DIVIDED ZYGOMA IN HOLOCENE HUMAN POPULATIONS FROM NORTHERN CHINA

Qun Zhang1,2† | Quanchao Zhang2† | Shiyu Yang2 | Paul C. Dechow3 | Hong Zhu2 | Hui-Yuan Yeh1 | Qian Wang3

1School of Humanities, Nanyang Technological University, Singapore, Singapore
2School of Archaeology, Jilin University, Jilin, China
3Department of Biomedical Sciences, Texas A&M University College of Dentistry, Dallas, Texas

Correspondence
Qian Wang, Department of Biomedical Sciences, Texas A&M University College of Dentistry, 3302 Gaston Ave, Dallas, TX 75246.
Email: qian.wang@tamu.edu
Hui-Yuan Yeh, School of Humanities, Nanyang Technological University, 48 Nanyang Ave, Singapore 639 818, Singapore.
Email: hyyeh@ntu.edu.sg

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Abstract
Objectives: Divided zygoma (DZ) occurs in contemporaneous human populations, with the highest incidences in people from East Asia and Southern Africa. The present study examines the prevalence and variation of this condition in the Holocene populations of Northern China for the first time.

Methods: In this study, 1145 skulls from various human populations living in Northern China from the Neolithic Age to recent dynasties (5000-300 years BP) were examined. Specifically, cranial measurements and a CT scan were conducted to quantify craniofacial morphology.

Results: Fifteen skulls were identified with DZ, revealing an overall prevalence of 1.3% in the collection, while it was determined to be higher in North Asian and Northeast Asian regional groups. In skulls with unilateral DZ, the superior division of the zygoma was generally slender, while the inferior division of the zygoma was more robust. In skulls with bilateral DZ, the maxillae were generally more laterally extended. Moreover, unilateral DZ skulls displayed differences in cortical bone thickness between two sides of the facial skeleton.

Discussion: In context, the distribution pattern within these data points toward a greater prevalence of the DZ phenotype in North and Northeast Asian regional groups, suggesting a hypothesis that the DZ trait is more frequent in populations characterized by flat and broad faces. Accordingly, further studies into the DZ condition will deepen our understanding of developments in plasticity, variation, and recent evolution of the human cranium.

1 | INTRODUCTION

The zygomatic bones are an important component of the midfacial skeleton, and they play a critical role in the support and integration of the craniofacial skeleton as well as the masticatory apparatus. Each zygoma is normally quadrangular in morphology and articulates with the ipsilateral maxilla, frontal, temporal, and sphenoid bones. Functionally, the zygoma exists as a crucial force dispersion and kinetic energy absorption site in the midface while being situated in the lateral zygomatico-maxillary buttress (Hardt & Kuttenberger, 2010). Furthermore, each zygoma provides an attachment for a masseter muscle, and plays an important functional role in the masticatory system. Thus, the integrity of zygomatic bones is very

†Joint first authors contributed equally to this article.

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important in maintaining normal function of the facial skeleton (Wang & Dechow, 2016). Apart from its practical applications, the zygoma has multiple variations among different populations due to differences in genetic and environmental influences, including population history. The bone can change in shape and size (Noback & Harvati, 2015; Oettlé, Demeter, & L'abbé, 2017; Oschinsky, 1962; Paschetta et al., 2010), presenting morphological differences in zygomatic projection, zygomaxillary tuberosity, the malar tubercle, zygomatic trigone, and the course of the zygomaxillary suture (Baab et al., 2010; Hefner, 2009; İşcan & Steyn, 2013; L'Abbé et al., 2011; Lahr & Wright, 1996; Oettlé et al., 2017; Oschinsky, 1962; Standring, 2008; Vitek, 2012). Yet, in a natural although rare form, the zygoma can also be divided by extra sutures into two or more parts (Hanihara, Ishida, & Dodo, 1998; Hrdlička, 1902; Ossenberg, 2013; Wang & Dechow, 2016). To illustrate, in most divided zygoma (DZ) phenotypes, the bone is affected by a supernumerary suture that divides the facial aspect of the zygoma into upper and lower divisions, giving the bone a bipartite morphology termed *os zygomaticum bipartitum*, previously called *os japonicum* due to its high prevalence in the Japanese population (Hrdlička, 1902).

In the past century, the condition of DZ was investigated among several populations, specifically in the Native Americans (Hrdlička, 1902, 1904; Oetteking, 1930), Asians (Anil, Peker, Turguta, Pelin, & Gülèköne, 2000; Bhargava, Garg, & Bhargava, 1960; Jeyasingh, Gupta, Arora, & Saxena, 1982; Koganei, 1926; Kundu et al., 2016; Mangalgiri, Satpathy, & Bhojwani, 2015; Ohnishi, 1940; Soni & Khatri, 2016), Europeans (Dimovski, 2012; Kundu et al., 2016; Martin & Saller, 1959; Nikolova, Teneva, & Georgiev, 2017; Soni & Khatri, 2016), Sub-Saharan Africans (De Villiers, 1968; Klopper II, 1943; Rightmire, 1972; Wells, 1947), and the Australian Aborigines (Pardoe, 1984). Actually, an investigation by Hanihara et al. (1998) that covered major populations is the most detailed scholarship on DZ to date. He examined 96 skeletal sample groups in Europe, North America, Australia, and Asia. Ultimately, his findings underscored that East Asians have a relatively higher incidence of DZ than any other geographical group. In fact, results from this work show that the prevalence in the main island of Japan is 2.3%. East and Northeast Asia garner respective rates of 2.8% and 2.5%. These prevalence values far exceed that of other populations. Similarly, the sample with the highest prevalence was a Neolithic sample from Lake Baikal in North Asia, reaching a score of 5.3%. However, this trait is less frequent in Europe than it is in the eastern parts of Eurasia, and DZ is sporadically observed in Oceania and America. Nonetheless, one exception to this concept is in Sub-Saharan Africa, where DZ has the second highest prevalence found in a geographic group besides Asia (Hanihara et al., 1998). After the comparison between main populations worldwide, Hanihara et al. (1998) concluded that the prevalence denotes geographic interregional clinal variation, from nil to 6.5%, most likely related to genetic factors. Likewise, research in primates by Wang and Dechow (2016) found a prevalence of 0.2% in rhesus macaques, 4.3% in orangutans, but nil in chimpanzees and gorillas. These regional variations in human populations and species differences among nonhuman primates suggest a genetic influence in presence of extra sutures in DZ phenotypes.

Namely, sutures are fibrous joints in vertebrate craniofacial skeletons, serving as important loci of craniofacial growth through their interactions with surrounding tissues and structures (Opperman, 2000; Rice, 2008). Biomechanically, sutures are mechanically weak sites in the otherwise rigid skull (Wang, Smith, et al., 2010; Wang et al., 2012; Wang & Dechow, 2016). Therefore, any disturbance can result in either premature closure of sutures or the addition of extra sutures. These actions alter the normal growth and function of the skull and possibly result in an abnormal skull shape as a consequence of adjusting growth direction and function. Hence, one ramification of this process is that suture morphology should be well patterned to maintain skull morphology according to species identity (Wang & Dechow, 2016). In nonhuman primates and modern humans, skulls with the DZ condition demonstrated significant morphological features such as asymmetry and regional bony strengthening, suggesting changes in midfacial modularity and functional adaptations (Wang & Dechow, 2016).

