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ORIGINAL PAPER

Bioarchaeological analysis of Bronze Age populations in the Xiaohe cemetery using dental non-metric traits

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Abstract
The archaeological site of the Xiaohe cemetery (3980 to 3540 years cal BP), one of the earliest sites in the Lop Nur Desert of Xinjiang, China, has attracted considerable attention in recent years due to its well-preserved organic materials such as mummified human remains. However, questions of the regional diversity of populations from this time period are still not well understood, as few detailed studies have been undertaken. This study utilizes 17 dental morphological traits to assess the phenetic relationships between Xiaohe (19 males and 17 females) and other ancient populations from northern China and Eurasia. Trait frequencies are determined and biodistances are calculated through Mean Measure of Divergence (MMD) statistics. Based on our MMD results, we suggest that there had already been a certain degree of genetic exchange between people of the Xiaohe area and other parts of Eurasia before the early Bronze Age. These results are consistent with other genetic studies on the Xiaohe cemetery.

Keywords Xiaohe cemetery · Bronze Age Xinjiang · Dental non-metric traits

1 Introduction

The Xinjiang Uygur Autonomous Region (also called Xinjiang 新疆 for short), located in the northwest region of China, has been identified as an important bridge connecting Eastern and Western populations and cultures from across the Eurasian continents. For example, it is well known that the ancient Silk Road connected Central Asia, Eastern Europe, and China. Human activities in Xinjiang can be traced almost as far back as 10,000 years ago (Wang 1992), and archaeological excavations in Xinjiang have been carried out since the late nineteenth century (Xiao 2004).

The Xiaohe 小河 (literally, "Small River") cemetery (40°20′11″N, 88°40′20.3″E), located in the northeastern part of Xinjiang, is one of the earliest Bronze Age sites in the region, radiocarbon dated to 3980–3540 cal BP (Li 2010). An aboriginal hunter named Ördek first found the site around 1910. Formal excavations began in 1934, when Folke Bergman, a Swedish archaeologist, excavated 12 burials, revealing "European-looking" mummies with brown hair and fine aquiline noses (Bergman 1939). After that, the Xiaohe cemetery was forgotten until the end of 2000, when a Chinese film crew entered the cemetery with the help of a Global Position System (GPS), and their rediscovery aroused widespread attention. To prevent the Xiaohe cemetery from being destroyed, a joint team from the Institute of Cultural Relics and Archaeology of Xinjiang and the Research Center for Chinese Frontier Archaeology of Jilin University excavated this cemetery from 2002 to 2005, but unfortunately, many of the burials had already been destroyed by treasure hunters (Yidilisi et al. 2007).

The Xiaohe cemetery was divided into southern and northern parts by a palisade, and excavation revealed a 5-layer stratigraphy. A total of 167 graves were excavated with remains of 107 human individuals identified. Mitochondrial DNA and Y chromosomal DNA analyses completed on these individuals suggest that the ancient Xiaohe people were admixtures of people originating from both eastern and western Eurasia,

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especially from southern or eastern Siberia and eastern Europe. This confirmed Bergman's observation that this region had been populated by groups of people with mixed European lineage some 4000 years ago (Li 2010; Li et al. 2010).

In recent years, comparative studies of populations using dental non-metric traits, characterized by the degree of expression or presence rather than their size, have gained momentum. Because the non-metric traits used are thought to be selectively neutral and because they have a high degree of heritability, they can serve as markers of phylogenetic relatedness. Such studies can be very useful for understanding genetic history, and they provide access to genetic relationships even if ancient DNA research fails, as different parts and amounts of the genome are assessed. Biological anthropologists thus use these studies to estimate the genetic similarity of past human populations.

Observations from people across the world show regional differences in trait pervasiveness and some traits that are unique to populations in specific geographic regions Scott and Turner 1997. Based on the extensive research and compilations of data from many other researchers, Scott and Turner (1997) list and discuss the global frequency of many crown and root traits and find that there is sufficient evidence to demonstrate differences in the occurrence and frequency of many dental non-metric traits between Western European and Central Asian populations. They note that one of the most interesting fields of dental non-metric trait research is on peoples who lived in areas of overlap between Asian and European population ranges. In particular, groups from Southern Siberia are of interest for their geographic intermediacy and because this region witnessed major migrations from a number of different populations and regions over the last 40,000 years, during which population admixture would be expected (Scott and Turner 1997).

In our study, the dental non-metric traits of individuals from the Xiaohe cemetery are used in comparison with other Eurasian inhabitants in order to analyze their biological distances. Given the assumptions that the phenetic similarity provides an acceptable estimate of genetic relationship (Scott et al. 1983) and the samples we observe are representative of the once living population, our results are used to interpret the peopling of Lop Nur Desert in order to assess the hypotheses of biological continuity or discontinuity through time in Xinjiang.

2 Materials and methods

The analyzed sample from the Xiaohe cemetery consists of 36 adult individuals (19 males and 17 females) with a total of 276 teeth. The individuals were mostly selected from cultural layers nos. 4 and 5 in both the northern and southern parts of Xiaohe cemetery (Table 1). Sex estimation of all skeletons followed osteological techniques summarized in Shao's Manual (Shao 1985) and Standards (Buikstra et al. 1994).

