal, A., Wabitsch, M., 2020. Factors affecting early-life intestinal microbiota development. Nutrition 78, 110812. https://doi.org/10.1016/j.nut.2020.110812.

Väre, T., Nordfors, U., 2025. Early childhood diets in medieval and Post-Medieval Pälkäne, Finland: Insights from stable isotope analysis. J. Archaeol. Sci. Rep. 63, 105113. https://doi.org/10.1016/j.jasrep.2025.105113.

Walsh, C., Lane, J.A., van Sinderen, D., Hickey, R.M., 2020. Human milk oligosaccharides: Shaping the infant gut microbiota and supporting health. J. Funct. Foods 72, 104074. https://doi.org/10.1016/j.jff.2020.104074.

Wang, J., 2013. Resear which in a agricultural aspect on the history of ancient Ch'iang (in Chinese). Xianyang: A Master Paper in Northwest Agriculture and Forestry University.

Wang, J., & Fan, Z., 2013. Research on Agricultural Production and Monthly Work of Chiang through the Han Dynasty (in Chinese). Agricultural History of China, 32(03), 123-131. https://doi.org/CNKI:SUN:ZGNS.0.2013-03-017.

Wang, L., & Wang, X., 2007. An Analysis of the Internal Migration of the Qiang People during the Eastern Han Dynasty (in Chinese). China's Borderland History and Geography Studies(03), 48-60+149.

Wang, T., Fuller, B.T., Jiang, H., Li, W., Wei, D., Hu, Y., 2022a. Revealing lost secrets about Yingpan Man and the Silk Road. Sci. Rep. 12 (1), 669. https://doi.org/10.1038/s41598-021-04383-5.

Wang, T., Wei, D., Yi, B., Jiang, H., Li, W., Hu, Y., Fuller, B.T., 2022b. Infancy, childhood, and puberty on the Silk Road revealed with isotopic analysis of incremental dentine. Sci. Rep. 12 (1), 19494. https://doi.org/10.1038/s41598-022-24119-3.

Wang, Y., 2012. Qinghai during the Han Dynasty (in Chinese). In: Cui, Y., Cong, Z. (Eds.), A Brief History of Qinghai. Qinghai People's Publishing House, Xining, pp. 25–30.

Wang, Y., Chen, G., Dong, J., 2019. Analysis of the effect of intensive health care on the growth and development of infants and young children and the incidence of nutritional diseases (in Chinese). Journal of Xinjiang Medical University 42 (4), 547–550.

Wang, Z., 1995. A Historical Examination of Climate Change in the Qin and Han Dynasties (in Chinese). Hist. Res. 2, 4.

Wu, L., 2014. An investigation of the impact of climate change on ancient Chinese agriculture during the historical period (in Chinese). China Agricultural Informatics (09), 175–176.

Xia, Y., Zhang, J., Yu, F., Zhang, H., Wang, T., Hu, Y., Fuller, B.T., 2018. Breastfeeding, weaning, and dietary practices during the Western Zhou Dynasty (1122-771 BC) at Boyangcheng, Anhui Province. China. Am J Phys Anthropol 165 (2), 343–352. https://doi.org/10.1002/ajpa.23358.

Xiao, J., Li, S., 2021. An Overview of Qiang-Chinese War Research in the Past Sixty Years (in Chinese). Journal of Aba Teachers University 38 (3), 27–35.

Yan, J., Liu, L., Zhu, Y., Huang, G., Wang, P.P., 2014. The association between breastfeeding and childhood obesity: a meta-analysis. BMC Public Health 14, 1267. https://doi.org/10.1186/1471-2458-14-1267.

Yang, B., 2018. Yanghuo. In: Yang, B., Yang, F. (Eds.), Commentary on the Analects of Confucius (in Chinese). Chinese Publishing House, Beijing, p. 219.

Yi, B., Liu, X., Yan, X., Zhou, Z., Chen, J., Yuan, H., Hu, Y., 2021. Dietary shifts and diversities of individual life histories reveal cultural dynamics and interplay of millets and rice in the Chengdu Plain, China during the Late Neolithic (2500-2000 cal. BC). Am. J. Phys. Anthropol. 175 (4), 762–776. https://doi.org/10.1002/ajpa.24259.

Yi, B., Liu, X., Yuan, H., Zhou, Z., Chen, J., Wang, T., Wang, Y., Hu, Y., Fuller, B.T., 2018. Dentin isotopic reconstruction of individual life histories reveals millet consumption during weaning and childhood at the Late Neolithic (4500 bp) Gaoshan site in southwestern China. Int. J. Osteoarchaeol. 28 (6), 636–644. https://doi.org/10.1002/oa.2676.

Yi, B., Yuan, H., Wang, T., Cao, D., Yang, Y., Hu, Y., 2024. Life history of a high-class noblewoman from the late Shu state in the Chengdu Plain during the Eastern Zhou period (770–221 BC): Childhood stresses and stable life. Int. J. Osteoarchaeol. 34 (1), e3282.

Yi, B., Zhang, J., Cai, B., Zhang, Z., Hu, Y., 2019. Osteobiography of a seventh-century potter at the Oupan kiln, China by osteological and multi-isotope approach. Sci. Rep. 9 (1), 12475. https://doi.org/10.1038/s41598-019-48936-1.

Zhang, J., 2008. The Research on the Human Skeletons of Han and Jin Dynasties from Taojiazhai graveyard in Xining City of Qinghai Province (in Chinese). Changchun: A Ph.D Paper in Jilin University.

Zhang, Q., Li, J., 2018. From the Huangshui Han Tomb to see 'the beginning of Hexi' when the integration of diverse ethnic groups (in Chinese). Journal of Qinghai Minzu University(Social Sciences) 44 (1), 117–124.

Zhu, K., 1972. A preliminary study of climate change in China over the past 5,000 years (in Chinese). Kaogu (Archaeology) 1, 15–38.

Zhu, S., 2015. A Strategic Study of the War of the Two Han Dynasty against the Xiongnu Western Regions and Western Qiang (in Chinese). Journal of Historical Science(5), 5-42.