While research has covered some parts of the world and incorporated the above primates, unknowns about this condition remain. The purpose of this study was to investigate the DZ phenomenon in Holocene human populations from Northern China. Northern China is a crucial part of East Asia, which contains a diverse history of human integration and migration (Black, 1928; Han, 2009; Wang et al., 2019; Wu & Poirier, 1995; Zhang, 1981; Zhu, 1993, 2014). In this study, the prevalence of DZ and the impact of supernumerary sutures on craniofacial morphology were examined at the macro-level, particularly for aspects including facial asymmetry, and at the micro-level for features such as the distribution of cortical bone thickness. This is the first systematic investigation of its kind on skeletal collections of ancient human populations living in Northern China, during the Neolithic Age to recent dynasties. The results will not only enrich our knowledge of DZ cases in terms of regional variations and population relationships, but also allow for better understanding of skull developmental plasticity and patterning.

## 2 Methods

Human skeletons from prehistoric and historic periods stored at the Research Center for Chinese Frontier Archeology at Jilin University were examined for signs of bilateral or unilateral DZ. These collections consisted of various human
populations from 49 archeological sites dispersed in Northern China, spanning across the Neolithic period to recent dynasties (5000 to 300 years BP) (Appendix 1, Figure 1). In addition to the two European derived populations from Xinjiang in western China, all other ancient populations involved were Asian with differing archeological cultures. During life, the subsistence patterns of these groups were especially distinct. The Neolithic populations were semi-agricultural or followed a hunter-gatherer pattern, while people of the Bronze Age used agricultural and nomadic patterns. In contrast, populations of the Iron Age and the later historical dynasties maintained a settled agricultural pattern. Through their differences, these groups basically represented the main regional subdivisions of the Asian population in northern China. These skulls from this area were also previously analyzed, then generally classified into four different morphological and geographical types (Zhu, 1993, 2002; Zhang, 2010). These types included the East Asian regional group, North Asian regional group, Northeast Asian regional group, and Western East Asian regional group. Moreover, anthropological evidence has demonstrated the diversity of these populations in ancient North China. For example, the East Asian regional group lived in central and eastern China and the North Asian regional group lived in northern China and the Mongolia plateau. Correspondingly, the Northeast Asian regional group resided in northeastern China, whereas the Western East Asian regional group lived in western China (Zhang, 2010; Zhu, 2014). However, it must be noted that these divisions were set and used for the purpose of description only (Wang et al., 2019).

Beyond geographical and cultural classifications, a total of 1145 skulls were visually examined to detect complete division of the zygomatic bone conditions, while partial supernumerary sutures were excluded. On this account, all supernumerary sutures on the identified DZ specimens were further differentiated from specimens with unhealed trauma fractures or other external force fractures. The identified specimens were also examined using a K9500 CBCT scanner (Kodak Dental Systems, Carestream Health Inc. Rochester, New York) within parameters of 80 kV; 80 mA; slice thickness of 0.3 mm in increments of 0.2 mm. Furthermore, prevalence pertaining to the complete horizontal division of the zygoma by the individual and side were calculated separately.

The morphology of the craniofacial bones was also recorded by examining the size, shape, and special features of the zygomatic bone, including its height, breadth, area, and symmetry. Specifically, in order to quantify the morphological impacts incurred by the DZ phenomenon, we selected and designed several cranial measurements based on zygoma shape, incorporating upper facial height (n-pr), height and breadth of the zygoma, minimum breadth of the zygomatic body, the height and thickness of the zygomatic arch, thickness regarding the zygomatic process of the maxilla, and the breadth of the zygomatic process of the frontal bone (Figure 2). The measurements were taken on both sides and different sets of comparisons were designed. By way of example, side-based comparisons were carried out in unilateral DZ specimens to examine the asymmetry between the DZ side and the normal side by calculating relevant size ratios. Likewise, in bilateral test subjects, the averages of
measurements on both sides were calculated. Meanwhile, 42 adult individuals with normal zygoma from the archaeological sites were chosen as a control group, with the sex and age numbers of the selected sample similar to that of the DZ samples. In addition, CT images were used to assess facial asymmetry patterns in skulls with unilateral DZ conditions by measuring the thickness of the cortical bone. Specifically, five points located on the body of the zygoma were selected, including the zygomatic process of the maxilla, the frontal zygomatic process, and the zygomatic arch (Figure 2). Correspondingly, determination of cortical bone thicknesses was performed using Mimics Research 16.0 software (Materialise Inc., Leuven, Belgium) to create measurements from virtual CT reconstructions (which were derived from the bone scans). It is also important to mention that all measurements were conducted by the same observer (QZ) three times and average values were recorded.

Data were then analyzed using a statistical analysis program named GraphPad 6.0 for Windows (GraphPad Software Inc., La Jolla, California). Descriptive statistics and Student $t$ tests were used to summarize and assess facial skeletal asymmetry. In addition, nonparametric Chi-square row by column tests for independence were used to assess group differences and their association with facial morphologies. The significance level was set at $\alpha = 0.05$.

3 | RESULTS

3.1 | The prevalence of divided zygomas in ancient Chinese populations

Fifteen adult individuals out of 1145 skulls were identified with the DZ phenotype, accompanied by an overall prevalence of 1.3%. Moreover, within the assigned classifications, the prevalence was 0.8% (6/777) in the East Asian regional group, 2.2% (12/546) in the North Asian regional group, and 2.7% (2/75) in the Northeast Asian regional group. In contrast, no individual was identified in the Western East Asian regional group (Tables 1 and 2). Although the sample sizes in each category differ, a deeper examination revealed that the combined North and Northeast Asian regional group had a significantly higher DZ frequency than other groups (Chi-Square test: $X^2 = 6.475$, df = 2, $P = .0393$). There were no sex differences (seven males, eight females) or side differences in terms of the prevalence, which is consistent with previous findings (Hauser & De Stefano, 1989). Furthermore, nine individuals had bilateral DZ, while others were identified as unilateral. In the unilateral cases, three specimens presented signs on the right side and another three on the left side. Those individuals with DZ came from 13 different populations located throughout Northern China, including Inner Mongolia, Jilin, Liaoning, Ningxia, and Shanxi Provinces (Figure 1), and who lived between 5000 and 300 years BP.