Table 1 Basic information on the Xiaohe samples used in this study

No.		Cemetery part	Layer	Sex	Age
1	04XHM39	Southern	No. 3	♂	Adult
2	04XHM62	Southern	No. 3	♂	Adult
3	04XHM63	Southern	No. 3	♂?	30±
4	04XHBM5	Northern	No. 4	♀	25±
5	04XHBM8	Northern	No. 4	♂	20–25
6	04XHBM10	Northern	No. 4	♂	35±
7	04XHBM20	Northern	No. 4	♀	25–30
8	04XHM70	Southern	No. 4	♂	30–40
9	04XHM87	Southern	No. 4	♂	45–50
10	04XHM88	Southern	No. 4	♀	Adult
11	04XHM96	Southern	No. 4?	♂	Adult
12	04XHM99	Southern	No. 4	♀	30–35
13	04XHM129	Southern	No. 4	♂	45–50
14	04XHM130	Southern	No. 4	♂	25–30
15	04XHM85	Southern	No. 5	♀	Adult
16	04XHM93	Southern	No. 5	♀	35–40
17	04XHM102	Southern	No. 5	♀	25–30
18	04XHM106	Southern	No. 5	♂	35±
19	04XHM107	Southern	No. 5	♀	40–45
20	04XHM109	Southern	No. 5	♀	50±
21	04XHM110	Southern	No. 5	♀	19–20
22	04XHM111	Southern	No. 5	♂	25–30
23	04XHM112	Southern	No. 5	♂	25–30
24	04XHM115	Southern	No. 5	♂	35–40
25	04XHM117	Southern	No. 5	♀	40±
26	04XHM120	Southern	No. 5	♂	45±
27	04XHM121	Southern	No. 5	♂	Adult
28	04XHM125	Southern	No. 5	♀	Adult
29	04XHM128	Southern	No. 5	♀	40
30	04XHM131	Southern	No. 5	♀	30–35
31	04XHM132	Southern	No. 5	♀	40±
32	04XHM134	Southern	No. 5	♂	14–15
33	04XHM135	Southern	No. 5	♀	40±
34	04XHM136	Southern	No. 5	♂	35±
35	04XHM138	Southern	No. 5	♀	35±
36	04XHM139	Southern	No.5	♂	40–45

Evaluation of dental non-metric traits varies from recording the presence or absence of a trait (e.g., Premolar Odontomes), counting the number of structures (e.g., root number), to scoring the expression of a trait on a graded scale (e.g., shoveling). For many traits, it is necessary to establish a range of presence (breakpoint) whereby the trait is considered present or absent, known as trait dichotomization, in order to include it in standard non-metric statistical tests. Our study uses the trait dichotomizations developed by Turner and scored based on the Arizona State University Dental Anthropology System (Turner et al. 1991).

Because dental wear greatly reduces the number of traits that can be observed in an individual, in many cases less than one-third of the full suite of dental non-metric traits could be scored. And because ante-mortem or post-mortem tooth loss also contributes to the loss of information, it was possible to observe a maximum of 17 traits in an individual (Table 2). Some of these traits are suggested to be the most efficient to distinguish differences between Eurasian populations (Scott and Turner 1997). For example, Europeans show simple crown morphology, they are characterized by moderate frequencies of incisor shoveling with few pronounced shovel forms, a high frequency of Carabelli's cusp, and low frequencies of cusp 6, cusp 7, and deflecting wrinkle, while Mongolian populations are characterized by high frequencies of incisor shoveling, central incisor double-shoveling, one-rooted upper first premolar, deflecting wrinkle, and 3-rooted lower first molar.

Basically, while both maxilla and mandible are scored for the trait, the trait is only counted once. In cases where there is symmetry in trait expression, the antimere with the maximum value is used, based on the assumptions that the trait with the higher expression represents the individual's maximum genetic potential, and that it occurs randomly with respect to the side of the jaw on which it occurs (Scott and Turner 1997).

Dental Non-metric trait data from previous studies on ancient people of northern China, where the same methodology was used, are used as comparison groups (Fig. 1, Table 3).

In addition, the data collected from 11 Eurasian populations by Scott and Turner (1997) were also used. These samples include (1) Western Eurasia, identified in Western European, Northern European, and Northern African groups, characterized by retained traits and a less complex dentition, (2) Sino-American, characteristic of China- Mongolian, Jomon, recent Japan, northeast Siberia, south Siberia, American Arctic, northwest north American Indians, and north and south American Indians. Geographic locations for all these samples are shown in Fig. 2 and the different frequencies of the non-metric traits in tooth crown and root of the Western Eurasia and Sino-Americas are listed in Table 4.

All the non-metric traits used in this study was chosen based on the congruity of traits between the data sets used.

Firstly, we exclude from analysis individuals whose traits are unobservable due to damage or wear, and then we calculate trait frequencies according to the number of observable individuals but not the number of teeth. That is, a trait was scored as present whether it was present on either the left or the right side. Also, we compare trait frequencies between sexes in the Xiaohe cemetery by using Fisher's exact test with significance determined at $P < 0.01$.

The Smith's Mean Measure of Divergence (MMD) is used as a statistical test of biological distance in order to study the phenetic distances between Xiaohe and the other populations. The MMD calculates dissimilarity for each trait frequency between two populations, and takes the mean of these measures to produce a distance value. The closer the value is to 0, the more closely related the two populations are. Likewise, the larger the value, the more phenetic distance the two populations share. This study

Table 2 Dental non-metric traits used in our study

No.	Traits	Abbreviation	Teeth	Grades	Range of presence
1.	Winging	WING	UI1	1–4	1–2
2.	Shoveling	SHOV	UI1	0–7	3–7
3.	Double-Shoveling	DSHOV	UI1	0–6	2–6
4.	Tuberculum Dental	TD	UI2	0–6	1–6
5.	Double-Rooted Upper Premolars	2RT UP1	UP1	1–3	2
6.	Cusp 5	CUSP5	UM1	0–5	1–5
7.	Carabelli's Trait	CARA	UM1	0–7	2–7
8.	Three-Rooted Upper Molars	3RT UM2	UM2	1–4	3
9.	Double-Rooted Lower Canines	2R LC	LC	1–2	2
10.	Multiple Lingual Cusps	MLC LP2	LP2	0–9	2–9
11.	Cusp 6	C6 LM1	LM1	0–5	1–5
12.	Cusp 7	C7 LM1	LM1	0–5	1–5
13.	Defecting Wrinkle	DW	LM1	0–3	2–3
14.	Three-Rooted Lower Molars	3R LM1	LM1	1–3	3
15.	Four-Cusped Lower Molars	4C LM2	LM2	4–6	4
16.	One-Rooted Lower Molars	1R LM2	LM2	1–2	1
17.	Premolar Odontomes	ODONT	U/LP	0–1	1

Fig. 1 Geographic locations of the Chinese sample data sets used in this study

calculates data from Xiaohe with the various comparative groups using the following formulas:

$$\theta = \frac{1}{2} sin^{-1}\left(1 - \frac{2m}{n+1}\right) + \frac{1}{2} sin^{-1}\left(1 - 2\left(\frac{m+1}{n+1}\right)\right) \quad (1)$$

Where m is the number of specimens with the expressed trait, and n is the total number of specimens observed for that trait. The resulting θ is used in the *MMD* formula.

$$MMD = \frac{\sum_{k=1}^{r}\left(\left(\theta_{ik} - \theta_{jk}\right)^2 - \left(\frac{1}{n_{ik} + \frac{1}{2}} + \frac{1}{n_{jk} + \frac{1}{2}}\right)\right)}{r} \quad (2)$$

Where θ_{ik} and θ_{jk} are the arcsine-transformed frequencies of samples i and j for trait k, n_{ik} and n_{jk} are the number of observed specimens for sample i and j for trait k, respectively, and r is the number of traits used.

The MMD result is statistically significant if it is larger than twice the standard deviation (Green and Suchey 1976; Harris and Sjøvold 2004). The two populations being compared were considered statistically significantly different ($P < 0.05$) when the MMD was greater than twice its standard deviation (Harris and Sjøvold 2004; Irish 2010). The standard deviation was calculated by obtaining the square root of the variance of the MMD, calculated as:

$$\mathrm{Var_{MMD}} = \frac{2}{r^2} \sum_{k=1}^{r} \left(\frac{1}{n_{ik} + \frac{1}{2}} + \frac{1}{n_{jk} + \frac{1}{2}}\right)^2 \quad (3)$$

$$\mathrm{SD_{MMD}} = \sqrt{\mathrm{Var_{MMD}}} \quad (4)$$

Where n_{ik} and n_{jk} are the number of observed specimens for sample i and j for trait k, respectively, and r is the number of traits used.

If the resulting calculations indicate a statistically insignificant MMD value, or a negative MMD value, then the value should be set at 0, meaning that no divergence exists between the two groups. This again follows the recommendations of previous research, given that negative MMD distances "have no biological meaning" (Harris and Sjøvold 2004), and should be set as such (Harris and Sjøvold 2004; Irish 2010).

3 Results

There were no significantly different trait frequencies at $P < 0.01$ between males and females in dental non-metric traits in the Xiaohe cemetery (Table 5), so we have pooled the two sexes for our analyses.

Among non-metric traits listed in Table 6, for maxillary teeth, 31.03% (9/29) of the observable Xiaohe individuals had Winging on the central incisor(s), almost the same frequency as in China-Mongolia and American Arctic (15–30% of individuals), and higher than in the three Western Eurasian groups (0–15%). 33.33% (5/15) of the Xiaohe individuals had Shoveling (Fig. 3a), in which the lowest frequencies are in

Table 3 The comparative samples from China used in this study

Sample	Size[a]	Time period	Location	Reference
Liushui 流水	108	Bronze Age	Xinjiang	Zhang et al. 2014
Yanghai 洋海	35	Early Iron Age	Xinjiang	Lee 2007
Jilintai 吉林台	78	Iron Age	Xinjiang	Zhang 2010
Yingpan 营盘	23	Iron Age	Xinjiang	Zhang and Zhu 2013
Miaozigou 庙子沟	28	Neolithic	Inner Mongolia	Liu and Zhu 1995
Xiawanggang 下王岗	187	Neolithic	Henan	Liu 1995
Jiangjialiang 姜家梁	62	Neolithic	Hebei	Li 2004
Mogou 磨沟	115	Bronze Age	Gansu	Zhao 2013
Taojiazhai 陶家寨	68	Iron Age	Qinghai	Zhang 2008
Longxian 陇县	97	Iron Age	Shanxi	Liu and Zeng 1996

[a] Because sample size varies per non-metric trait within a single sample, the means of these sizes are presented here