3.2 | Side-based morphological difference in unilateral DZ specimens

In an additional exploration of our results, the measurements on both sides in unilateral DZ skulls displayed a significant asymmetry between the DZ side and the normal side (Table 3). Overall, total zygoma height, breadth, and area on the DZ side were larger than that of the normal side, whereas the minimum breadth of the zygomatic body was smaller on the DZ side than on the normal side. In the inferior part of the skull, the height, thickness, and area of zygomatic arch along with the thickness of the zygomatic process of the maxilla were both larger than on the normal side. Conversely, on the superior part, the breadth of the frontal zygomatic process was relatively smaller than on the normal side. Furthermore, these unilateral DZ skulls demonstrated a side-based asymmetry larger than in normal subjects (Table 4; Figure 3). In general, the area of the zygoma on the DZ side was larger than on the normal side, with an average ratio of 1.14. Accordingly, in the inferior part of the zygoma, the area of the zygomatic arch and the zygomatic process of the maxilla thickness were larger on the DZ side with average ratios of 1.36 and 1.13, respectively. In the superior part of the zygoma, the minimum breadth of the zygomatic body and the breadth of the frontal zygomatic process were smaller on the DZ side,
with respective average ratios of 0.90 and 0.91. Finally, CT images showed that the cortical bone thickness measurements were larger on the DZ sides than on the corresponding normal sides (Table 5; Figure 4).

### 3.3 Differences between bilateral skulls and normal skulls

The size and shape of the zygomatic bones were also different between bilateral DZ skulls and normal skulls (Table 6; Figure 5). In bilateral DZ specimens, not only was the minimum breadth of the zygomatic body smaller in typical humans than on the DZ skull, the ratio of zygoma height to zygoma breadth was larger on the DZ skull as well. Meanwhile, in a comparison of zygoma size to overall facial size, the zygoma height was larger relative to the upper facial height in DZ skulls, while the zygoma breadth showed no significant differences relative to midfacial breadth, indicating that the zygoma in bilateral DZ skulls was more slender relative to the whole facial skeleton than in the normal skulls (Table 6). Simultaneously, the lower division of the zygoma and the adjacent bones demonstrated structural changes indicating increased strength. This finding was especially true for the maxilla, as both sides had a “wedge-like process” that extended laterally with curved inferior borders, resulting in remarkably prominent muscle attachment markings (Figure 6). The area of zygomatic arch was also much larger on DZ skulls, suggesting greater strength. In addition, differences between the superior and inferior divisions in bilateral DZ skulls

### TABLE 1 The description of the specimens with divided zygoma

| No. | Sample        | Period          | Sample size | Sex of DZ specimen | Age of DZ specimen | DZ location | Regional type                      |
|-----|---------------|-----------------|-------------|--------------------|-------------------|-------------|------------------------------------|
| 1   | Zhukaigou M1064 | 3000-1600 BCE   | 22          | F                  | 30±               | Bilateral   | East Asian region                  |
| 2   | Baiyan H2005  | 2000-1046 BCE   | 10          | M                  | 40±               | Bilateral   | East Asian region                  |
| 3   | Xindianzi M33:1| 600 BCE         | 25          | F                  | 25-30             | Bilateral   | North Asian region                 |
| 4   | Jinggouzi M46-B| 500 BCE         | 27          | M                  | 22±               | Right       | North Asian region                 |
| 5   | Da'an M74C    | 475 BCE-220 CE  | 75          | F                  | 35±               | Bilateral   | North Asian region/ Northeast Asian region |
| 6   | Da'an M30     | 475 BCE-220 CE  | M           | 20-25              |                   | Bilateral   |                                    |
| 7   | Dongdajing M4:2| 8-220 CE       | 11          | F                  | 15-16             | Left        | North Asian region                 |
| 8   | Qiliangshan M18| 220-420 CE     | 4           | F                  | 25-30             | Bilateral   | North Asian region                 |
| 9   | Tuchengzi M170| 220-420 CE     | 103         | F                  | 25-30             | Bilateral   | North Asian region                 |
| 10  | Lamadong M217 | 300-420 CE      | 155         | M                  | 24-35             | Right       | East Asian region/ North Asian region |
| 11  | Lamadong M371 | 300-420 CE      | M           | 35±               |                   | Left        | East Asian region/ North Asian region |
| 12  | Sanmianjing M6| 1271-1368 CE    | 6           | M                  | 20±               | Right       | North Asian region                 |
| 13  | Zhanzishan M68| 1271-1368 CE    | 29          | M                  | 25±               | Bilateral   | East Asian region/ North Asian region |
| 14  | Kaicheng M65  | 1271-1368 CE    | 12          | F                  | 35-50             | Left        | North Asian region                 |
| 15  | Yuci Mi5-1    | 1368-1800 CE    | 111         | F                  | 30-35             | Bilateral   | East Asian region                  |

### TABLE 2 The prevalence of divided zygoma among different Asian regional subgroups

| Sample name                     | Right (%) | Left (%) | By individual (%) | By side (%) |
|---------------------------------|-----------|----------|-------------------|-------------|
| East Asian regional group       | 0.64 (5/777) | 0.64 (5/777) | 0.77 (6/777) | 0.64 (10/1554) |
| North Asian regional group      | 1.65 (9/546) | 1.65 (9/546) | 2.20 (12/546) | 1.65 (18/1092) |
| Northeast Asian regional group  | 2.67 (2/75)  | 2.67 (2/75)  | 2.67 (2/75)  | 2.67 (4/150)   |
| Western East Asian region group | 0.00 (0/60)  | 0.00 (0/60)  | 0.00 (0/60)  | 0.00 (0/120)   |
| Total                           | 1.05 (12/1145) | 1.05 (12/1145) | 1.31 (15/1145) | 1.05 (24/2290) |

*Note:* six archeological sites contained two regional groups which they were included in both groups. Chi-square test: Four groups, $X^2 = 6.582$, df = 3, $P = .0865$; three groups with North and Northeast combined $X^2 = 6.475$, df = 2, $P = .0393$. The combined North and Northeast Asian regional group had significantly higher prevalence than the other groups.
were bigger than in normal skulls. Moreover, compared to normal skulls, the ratio of the zygomatic arch height to the breadth of the frontal zygomatic process was much larger, generating a consistency with observations that the bilateral DZ specimens have relatively small zygomatic processes of the frontal bone and a larger zygomatic arch size. The middle facial breadth and the upper facial height showed no significant differences (Table 6).