Fig. 2 Map of the locations of the Eurasian populations' dental samples (modified from Scott and Turner 1997)

Western Eurasian groups (0–15%), then South Siberia and Jomon (20–50%), and highest in Native Americans and China-Mongolia. Only one of sixteen (6.25%) Xiaohe individuals had double-shoveling on the central incisor(s) in which the lowest frequencies are in three Western Eurasian groups (0–15%), then China-Mongolia and American Arctic (20–40%), and highest in Native Americans (55–70%). Almost two thirds (63.64%, 7/11) of the individuals from Xiaohe had the tuberculum on the lateral incisor(s). 4% (1/25) of the individuals from Xiaohe had odontomes on upper premolars. 55.56% (20/36) of the individuals at Xiaohe had two roots on the first premolar (Fig. 3b), which is more like the frequencies in the three Western Eurasian groups (30–60%). Three (30%, K = 10) of the Xiaohe people had five crowns, while two (22.22%, K = 9) had Carabelli's trait on the first molar, the same as in the three Western Eurasian groups (>20%), then China-Mongolia, and rarest in Native Americans and Jomon (0–10%). 71.43% (20/28) of the Xiaohe people had three roots on the second molar (Fig. 3c).

For mandible teeth, none (0 of K = 11) had a Cusp 7 and defecting wrinkle, the same frequency as three roots on the first molars (0 of K = 34). One (3.13% of K = 32) of the individuals at Xiaohe in whom the trait could be observed had 2 Roots on lower canines, and one (4% of K = 25) had odontomes on lower premolars and one (7.14% of K = 14) had multiple lingual cusps on second premolars. All the above frequencies are more like in the three Western Eurasian groups. While two (16.67% of K = 12) had a cusp 6 like people in South Siberia (10–20%), and four (12.9% of K = 31) had one-rooted lower molars like the population in Northern Africa (10–20%). Seven out of nine (77.78%) individuals had 4 cusps on second molars, more like in the three Western Eurasian groups (>80%).

Xiaohe people, like most Western European populations, have higher frequencies of traits such as Carabelli's trait absence, and 2-rooted upper first premolars, while like typical China-Mongolian people, have Moderate frequencies of shoveling, and higher frequencies of upper central incisor winging.

Based on frequency data and MMD results between Xiaohe and the other compared groups (Tables 7 and 8), all of the MMD scores are larger than twice the standard deviation, showing that all the resulting distances are statistically significant.

According to the frequency data from Table 7, there are no common trends among the distances between Xiaohe and other ancient Chinese groups. Among all eleven groups, the frequency data of Xiaohe and Jilintai have the smallest MMD score (0.221), followed by the MMD result between Xiaohe and Liushui (0.262). Yingpan is another group with the MMD distance not very far away from Xiaohe (0.361). Otherwise, Miaozigou is most distantly related to Xiaohe (0.735), followed by the Xiawanggang (0.676) and Longxian samples (0.660). Moreover, Xiaohe and the Taojiazhai and the Yanghai samples are distinct, with increasing MMD values of 0.625 and 0.649 respectively.

Table 4 Frequencies of the non-metric traits in tooth crown and root of the Western Eurasian and Sino-American groups

Trait	Frequency		Trait	Frequency	
WING	0–15%:	Western Eurasian groups	C7 LM1	0–10%:	Western Eurasian groups, Sino-American groups
	15–30%:	China-Mongolia, American Arctic			
SHOV	0–15%:	Western Eurasian groups	DW	5–15%:	Western Eurasian groups
	20–50%:	South Siberia, Jomon		20–35%:	China-Mongolia
	60–90%:	China-Mongolia, American Arctic, Northwest North American Indians, North and South American Indians		35–55%:	American Arctic, Northwest North American Indians, North and South American Indians
D SHOV	0–15%:	Western Eurasian groups	4C LM2	10–30%:	American Arctic, Northwest North American Indians, North and South American Indians
	20–40%:	China-Mongolia, American Arctic		30–60%:	China-Mongolia
	55–70%:	Northwest North American Indians, North and South American Indians		>80%:	Western Eurasian groups
2RT UP1	5–15%:	American Arctic, Northwest North American Indians, North and South American Indians	3R LM1	0–5%:	Western Eurasian groups, Jomon, South Siberia
	20–30%:	China-Mongolia, Jomon		5–15%:	Northwest North American Indians, North and South American Indians
	30–60%:	Western Eurasian groups		>20%:	China-Mongolia, American Arctic
CUSP5	10–25%:	Western Eurasian groups, Sino- American groups	1R LM2	0–10%:	Jomon
				10–20%:	Northern Africa
				20–30%:	Western Europe, Northern Europe
CARA	0–10%:	American Arctic, Northwest North American Indians, North and South American Indians, Jomon		>30%:	China-Mongolia, South Siberia, Northwest North American Indians, North and South American Indians
	10–15%:	China-Mongolia			
	>20%:	Western Eurasian groups			
C6 LM1	0–10%:	Western Eurasian groups	ODONT	0–1%:	Western Eurasian groups, Jomon, South Siberia
	10–20%:	South Siberia		1–3%:	Northeast Siberia
	30–50%:	China-Mongolia, American Arctic, Northwest North American Indians, North and South American Indians		4–7%:	China-Mongolia, American Arctic, Northwest North American Indians, North and South American Indians

According to the MMD results listed in Table 8, all distances between Xiaohe and the comparison groups from Western Eurasia are small. Northern Africa is most similar to Xiaohe (0.060). The MMD scores between Xiaohe and Western Europe is 0.104, and with Northern Europe is 0.109. Among the Sino-Chinese groups, South Siberia is more closely related to Xiaohe with the MMD result 0.119, and Jomon also shares a slight distance with Xiaohe (0.156). The Northeast Siberia and the three Native American groups are distantly related to Xiaohe within the MMD values.

In order to visualize the relationships between Xiaohe and the comparison groups, a distance dendrogram was subjected to cluster analysis using Ward's method (Figs. 4 and 5).

Within Fig. 4, there are three primary clusters: Yingpan, Yanghai and Taojiazhai are included in the first cluster. Yingpan and Yanghai are found in the same subcluster, followed by the Taojiazhai sample. Likewise, Jiangjialiang, Mogou, Miaozigou, Longxian, and Xiawanggang are found within the second cluster, with the Jiangjialiang and Mogou, as well as the Miaozigou, Longxian, and Xiawanggang samples respectively making up two subclusters. While Xiaohe,

Table 5 *P*-values from Fisher's exact test of the differences in number of individuals at or above the presence threshold for each trait between sexes of the Xiaohe cemetery

No.	Traits	*P*-values
1.	WING	1
2.	SHOV	1
3.	DSHOV	0.471
4.	TD	1
5.	2RT UP1	1
6.	CUSP5	1
7.	CARA	1
8.	3RT UM2	1
9.	2R LC	1
10.	MLC LP2	1
11.	C6 LM1	1
12.	C7 LM1	–
13.	DW	–
14.	3R LM1	–
15.	4C LM2	1
16.	1R LM2	1
17.	ODONT	1

Table 6 Frequencies of dental non-metric traits of the Xiaohe cemetery

Traits	Range of presence	Times seen (N)	Number of samples (K)	Frequency
Maxillary				
WING	1–2	9	29	31.03
SHOV	3–7	5	15	33.33
DSHOV	2–6	1	16	6.25
TD	1–6	7	11	63.64
ODONT	1	1	25	4.00
2RT UP1	2	20	36	55.56
CUSP5	1–5	3	10	30.00
CARA	2–7	2	9	22.22
3RT UM2	3	20	28	71.43
Mandible				
2R LC	2	1	32	3.13
ODONT	1	1	25	4.00
MLCLP2	2–9	1	14	7.14
C6 LM1	1–5	2	12	16.67
C7 LM1	1–5	0	11	0
DW	2–3	0	11	0
3R LM1	3	0	34	0
4C LM2	4	7	9	77.78
1R LM2	1	4	31	12.90

Jilintai, and Liushui are found in the third cluster, Xiaohe and Jilintai are found in the same subcluster, followed by the Liushui sample.

In Fig. 5, the Eurasian comparison groups are shown divided into two main distinct groups: China-Mongolia, Recent Japan, Northeast Siberia, and three Native American groups are included in the first cluster, while Xiaohe, Western Europe, Northern Europe, Northern Africa, Jomon, and South Siberia are found in the other cluster. Within the first cluster, China-Mongolia and Recent Japan, Northeast Siberia and American Arctic, Northwest North American Indians and North and South American Indians are respectively found in three subclusters. For the second cluster, Xiaohe, Northern Europe, Western Europe, and Northern Africa samples firstly cluster together and the second subcluster includes Jomon and South Siberia.

4 Discussion

A general summary of how dental trait variation corresponds to the five peopling scenarios in the Xinjiang area is provided in Fig. 6. This figure is divided between the ten traits that characterize Xiaohe and the other four groups of people in the Xinjiang area. By exploring population relationships based on univariate trait frequencies and bio-distance analyses, the assumptions of the various peopling models can be individually evaluated. Of the ten non-metric traits, only three-rooted upper second molar tends to be more consistent. Five traits of Xiaohe and Jilintai, including Carabelli's trait on upper first molars, three-rooted upper second molars, Cusp 7 and three-rooted lower first molars, and four-cusped lower second molars are almost consistent with each other. Six traits of Xiaohe and Liushui, including tuberculum on second incisor, Cusp 5 and Carabelli's trait on upper first molars, three-rooted upper second molars, Cusp 7, and three-rooted lower first molars, are almost consistent with each other. Few traits of Xiaohe exhibit consistency with the other two Xinxiang populations.

From the MMD results presented in Table 6, the dental non-metric traits trends in the Xinjiang area are clearly discerned. Xiaohe probably shares some common dental non-metric traits with the Jilintai sample, which indicates that these two groups are likely more closely related genetically than Xiaohe people with other samples, although they are geographically far away from each other. Considering previous anthropological studies that used both dental non-metric and cranial metric/non-metric traits, people from Jilintai were a European and Mongolian mixed group that migrated to Xinjiang from the west during the Bronze Age. The European traits were from neighboring Caucasoid groups, and the Mongolian traits possibly originated in Mongolia or Siberia but not from the Central Plains of China. In the Iron Age, many new people entered this region, settled, and intermarried, and then after this period, these populations migrated westward into Central Asia (Zhang 2010), such that the dental morphological affinities between the Jilintai and Xiaohe samples are likely representative of migration from the west and east already happening in the Bronze Age to early Iron Age periods, with these outside populations arriving in the Xiaohe region.