**TABLE 3**  Linear measurements of skulls with unilateral DZ

| Specimens with unilateral DZ | Jinggouzi M46:B | Sanmianjing M6 | Lamadong M217 | Dongdajing M4:2 | Lamadong M371 |
|-----------------------------|-----------------|----------------|---------------|-----------------|---------------|
| DZ side                     | Right           | Right          | Right         | Left            | Left          |
| Upper facial height         | 73.45           | 82.30          | 74.92         | 74.92           | 69.21         |
| Zygoma height right         | 59.04           | 59.74          | 49.66         | 48.76           | 43.55         |
| Zygoma breadth right        | 57.81           | 59.23          | 57.46         | 50.11           | 43.96         |
| Zygoma height left          | 54.03           | 53.99          | 47.43         | 56.27           | 48.03         |
| Zygoma breadth left         | 57.72           | 56.09          | /             | 50.56           | /             |
| Area of zygoma               | 3413.10         | 3538.40        | 2853.46       | 2443.36         | 1914.46       |
| Area of zygoma left         | 3118.61         | 3028.30        | /             | 2845.01         | /             |
| Zygomatic body minimum breadth right | 21.82 | 24.32 | 22.92 | 24.54 | 19.45 |
| Zygomatic body minimum breadth left | 22.64 | 25.71 | / | 23.2 | 14.35 |
| Zygomatic arch height right | 17.63           | 18.50          | 16.75         | 14.59           | 9.58          |
| Zygomatic arch thickness right | 5.32 | 5.83 | 4.46 | 4.75 | 4.12 |
| Zygomatic arch height left  | 15.04           | 15.97          | /             | 22.36           | /             |
| Zygomatic arch thickness left | 4.77 | 5.49 | / | 4.83 | / |
| Area of zygomatic arch left | 93.79           | 107.86         | 74.71         | 69.30           | 39.47         |
| Area of zygomatic arch right | 71.74 | 87.68 | / | 108.00 | / |
| Zygomatic process of the maxilla thickness right | 10.03 | 12.90 | 8.99 | 8.7 | 6.66 |
| Zygomatic process of the maxilla thickness left | 9.50 | 12.22 | / | 9.28 | 7.58 |
| Zygomatic process of the frontal breadth right | 8.15 | 7.48 | 8.71 | 9.06 | 7.93 |
| Zygomatic process of the frontal breadth left | 8.71 | 7.73 | 10.66 | 8.35 | / |

**Note:** 1: the area of the zygoma is zygoma height times zygoma breadth; 2: the area of the zygomatic arch is zygomatic arch height times zygomatic arch thickness. DZ side was highlighted in bold. Unit: mm. “/” indicates that the measurement item is unavailable on the specimen.

**TABLE 4**  Ratios of side-based differences on unilateral DZ skulls

| Specimens | Ratio of side-based difference | Area of zygoma | Zygomatic body minimum breadth | Area of zygomatic arch | Zygomatic process of the maxilla thickness | Zygomatic process of the frontal breadth |
|-----------|--------------------------------|----------------|-------------------------------|------------------------|-------------------------------------------|----------------------------------------|
| Jinggouzi M46:B | DZ/Left | 1.09 | 0.96 | 1.31 | 1.23 | 0.94 |
| Lamadong M371 | DZ/Right | / | 0.74 | / | 1.14 | / |
| Lamadong M217 | DZ/Left | / | / | / | / | 0.82 |
| Sanmianjing M6 | DZ/Left | 1.17 | 0.95 | 1.23 | 1.06 | 0.97 |
| Dongdajing M4:2 | DZ/right | 1.16 | 0.95 | 1.56 | 1.07 | 0.92 |
| DZ mean (N = 5) | DZ/normal Mean ± SD | 1.14 ± 0.04 | 0.90 ± 0.11 | 1.36 ± 0.17 | 1.13 ± 0.79 | 0.91 ± 0.07 |
| Normal mean (N = 42) | Right/left Mean ± SD | 1.00 ± 0.05 | 1.01 ± 0.04 | 1.03 ± 0.14 | 1.01 ± 0.10 | 0.98 ± 0.07 |

**P value**  
<.001 | .128 | <.001 | .025 | .084

**Note:** In unilateral DZ specimens, the values of the DZ side were used as the numerator, while the values of the normal side were used as the denominator.
4.1 The prevalence of DZ in different populations

This is the first systematic investigation of the DZ phenomenon in Holocene human populations from Northern China.

Forty-nine ancient populations that lived in the Northern China area for over 5000 years represented the main population types studied. Except for the two European derived groups in western China, the specimens consisted of relatively isolated Asian populations with different cultures and subsistence patterns. The frequency of DZ in the whole...
ancient Chinese population was found to be 1.3%, with a higher incidence of 2.3% in North Asian and Northeast Asian regional groups combined, demonstrating a difference of prevalence among separate regional groups. Otherwise, there were no sex or side differences. In larger context, a comparison with other main populations worldwide asserts that the incidence of this phenomenon in the East Asian populations is relatively higher, indicating that there could be some genetic factors behind the occurrence of DZs. However, in further regard to the Chinese population, very limited investigations have been conducted on either modern Northern or Southern Chinese (Table 7). The populations from Yingchuan (Li, 1985a), Gansu (Li, 1985b), Shaanxi (Li, 1985b), and Qingdao (Ding, 1961), which represented the Northern Chinese, have a respective prevalence of 2.3%, 3.6%, and 1.3%, while the populations from Nanjing (Gong & Du, 1965), Jiangxi (Hu et al., 1985), and Kunming (Yang, 1987), which represented the Southern Chinese, have their own respective prevalence rates at 0.5%, 0.7%, and 0.2%. These prevalence values show a decline from the Northern to the Southern populations, suggesting clinal variation. For example, there is a high DZ prevalence among North Asian regional populations, who were characterized by flat and broad faces, suggesting a morphological or genetic link to this phenomenon. Generally, Asians are characterized by high cheek bones with flat faces. This point is especially reinforced among North Asian and Northeast Asian regional populations. In these groups, there are very flat faces in the transverse midfacial plane, along with lateral and forward positioned zygomas (Baba & Narasaki, 1991; Chen et al., 2011; Hamilton, 2008; Hanihara, 2000; Hanihara, Ishida, & Dodo, 2003; Oettlé et al., 2017). A few Sub-Saharan Africans also present similar characteristics with flat faces and projecting zygomas (Hanihara, 2000). Intriguingly, the prevalence of DZ attained a higher rate in both the East Asian and South African populations. Indeed, this particularly high prevalence was among the populations with flat faces and projecting zygomas. Thus, it is hypothesized that DZs develop more often in individuals with broad facial morphologies. In context, broad facial morphology has been linked to increased anterior teeth loading stress and efficiency (Wang et al., 2019; Wang, Wright, Smith, Chalk, & Byron, 2010). Hence, the presence of supernumerary sutures in the midface under a high stress environment will have a negative impact, which in turn demands a functional and morphological adaptation to alleviate the situation. This reaction may represent an example of developmental plasticity in the craniofacial skeleton (Wang & Dechow, 2016).

Developmental plasticity is defined as “the ability of an organism to react to an internal or external environmental input with a change in form, state, movement, or rate of...
### TABLE 6 Comparisons between bilateral DZ and normal skulls on zygomatic morphology

|                | Zygomatic arch height/zygomatic process of the frontal breadth | Zygoma height/zygoma breadth | Zygoma height/upper facial height | Zygoma breadth/middle facial breadth | Zygomatic body minimum breadth | Area of zygomatic arch |
|----------------|---------------------------------------------------------------|-------------------------------|-----------------------------------|--------------------------------------|-------------------------------|-------------------------|
| **Male**       |                                                               |                               |                                   |                                      |                               |                         |
| Da’an M30      | 2.27                                                          | 1.11                          | 0.83                              | 0.48                                 | 21.97                        | 67.92                   |
| Zhenzishan M68 | 2.34                                                          | 1.06                          | 0.82                              | 0.56                                 | 20.21                        | 91.10                   |
| Baiyan H2005   | 1.78                                                          | 1.01                          | 0.81                              | 0.54                                 | 23.30                        | 89.19                   |
| DZ mean (N = 3) Mean ± SD | 2.13 ± 0.31                           | 1.06 ± 0.05                           | 0.82 ± 0.01                       | 0.52 ± 0.04                           | 21.83 ± 1.55                           | 82.74 ± 12.87          |
| Normal mean (N = 17) Mean ± SD | 1.66 ± 0.29                           | 0.88 ± 0.05                           | 0.69 ± 0.03                       | 0.55 ± 0.04                           | 27.15 ± 2.16                           | 68.67 ± 17.86          |
| P value        | .020                                                          | <.001                         | <.001                             | .167                                 | .001                          | .212                    |
| **Female**     |                                                               |                               |                                   |                                      |                               |                         |
| Zhukaigou M1064 | 2.20                                                          | 1.05                          | 0.73                              | 0.52                                 | 24.58                        | 86.25                   |
| Xindianzi M33:1 | 2.16                                                          | 1.06                          | 0.78                              | 0.53                                 | 20.48                        | 62.19                   |
| Da’an M74C     | 2.34                                                          | 1.15                          | 0.89                              | 0.51                                 | 23.78                        | 80.20                   |
| Qilangshan M18 | 2.09                                                          | 1.00                          | 0.78                              | 0.54                                 | 21.81                        | 94.37                   |
| Yuci M15-1     | 2.04                                                          | 1.22                          | 0.82                              | 0.50                                 | 19.62                        | 97.32                   |
| DZ mean (N = 5) Mean ± SD | 2.16 ± 0.12                           | 1.10 ± 0.09                           | 0.80 ± 0.06                       | 0.52 ± 0.02                           | 22.05 ± 2.11                           | 84.07 ± 13.97          |
| Normal mean (N = 25) Mean ± SD | 1.65 ± 0.29                           | 0.89 ± 0.08                           | 0.67 ± 0.03                       | 0.53 ± 0.06                           | 25.12 ± 2.86                           | 66.90 ± 16.88          |
| P value        | .001                                                          | <.001                         | .007                              | .671                                 | .032                          | .043                    |
FIGURE 5 Illustrations of the bilateral DZ skull (Yuci Mf5-1 and Yuci Mb7-1 on the left, Da’an M74C and Da’an M39A are on the right). Remarkable facial morphological differences are shown between the DZ skulls and the normal skulls along the inferior border of the maxillary and zygomatic bones.

FIGURE 6 Bilateral DZ conditions illustrated on macroscopic and CT images (Yuci Mf5-1 and Yuci Mb7-1 on the top, Da’an M74C and Da’an M39A below). The red lines indicate the normal shape and “wedge-like process” of the maxilla with the laterally extended and curved inferior borders in the DZ skull, while the red arrows show morphological differences associated with structural strengthening on the inferior borders in the DZ skull.
activity” (West-Eberhard, 2003). To explain, selection can act on phenotypes expressed in developmentally plastic systems in response to environmental factors, thereby linking developmental plasticity to adaptive evolutionary change (West-Eberhard, 2005). In the case of the highly integrated aspects within craniofacial skeletons, plasticity in the midface and surrounding areas is fundamental to their ability to respond independently or collectively to environmental conditions and ultimately their ability to respond adaptively to selection. Hence, although this study has identified the rates of DZ itself in China, developmental plasticity in populations with broad faces and the tendency to have a high incidence of DZ warrants more investigation. The skeletal collections of Neolithic and Dynastic population in Northern China have a chronological depth that shows in-situ evolution, and thus provides a rare opportunity for the study of the evolution and adaptation of craniofacial morphology in modern humans. Further insights into this rare DZ condition would deepen our understanding of craniofacial form, adaptation, developmental plasticity, and evolution.

### 4.2 The occurrences and mechanisms of divided zygoma

One explanation for the rarity of this condition is that it could be a random mutation related to the developmental failure of sutural fusion. The mechanisms that cause the supernumerary sutures (such as those displayed in DZs) remain unclear. Typically, the horizontal supernumerary sutures on the DZ samples were located on the relatively fixed inferior part of the zygoma - a term used when dividing the zygoma into portions, with a larger superior part and a smaller inferior part. In the case of the unilateral DZ samples, the incomplete horizontally divided zygomatic suture can also be observed at the same location on the other side (Table 8). These phenomena suggest that the occurrence of

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### Table 7: The prevalence of DZ in various populations

| Populations       | By individual (%) | By side (%) | Resource       |
|-------------------|-------------------|-------------|----------------|
| Yingchuan         | 3.0 (6/200)       | 2.25 (9/400) | Li, 1985a      |
| Gansu, Shaanxi    | 3.92 (13/332)     | 3.61 (24/664) | Li, 1985b      |
| Qingdao           | /                 | 1.28 (21/1638) | Ding, 1961    |
| Nanjing           | 0.59 (6/1018)     | 0.49 (10/2036) | Gong & Du, 1965 |
| Jiangxi           | 0.88 (7/800)      | 0.69 (11/1600) | Hu, Li, & Zhen, 1985 |
| Kunming           | /                 | 0.24 (4/1666) | Yang, 1987     |
| East Asia         | 2.79 (8/287)      | 1.98 (12/607) | Hanihara et al., 1998 |
| Northeast Asia    | 2.53 (13/514)     | 1.36 (15/1101) | Hanihara et al., 1998 |
| Southeast Asia    | 0.99 (11/1115)    | 0.65 (15/2320) | Hanihara et al., 1998 |
| Subsaharan Africa | 0.81 (6/743)      | 0.67 (11/1648) | Hanihara et al., 1998 |
| North Africa      | 0.75 (5/669)      | 0.49 (7/1434) | Hanihara et al., 1998 |
| Indian subcontinent | 0.57 (4/696)   | 0.49 (7/1438) | Hanihara et al., 1998 |
| Europe            | 0.45 (6/1336)     | 0.32 (9/2836) | Hanihara et al., 1998 |
| Oceania           | 0.10 (2/2015)     | 0.07 (3/4354) | Hanihara et al., 1998 |
| West-central Asia | 0.00 (0/312)      | 0.14 (1/711) | Hanihara et al., 1998 |
| Arctic group      | 0.00 (0/376)      | 0.12 (1/809) | Hanihara et al., 1998 |
| American Indians  | 0.00 (0/490)      | 0.00 (0/1120) | Hanihara et al., 1998 |