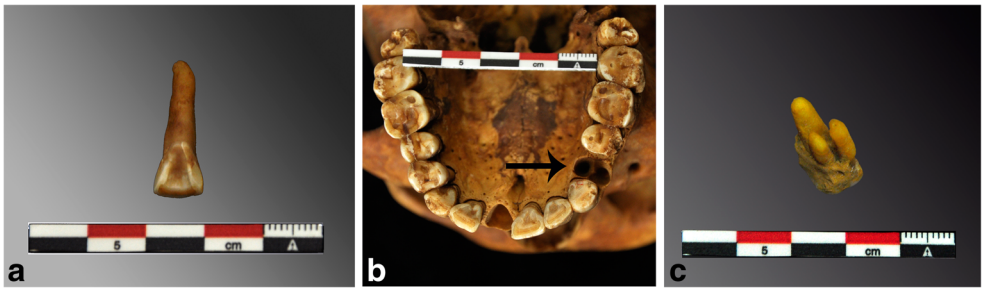

Fig. 3 Typical specimens of the dental non-metric traits from the Xiaohe cemetery. **a** Shoveling: 04XHM130; **b** Double-Rooted Upper Premolars: 04XHM112; **c** Three-Rooted Upper Molars: 04XHBM20

Table 7 Frequencies of 10 non-metric traits of the tooth crown and root in the Xiaohe and other Northern Chinese populations

Traits (teeth)	Range of presence	XH[a]		LS		JLT		YP		YH		MZG		XWG		JJL		MG		TJZ		LX	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
TD	1–6	11	63.6	36	100	31	12.9	8	12.5	8	0	20	45.0	78	35.9	49	55.2	72	37.5	12	0	31	22.5
CUSP5	1–5	10	30.0	42	33.3	69	7.2	23	4.3	32	0	18	16.7	125	4.0	52	3.8	111	6.3	53	5.7	55	3.6
CARA	2–7	9	22.2	39	30.8	53	22.6	21	28.6	31	16.1	17	11.8	128	0	56	7.2	107	15.0	56	17.9	54	5.6
3RT UM2	3	28	71.4	89	69.7	70	75.7	22	72.7	27	70.4	18	88.9	115	77.4	59	64.4	91	54.9	58	58.6	56	71.4
MLC LP2	2–9	14	7.1	64	40.6	62	50.0	16	62.5	19	57.9	23	87.0	135	77.8	59	67.8	99	76.8	41	61	48	75
C6 LM1	1–5	12	16.7	60	43.3	76	6.6	18	0	32	0	16	31.3	162	14.8	59	50.1	102	22.5	56	7.1	65	46.2
C7 LM1	1–5	11	0.0	59	5.1	75	5.3	19	15.8	34	5.9	17	11.8	155	2.6	57	15.8	103	8.7	60	0	60	1.7
3R LM1	3	34	0.0	103	1.0	78	0	23	0	29	0	21	47.6	187	36.4	61	11.5	103	15.5	66	21.2	76	26.3
4C LM2	4	9	77.8	59	45.8	76	88.2	22	86.4	32	81.3	16	18.8	156	27.6	59	22.4	73	43.8	54	42.6	54	18.5
1R LM2	1	31	12.9	99	23.2	74	20.3	23	8.7	28	0	18	27.8	184	31.0	66	21.2	73	34.2	60	30	70	34.3
MMD		–		0.262		0.221		0.361		0.649		0.735		0.676		0.495		0.435		0.625		0.660	
SD_{MMD} [b]		–		0.045		0.044		0.062		0.057		0.060		0.040		0.044		0.041		0.048		0.045	
$2*SD_{MMD}$		–		0.089		0.087		0.124		0.114		0.121		0.079		0.088		0.082		0.096		0.089	

[a] XH-Xiaohe, LS-Liushui, JLT-Jilintai, YP-Yingpan, YH-Yanghai, MZG-Miaozigou, XWG-Xiawanggang, JJL-Jiangjialiang, MG-Mogou, TJZ-Taojiazhai, LX-Longxian

[b] SD_{MMD} -Standard deviation

Liushui is another comparison group that has a relatively close MMD distance to Xiaohe. Previous anthropological research demonstrates that Liushui was also a group consisting of an admixture population deriving from both east and west Eurasia that arrived in southwestern Xinjiang as early as the Bronze Age (Zhang et al. 2014). Considering that the time period of Xiaohe was much later than Liushui, our biodistance study indicates that the common dental traits in both the Liushui and Xiaohe samples maybe were transmitted from the same progenitor, but some traits were also influenced by other groups of people, and this effect becomes more obvious in the Xiaohe sample, which belongs to a later time period. The cluster dendrogram in Fig. 3 also arrives at similar results.

Interestingly, Xiaohe shares the largest MMD distance with Yanghai. This indicates that, although they are geographically close to each other and their time period are almost the same, the groups each inherited a different genetic makeup. The archaeological discoveries at the Yanghai cemetery are very rich and reflect multi-aspect cultural relations with the peripheral regions (Li et al. 2011). A cranial metric study shows that the Yanghai sample is a group of nomadic people, mainly with Caucasoid cranio-facial features, who came from the northern Altai region or western Xinjiang 3500 years ago (Cui et al. 2002). Moreover, Xiaohe and Yingpan share the second largest MMD distance in the Xinjiang area, and they are also geographically close to each other. A cranial metric study of Yingpan indicates that it is a group of people mainly consisting of ancient Europeans dating to the Han-Jin period, but they also inherited a few cranio-facial features from Mongolian, i.e., the brachycephalic type (Chen 2002). We can tell from Fig. 4 that Xiaohe shared some dental non-metric traits with Bronze Age people from Mogou, in Gansu 甘肃 Province. It is probably due to early genetic exchange by their ancestors, owing to their very close geographical distance.