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### Table 8: The occurrence of incomplete sutures on the normal side in the unilateral DZ skulls

| No. | Site          | Sex | Age | Location | Incomplete sutures |
|-----|---------------|-----|-----|----------|--------------------|
| 1   | Jinggouzi M46-B | M   | 22± | Right    | Posterior          |
| 2   | Dongdajing M4:2 | F   | 15-16 | Left    | Posterior          |
| 3   | Sanmianjing M6  | M   | 20± | Right    | Posterior          |
| 4   | Kaicheng M65    | F   | 35-50 | Left    | Anterior           |
| 5   | Lamadong M217   | M   | 24-35 | Right   | Anterior           |
| 6   | Lamadong M371   | M   | 35± | Left     | N/A                |
the supernumerary sutures should be related to the number of ossification centers in the ontogeny and development of the bone (Bhargava et al., 1960; De Villiers, 1968; Jeyasingh et al., 1982). Generally, it is thought that the human zygoma has only one ossification center, which appears in a fetus at eight weeks (Cunningham, 1947; Grant, 1952; Mall, 1906; Morris & Schaeffer, 1953; Woo, 1956). However, more ossification centers develop in some circumstances. Buchanan's Manual of Anatomy emphasizes that three ossification centers of the anterior, posterior, and inferior parts of the zygoma fuse to form the mature bone. Accordingly, the DZ will occur if these three ossification centers fail to fuse, resulting in *zygomaticum bipartium* or more divisions (Jones, 1946).

Also, from the perspective of calvarial embryogenesis, wormian bones and associated supernumerary sutures vary in different parts of the cranium. These conditions are usually associated with areas such as the lambda and bregma, as they develop fontanelles during the early stages of skull ontogeny (Anton, Jaslow, & Swartz, 1992). Moreover, both the zygoma and cranium are derived from intramembranous bone, suggesting similarities in developmental pathways. DZ have been observed on some basal tetrapods (Stegocephalia) as well, suggesting that these pathways and their perturbations are ancient in vertebrate cranial development (Gong & Du, 1965).

4.3 The effect of DZ on craniofacial morphology and the adaptability of morphological mechanisms

As observed by Wang and Dechow (2016) in rhesus monkeys, there were remarkable side-based differences in unilateral DZ skulls with facial asymmetry due to the differences in the size of the zygoma and subtle differences in adjacent bones, including the maxillary, temporal, and frontal bones. For instance, the superior division of the zygoma was more gracile compared to the normal side, while the inferior division was more robust. The same facts were true for bilateral DZ skulls compared to normal skulls. Thus, the DZ morphology consequently disturbs developmental modularity and the normal inferosuperior buttressing of biting and masticatory loads from the maxilla to the frontal, leading to facial asymmetries, regional strengthening of the cortical bone, and changes in patterns of muscle attachment (Wang & Dechow, 2016).

Morphological adaptations within and surrounding the DZ (including the cortical thickness asymmetries) led us to ponder the correlations between morphology and functional adaptation. Functional adaptations of bone can be a response to changes in mechanical stress. For example, as the outer layer of a bone organ, cortical bone grows and remodels in response to changes in mechanical loading and increased bone strain (Baab, Copes, Ward, Wells, & Grine, 2018; Lanyon, Goodship, Pye, & Macfie, 1982; Robling, Hinant, Burr, & Turner, 2002; Warden et al., 2005). Previous studies have shown in detail that the presence or absence of muscle and the degree of muscle attachment have an impact on cortical bone properties. The bone underlying the muscle-bearing sites may adapt to the local “strain microenvironment” by increasing maximum stiffness (Peterson & Dechow, 2003). In the DZ condition, the morphology of the zygoma likely adapt to loading changes caused by the presence of a supernumerary suture such that some local structures in maxillary bone and zygomatic arch are strengthened to allow sufficient muscle attachment and muscle force for orofacial activities. Accordingly, the cortical bone on the DZ side thickens in coordination with morphological shape change in response to function.

5 CONCLUSION

DZ is a rare yet significant trait that allows the study of ontogenetic variations in the supernumerary sutures of skulls and their biomechanical effects. In the present study, crania from Northern China retrieved in archeological excavations were examined to determine the prevalence of the DZ condition in these Holocene populations for the first time. Fifteen adult individuals were identified with types of DZ out of the 1145 skulls examined, giving a prevalence of 1.3% overall, along with a greater prevalence of 2.2% in the North Asian regional group and 2.7% in the Northeast Asian regional group. This pattern of distribution led to the hypothesis that the DZ trait is more frequent in populations characterized by flat and broad faces. Further, our measurements of zygoma morphology and cortical bone thickness indicated remarkable differences between divided and normal zygoma in both macroscopic morphology and microstructure. The superior division of the DZ was normally more slender along with a weaker adjacent frontal bone articulation; while the inferior division of the DZ was normally more robust, including correspondingly stronger temporal and maxillary bones. These adaptations in bone morphology demonstrate that a supernumerary suture within the zygoma may alter the pattern of stress distribution in the midface during function and, therefore, affect both macroscopic and microscopic aspects of facial morphology. Our findings reveal relationships between craniofacial features, geographic location, and substance pattern, which warrants more morphological and ethnogeographic studies toward a better understanding of this interesting feature.

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**AUTHOR CONTRIBUTIONS**

Q.W., Q.C.Z., H.Y., and Q.Z. designed the study and directed implementation. Q.Z., S.Y., and Q.W. collected the data. Q.Z. and Q.W. analyzed the data and drafted the manuscript. Q.W., P.C.D., H.Y., Q.C.Z. and H.Z. edited the manuscript for intellectual content and provided critical comments on the manuscript.

**ORCID**

Qian Wang https://orcid.org/0000-0002-3303-1183

**REFERENCES**

Anil, A., Peker, T., Turguta, H. B., Pelin, C., & Gülekone, N. (2000). Incidence of Os japonicum in anatomical dry skulls and plain cranial radiographs of modern anatomical population. *Journal of Cranio-Maxillofacial Surgery*, 28, 217–223.

Anton, S. C., Jaslow, C. R., & Swartz, S. M. (1992). Sutural complex of *Os Zygomaticum Bipartitum*. *Cunningham's text-book of anatomy* (7th ed., p. 539). London: Bailliere, Tindall and Cox.

Baab, K. L., FreidlineS, E., Wang, S. L., & Hanson, T. (2010). Relationship of cranial robusticity to cranial form, geography and climate in Homo sapiens. *American Journal of Physical Anthropology*, 141, 97–115.

Baba, H., & Narasaki, S. (1991). Minatogawa man, the oldest type of modern *Homo sapiens* in East Asia. *Quaternary Research (Daisyonki-Kenkyu)*, 30, 221–230.

Bhargava, K. N., Garg, T. C., & Bhargava, S. N. (1960). Incidence of *Os japonicum* (bipartite zygomatic bone) in Madhya Pradesh skulls. *Journal of the Anatomical Society of India*, 9, 21–23.

Black, D. (1928). A study of Kansu and Honan aeneolithic skulls and specimens from later Kansu prehistoric sites in comparison with north China and other recent crania. *Palaeontologica Sinica*, Vol. 6, Fascicle 1, Peking: Geological survey of China.

Chen, T., Hsu, Y., Li, J., Hu, J., Khadka, A., Wang, Q., & Wang, D. (2011). Correction of zygozma and zygomatic arch protrusion in East Asian individuals. *Oral Surgery, Oral Medicine, Oral Pathology, and Oral Radiology*, 112, 307–314.

Cunningham, D. J. (1947). *Cunningham's text-book of anatomy* (8th ed., pp. 221–222). London: Oxford University Press.

De Villiers, H. (1968). *The skull of the South African Negro*. Johannesburg: Witwatersrand University Press.

Dimovski, N. (2012). *Os Zygomaticum Bipartitum* Na Lobanjama Sa Srednjevekovnog Nanalizista Manastiriste U Majdanu. *Glasnik Antropološkog draštva Srbije*, 47, 9–16.

Ding, S. H. (1961). Measurement and observation of Chinese orbit and design of several measuring tools. *Journal of Qingdao Medical College*, 02, 15–24.

Gong, S. Q., & Du, Y. L. (1965). The characteristic of Chinese zygozma. *Acta Anatomica Sinica*, 02, 223–233.

Grant, J. C. B. (1952). A method of anatomy, descriptive and deductive (5th ed., p. 68). Philadelphia: Williams & Wilkins.

Hamilton, A. (2008). Taxonomic approaches to race. *Occidental Quarterly*, 8(3), 11–36.

Han, K. (2009). Studies of ancient populations along the silk road. Unruchchi: Xingjiang Renmin Press.

Hanihara, T. (2000). Frontal and facial flatness of major human populations. *American Journal of Physical Anthropology*, 111, 105–134.

Hanihara, T., Ishida, H., & Dodo, Y. (1998). *Os zygomaticum bipartitum*: Frequency distribution in major human populations. *Journal of Anatomy*, 192, 539–555.

Hanihara, T., Ishida, H., & Dodo, Y. (2003). Characterization of biological diversity through analysis of discrete cranial traits. *American Journal of Physical Anthropology*, 121, 241–251.

Hardt, N., & Kutenberger, J. (2010). Craniomaxilfacial trauma: Diagnosis and management. Verlag Berlin Heidelberg: Springer.

Hauzer, G., & De Stefano, G. F. (1989). Epigenetic variants of the human skull. Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung.

Hefner, J. T. (2009). Cranial nonmetric variation and estimating ancestry. *Journal of Forensic Sciences*, 54, 985–995.

Hrdlička, A. (1902). New instances of complete division of the malar bone, with notes on incomplete division. *American Naturalist*, 36, 273–294.

Hrdlička, A. (1904). Further instances of malar division. *American Naturalist*, 38, 361–366.

Hu, X. H., Li, P. Z., & Zhen, J. G. (1985). Observation of the zygomatic bone. *Acta Academiae Medicinae Jiangxi*, 01, 11–15.

Işıkcan, M. Y., & Steyn, M. (2013). *The human skeleton in forensic medicine*. Springfield: Charles C. Thomas.

Jeyasingh, P., Gupta, C. D., Arora, A. K., & Saxena, S. K. (1982). Study of *Os japonicum* in Uttar Pradesh crania. *Anatomischer Anzeiger*, 152, 27–30.

Jones, F. W. (1946). *Buchanan's manual of anatomy* (7th ed., pp. 198–200). London: Bailliere, Tindall and Cox.

Klopper, A., II. (1943). A report on a collection of skulls from Kruidfontein, Prince Albert district, Cape Province. *South African Journal of Science*, 40, 240–245.

Koganei, Y. (1926). *Suture of zygomatic bone*. Tokyo: University of Tokyo Press.

Kruidfontein, Prince Albert district, Cape Province. *South African Journal of Science*, 40, 240–245.

Koganei, Y. (1926). *Suture of zygomatic bone*. Tokyo: University of Tokyo Press.

Kundu, B., Sarkar, S., Sarkar, T., Kundu, S., Saha, P. K., & Basak, S. (2016). Incidence of bipartite zygomatic bone in East Indian population. *Indian Journal of Basic and Applied Medical Research*, 5(4), 154–158.

L’Abbé, E. N., VanRooyen, C., Nawrocki, S., & Becker, P. J. (2011). An evaluation of non-metric cranial traits used to estimate ancestry in a South African sample. *Forensic Science International*, 209, 195, e191–e195 e197.

Lahr, M. M., & Wright, R. V. (1996). The question of robusticity and the relationship between cranial size and shape in Homo sapiens. *Journal of Human Evolution*, 31, 157–191.

Lanyon, L. E., Goodship, A. E., Pye, C. J., & Macfie, J. H. (1982). Mechanically adaptive bone remodeling. *Journal of Biomechanics*, 15, 141–154.

Li, Y. Y. (1985a). Observation on the Chinese Zygomatic bone. *Acta Anthropologica Sinica*, 03, 281–285.

Li, Y. Y. (1985b). Observation of divided zygoma in North-West Chinese. *Journal of Ningxia Medical College*, 03, 27–30.
Mall, F. P. (1906). On ossification centers in human embryos less than one hundred days old. American Journal of Anatomy, 5, 433–458.
Mangalgiri, A. S., Satpathy, D. K., & Bhojwani, R. (2015). Study of Os Zygomaticum Bipartitum in skulls of Central India. Journal of Indian Academy of Forensic Sciences, 37, 59–61.
Martin, R., & Saller, K. (1959). Lehrbuch der Anthropologie, Band II. Stuttgart: Fischer.
Morris, H., & Schaeffer, J. P. (1953). *Morris’ human anatomy: A complete systematic treatise* (11th ed., pp. 180–182). Blakiston: Philadelphia.
Nikolova, S., Toneva, D., & Georgiev, I. (2017). A case of bipartite zygomatic bone. European Journal of Forensic Sciences, 4(4), 1–4.
Noback, M. L., & Harvati, K. (2015). The contribution of subsistence to global human cranial variation. Journal of Human Evolution, 80, 34–50.
Oettmeling, B. (1930). The Jessup North Pacific expedition XI, craniology of the North Pacific Coast. New York: G. E. Stechert & Co.
Oettlé, A. C., Demeter, F. P., & L’abbe, E. N. (2017). Ancestral variations in the shape and size of the Zygoma. Anatomical Record, 300, 196–208.
Ohnishi, M. (1940). Anthropologische Untersuchungen über das Jochbein an Mongolen, Chinesen und Koreanern. Journal of the Anthropological Society of Nippon, 55, 263–296.
Opperman, L. A. (2000). Cranial sutures as intramembranous bone growth sites, Developmental Dynamics, 219, 472–485.
Oschinsky, L. (1962). Facial flatness and cheekbone morphology in arctic mongoloids: A case of morphological taxonomy. Anthropologica, 349–377.
Ossenberg, N. S. (2013). Brief communication: Cranial nonmetric trait database on the internet. American Journal of Physical Anthropology, 152, 551–553.
Pardoe, C. (1984). Prehistoric human morphological variation in Australia. (PhD thesis). The Australian National University, Canberra.
Paschetta, C., DeAzevedo S., Castillo L., Martinez-Abadías N., Hernández M., Lieberman D. E. González-José R. (2010). The influence of masticatory loading on craniofacial morphology: A test case across technological transitions in the Ohio Valley. Am J Phys Anthropol, 141, 297–314.
Petersen, J., & Dechow, P. C. (2003). Material properties of the human cranial vault and zygoma. Anatomical Record, 274A, 785–797.
Rice, D. P. (2008). Developmental anatomy of craniofacial sutures. In D. P. Rice (Ed.), Craniofacial sutures: Development, disease and treatment (pp. 1–21). Basel: Karger.
Rightmire, G. P. (1972). Cranial measurements and discrete traits compared in distance studies of African Negro skulls. *Human Biology, 44*, 263–276.
Robling, A. G., Hinant, F. M., Burr, D. B., & Turner, C. H. (2002). Improved bone structure and strength after long-term mechanical loading is greatest if loading is separated into short bouts. Journal of Bone and Mineral Research, 17, 1545–1554.
Standring, S. (2008). Gray’s anatomy (pp. 483–484). In: S Standring (ed.). Spain: Churchill Livingstone Elsevier.
Soni, J. S., & Khatri, C. R. (2016). A study on variation of zygomatic bone in relation to bipartitism in Gujarat State. International Journal of Medical Science and Public Health, 5, 1237–1239.
Vitek, C. L. (2012). A critical analysis of the use of non-metric traits for ancestry estimation among two North American population samples. (Dissertation). University of Tennessee, Knoxville.
## APPENDIX 1 SKELETAL COLLECTIONS SCREENED FOR DZ SPECIMENS