It also indicated that there are some common dental traits among Longxian, Miaozigou, and Xiawanggang, and these differ from the other comparison groups. These dental traits probably represent the typical dental non-metric traits of people living around the Central Plains of China, and they are significantly different from the Xiaohe sample, as indicated in Table 7 and Fig. 4.

The biodistance study of the Western Eurasian and Sino-American populations shown in Table 8 and Fig. 5 emphasizes the importance of Xiaohe's position in Eurasian dental morphology. The samples that cluster closest with Xiaohe is Northern Africa, then the Western Eurasia group modified by Scott and Turner (1997), and then the other two Western Eurasian groups. Xiaohe is also distinct from the three Native American groups. South Siberia is another sample that is similar to Xiaohe in dental morphological traits because of the lower MMD values.

Genetic analysis of the Xiaohe mummies shows that people of Xiaohe were an admixture population originating from both western and eastern Eurasia (Li et al. 2010). Mitochondrial DNA analysis, which reveals maternal ancestry, shows that the Xiaohe people carried both the East

Table 8 Frequencies of 15 non-metric traits of the tooth crown and root in the Western Eurasia and Sino-American populations

Traits (teeth)	Range of presence	XH[a]		WE		NE		NA		CM		JO		RJ		NES		SS		AA		NWA		NSAI	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
WING	1–2	29	31.0	180	7.2	150	5	460	7.5	591	24.5	166	19.9	265	21.9	112	33.9	109	18.3	220	23.2	226	35.8	1177	50
SHOV	3–7	15	33.3	186	2.7	46	2	194	7.5	542	72	117	25.7	276	66	61	62	98	36.7	172	69.2	172	83.1	1368	91.9
DSHOV	2–6	16	6.3	184	3.8	100	5	175	8.6	545	28.8	138	1.4	267	19.5	43	32.5	92	15.2	155	34.9	158	56.7	1231	70.5
2RT UP1	2	36	55.6	317	40.7	194	46	468	57.1	645	27.2	241	24.5	506	24.9	375	6.9	278	31.3	1022	4.9	693	6.7	2849	14.3
CUSP5	1–5	10	30.0	238	11.8	140	26	357	18.5	633	24.2	146	31.5	390	19.7	106	10.4	191	25.1	418	16.7	378	21.4	1780	16.7
CARA	2–7	9	22.2	249	27.3	138	18	200	20	774	16.2	181	2.3	458	14.9	172	5.3	186	14	477	1.9	388	5.5	2054	5.6
3RT UM2	3	28	71.4	265	57.4	227	61	364	78.6	591	65	254	46.9	495	68.9	260	50.8	247	47	836	37.4	523	41.5	2054	55.9
2R LC	2	42	2.4	314	5.7	214	6.1	347	2.3	401	0	203	1	335	1.2	206	0	260	3	733	0.3	500	0	2404	0.7
C6 LM1	1–5	12	16.7	217	8.3	130	16.9	352	7.7	538	35.9	214	46.7	314	42.7	90	50	195	20.5	355	50.4	322	50.3	1847	55.1
C7 LM1	1–5	11	0	291	4.5	179	5	414	9.4	721	7.9	285	3.1	382	5.7	151	6	272	9.9	565	8.5	473	6.8	2756	8.5
DW	2–3	11	0	154	5.2	75	16	267	8.2	343	15.7	162	4.9	262	14.9	81	39.5	142	16.9	230	30	192	36.5	1311	38.1
3R LM1	3	34	0	357	6	198	0	337	1.2	604	28.3	377	3.4	429	24.2	238	22.3	242	2.5	871	31.1	741	16.5	3276	6.5
4C LM2	4	9	77.8	284	71.1	225	84.4	381	66.4	639	20.8	244	28.7	345	13.6	138	6.5	225	54.2	484	5.2	447	4.4	2462	8.6
1R LM2	1	31	12.9	318	28	269	20.8	333	11.7	548	39.8	336	9.8	407	32.9	220	35.5	242	46.3	772	31.2	659	38.7	2703	32.8
ODONT	1	25	4.0	246	8	111	0	545	2	639	5.5	260	0.4	462	5	95	2.1	155	6	372	6.2	371	6.5	1787	4.4
MMD		–		0.104		0.109		0.060		0.326		0.156		0.310		0.566		0.119		0.637		0.687		0.684	
SD_{MMD} [b]		–		0.002		0.002		0.001		0.001		0.002		0.001		0.002		0.002		0.002		0.002		0.001	
$2*SD_{MMD}$		–		0.027		0.028		0.027		0.026		0.027		0.027		0.029		0.028		0.027		0.027		0.026	

[a] XH-Xiaohe, WE-Western Europe, NE-Northern Europe, NA-Northern Africa, CM-China-Mongolia, JO-Jomon, RJ-Recent Japan, NS-Northeast Siberia, SS-South Siberia, AA-American Arctic, NWA-Northwest North American Indians, NSAI-North and South American Indians