| Site          | Period                | Sample size | Location | Regional type                        |
|---------------|-----------------------|-------------|----------|--------------------------------------|
| Baiyinchanghan | 4000 BCE              | 1           | Inner Mongolia | East Asian region                   |
| Miaozigou     | 3000 BCE              | 9           | Inner Mongolia | East Asian region                   |
| Dabagou       | 3000 BCE              | 2           | Inner Mongolia | East Asian region                   |
| Zhukaigou     | 3000-1600 BCE         | 22          | Inner Mongolia | East Asian region                   |
| Baiyan        | 2000-1046 BCE         | 10          | Shanxi    | East Asian region                   |
| Xicha         | 2500-2000 BCE         | 10          | Inner Mongolia | East Asian region                   |
| Mapai         | 2200-2000 BCE         | 3           | Qinghai   | East Asian region                   |
| Dashanqian    | 2000-1500 BCE         | 2           | Inner Mongolia | East Asian region                   |
| Xiaohandi     | 1600 BCE              | 13          | Qinghai   | East Asian region                   |
| Dahei         | 1500-500 BCE          | 14          | Liaoning  | East Asian region                   |
| Longtoushan   | 1046-771 BCE          | 12          | Inner Mongolia | East Asian region                   |
| Lichengxiguan | 1046-771 BCE          | 4           | Shanxi    | East Asian region                   |
| Ximaqing      | 771 BCE               | 9           | Inner Mongolia | East Asian region                   |
| Xindianzi     | 600 BCE               | 25          | Inner Mongolia | North Asian region                 |
| Jinggouzi     | 500 BCE               | 27          | Inner Mongolia | North Asian region                 |
| Bancheng      | 500 BCE               | 24          | Inner Mongolia | North Asian region/East Asian region |
| Guoxianyaozi  | 500 BCE               | 5           | Inner Mongolia | North Asian region/East Asian region |
| Shuanggucheng | 500-400 BCE           | 4           | Inner Mongolia | North Asian region/East Asian region |
| Yanghai       | 500-400 BCE           | 49          | Xinjiang  | Western East Asian region            |
| Jilintai      | 500-100 BCE           | 11          | Xinjiang  | Western East Asian region            |
| Da'an         | 475 BCE-220 CE        | 75          | Jilin     | North Asian region/Northeast Asian region |
| Houchengzui   | 475-221 BCE           | 5           | Inner Mongolia | East Asian region                   |
| Dongtouhao    | 475-221 BCE           | 14          | Inner Mongolia | East Asian region                   |
| Jiangjungou   | 300-221 BCE           | 14          | Inner Mongolia | East Asian region                   |
| Yinniugou     | 200 BCE               | 20          | Inner Mongolia | East Asian region                   |
| Zhalainuoer   | 202 BCE-220 CE        | 7           | Inner Mongolia | North Asian region/East Asian region |
| Fenghuangshan | 202 BCE-220 CE        | 3           | Inner Mongolia | -                                   |
| Xitun         | 202 BCE-300 CE        | 130         | Beijing   | East Asian region                   |
| Taojiazhai    | 202 BCE-300 CE        | 127         | Qinghai   | East Asian region                   |
| Sandaowan     | 8-220 CE              | 10          | Inner Mongolia | North Asian region                 |
| Dongdajing    | 8-220 CE              | 11          | Inner Mongolia | North Asian region                 |
| Bagou         | 8-266 CE              | 4           | Inner Mongolia | North Asian region                 |
| Damaoqi       | 220-420 CE            | 6           | Inner Mongolia | North Asian region                 |
| Qilangshan    | 220-420 CE            | 4           | Inner Mongolia | North Asian region                 |
| Tuchengzi     | 220-420 CE            | 103         | Inner Mongolia | North Asian region                 |
| Lamadong      | 300-420 CE            | 155         | Liaoning  | East Asian region/North Asian region |
| Danjiadian    | 300-420 CE            | 1           | Inner Mongolia | North Asian region                 |
| Shanzuizi     | 916-1125 CE           | 10          | Inner Mongolia | North Asian region                 |
| Yelvyuzhi     | 916-1125 CE           | 4           | Inner Mongolia | North Asian region                 |
| Dongshan      | 916-1125 CE           | 3           | Inner Mongolia | North Asian region                 |

(Continues)
| Site   | Period          | Sample size | Location    | Regional type                  |
|--------|----------------|-------------|-------------|-------------------------------|
| Qianhaizi | 916-1125 CE | 2           | Inner Mongolia | North Asian region          |
| Chengbuzi | 1115-1368 CE | 17          | Inner Mongolia | East Asian region/North Asian region |
| Woniushi | 1271-1368 CE | 1           | Inner Mongolia | North Asian region          |
| Yikeshu | 1271-1368 CE | 4           | Inner Mongolia | East Asian region          |
| Wulagai | 1271-1368 CE | 1           | Inner Mongolia | North Asian region          |
| Sanmianjing | 1271-1368 CE | 6           | Inner Mongolia | North Asian region          |
| Zhenzishan | 1271-1368 CE | 29          | Inner Mongolia | East Asian region/North Asian region |
| Kaicheng | 1271-1368 CE | 12          | Ningxia      | North Asian region          |
| Yuci    | 1368-1800 CE  | 111         | Shanxi       | East Asian region          |
| **Total** | **1145** | **Total**   | **1145**    | **Total**                   |