[b] SD_{MMD} -Standard deviation

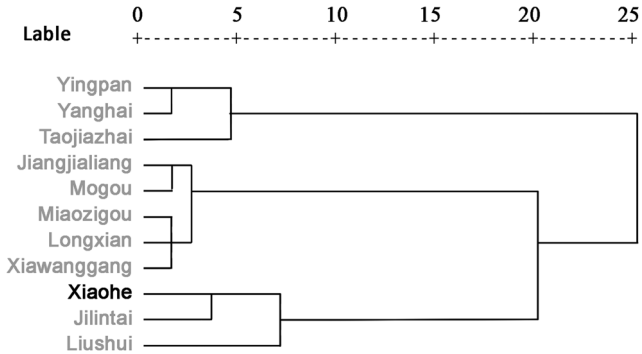

Fig. 4 Cluster analysis of MMD for the Chinese samples using Ward's method

Eurasian haplogroup (C4) and the West Eurasian haplogroups (H and K). The East Eurasian lineage C4, which is the dominant haplogroup found in the remains (58.13%), suggests that the east Eurasian component in the Xiaohe people originated from Siberian populations, especially the southern or eastern Siberian populations. The mtDNA haplogroups H and K are common in Western Europe, suggesting that the West Eurasian component of the maternal ancestry observed in the people of Xiaohe might have a close relationship with Western Europeans. The Y chromosomal DNA analysis, which reveals paternal lineage, shows only the West Eurasian haplogroup R1a1a in the male individuals. All these DNA analysis results are almost confirmed by the MMD results in our study.

The cultural remains discovered in the Xiaohe cemetery suggest that the culture of Xiaohe originated in the Okunev and Sintasha-Petrovka Cultures coming from the South Siberia area, and also there is a suggestion that the culture of Xiaohe is closely related to the Afanasevo Culture, which was the earliest Eneolithic archaeological culture found until now in south Siberia (Guo 2012). This hypothesis is supported by the MMD cluster result in Fig. 4, which exhibits close distance between people from Xiaohe and South Siberia.

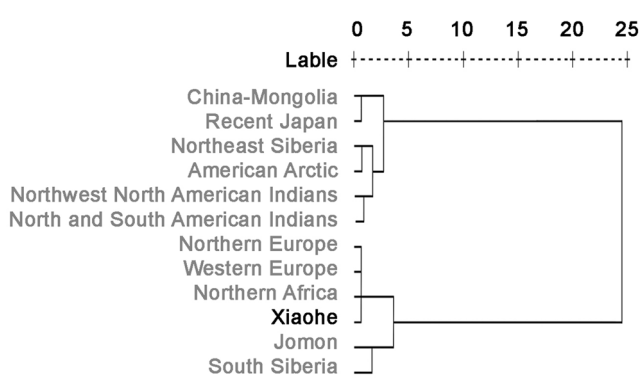

Fig. 5 Cluster analysis of MMD for Eurasian samples using Ward's method

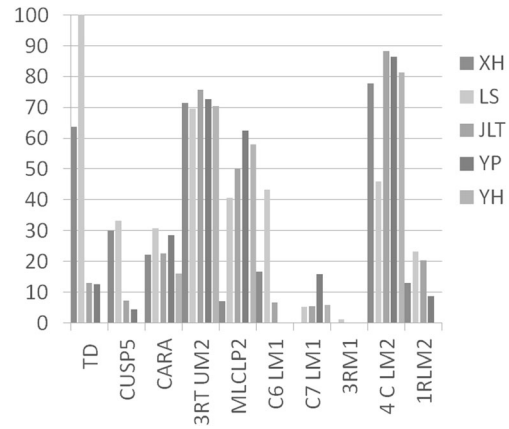

Fig. 6 Frequencies of 10 non-metric traits of the tooth crown and root within the Xiaohe and other Xinjiang populations

5 Conclusion

The Eurasian Steppe provided very suitable conditions for living as well as for the transmission of information and technology, and it also promoted cultural integration. This has resulted in the modern ethnic diversity seen in this region and its great variety of biological subtypes (Khudaverdyan 2013). The Xiaohe region, as a part of the Eurasian Steppe, is an area where people have a variety of genetic origins, as has been shown in previous bioarchaeological research (Li et al. 2010). With reference to dental morphological traits of ancient people in Eurasia, our study provides insight into the complex relationships between the ancient people from Xiaohe and the other comparison groups.

The biodistance results reported in this study indicate that the Xiaohe population was an admixture, showing features mostly resultant from people who had migrated from Europe but who had also exchanged genes with Mongolians: this can be supported by previous historical, craniometric, and DNA analyses (Li et al. 2010). Further, two main interaction spheres, seen through dental non-metric traits, can be identified in the Xinjiang area. The first one comprises Xiaohe, Jilintai, and Liushui, and the second one includes Yanghai and Yingpan, but the reasons that made these groups different have not yet been found by our study, although it is possibly due to how gene flow occurred in the Eurasian area.

In this study, one of the limits to the exploration of the origins of the population in the Xiaohe area is the small sample size. However, the biodistance results reported in our study demonstrate the complexity of the population structure of the Xiaohe cemetery. Additional data from the Xiaohe region and more samples from earlier time periods in the Xinjiang area are still required. Likewise, other factors need to be considered, as well, including material culture studies and linguistics: these could also help to differentiate the Xiaohe population.

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