Early evidence for mounted horseback riding in northwest China

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Horseback riding was a transformative force in the ancient world, prompting radical shifts in human mobility, warfare, trade, and interaction. In China, domestic horses laid the foundation for trade, communication, and state infrastructure along the ancient Silk Road, while also stimulating key military, social, and political changes in Chinese society. Nonetheless, the emergence and adoption of mounted horseback riding in China is still poorly understood, particularly due to a lack of direct archaeological data. Here we present a detailed osteological study of eight horse skeletons dated to ca. 350 BCE from the sites of Shirenzigou and Xigou in Xinjiang, northwest China, prior to the formalization of Silk Road trade across this key region. Our analyses reveal characteristic osteological changes associated with equestrian practices on all specimens. Alongside other relevant archaeological evidence, these data provide direct evidence for mounted horseback riding, horse equipment, and mounted archery in northwest China by the late first millennium BCE. Most importantly, our results suggest that this region may have played a crucial role in the spread of equestrian technologies from the Eurasian interior to the settled civilizations of early China, where horses facilitated the rise of the first united Chinese empires and the emergence of transcontinental trade networks.

horseback riding | zooarchaeology | early Iron Age | Xinjiang | China

The use of domestic horses for traction and riding stimulated remarkable changes to the social, political, and economic landscape of ancient Eurasia (1–5). Mounted horseback riding, in particular, accelerated human migrations and cultural interactions across the continents. It also transformed military practice and strategy, facilitating the expansion of such early equestrian empires as the Achaemenid and Xiongnu, which posted far-reaching consequences for socio-politics across a vast area of Eurasia (4).

In China, the earliest date for the clear practice of horseback riding, documented in historical texts, was 307 BCE, when King Wuling of the Zhao State adopted horseback archery in response to incursions of neighboring mounted pastoralists (6, 7). Other contemporaneous agricultural states also developed mounted cavalry, with some maintaining over 10,000 cavalrymen, a transformation that altered tactical battlefield strategies in ancient China (4, 8–10). Military horsepower was also crucial to the rise of the first united Chinese empires of Qin and Han (221 BCE to 220 CE), playing a significant role in political disputes and socioeconomic developments (11). These shifts in the importance of the horse drove an increasing demand for quality riding horses that ultimately played a key role in the formalization of Silk Road trade through northwest China by the end of the second century BCE (12, 13), initiating a long process of significant cultural and economic exchange across the Eurasian Steppes (14). Accordingly, understanding when and where horseback riding emerged in China's frontier is crucial to understanding both the emergence of empire and the consolidation of trans-Eurasian trade. Nevertheless, despite some fragmentary historic records pointing to a pre-Silk Road emergence of horseback riding (13) and some material culture such as bridle artifacts and trousers linked with riding (15–18), direct evidence of when and where equestrianism was first adopted in China is still lacking.

Osteological analysis of equine skeletal remains provides one of the strongest direct lines of evidence for identifying horseback riding in the archaeological record (3, 19–22), but few attempts have been made to investigate this issue in China (23, 24). We analyzed an assemblage of eight horse skeletons, directly dated to ca. 350 BCE, from the sites of Shirenzigou and Xigou in eastern Xinjiang of China. These horses provide a dataset to directly evaluate the presence of equestrianism in China's frontier prior to the emergence of the Silk Road. We explore the implications of these data for understanding trans-Eurasian trade, nomadic steppe tribes, and early state polities in China's hinterland.

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The Sites of Shirenzigou and Xigou

Located in the Xinjiang Uyghur Autonomous Region of China, a critical link on the ancient Silk Road (Fig. 1), Shirenzigou and Xigou are two adjacent sites of the late Bronze Age to the early Iron Age in present-day Balikun County. Situated on the northern slopes of the eastern Tianshan Mountain range,

Significance

This study provides insights into the emergence and adoption of equestrian technologies in China. Analysis of ancient horse bones from Shirenzigou and Xigou in eastern Xinjiang demonstrates that pastoralists along China's northwest frontier practiced horseback riding and mounted archery by the fourth century BCE. This region may have played a key role in the initial spread of equestrian technologies from the Altai region into the heartland of China's early settled states, where they eventually facilitated the rise of the first united empires in China and triggered extensive social, political, and economic exchanges between China and its neighbors on the Eurasian Steppes.

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The authors declare no competing interest.

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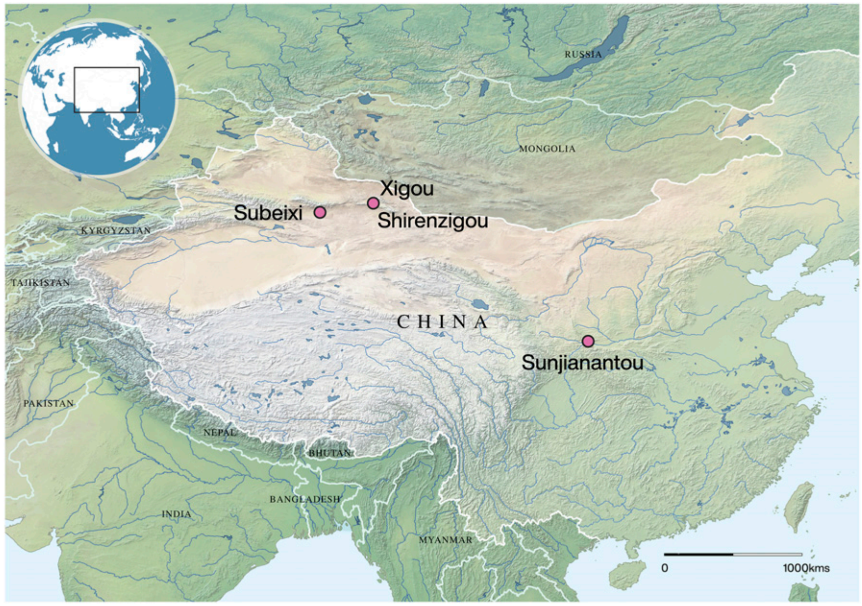

Fig. 1. Map showing the location of major archaeological sites mentioned in this study.

Shirenzigou sits on moraine hills and alluvial fans at an elevation of 2,000 to 2,200 m above sea level (25) (*SI Appendix*, Fig. S1). Since 2005, archaeological field surveys and excavations at Shirenzigou have revealed a large number of stone platforms, houses, burials, and rock paintings (26, 27). Rescue excavations in 2012 revealed one elite burial at Xigou, similar in structure and mortuary rituals to the early Iron Age burials at Shirenzigou (28, 29). Wang et al. (26, 27) have suggested that Shirenzigou might be associated with the royal court of elite pastoral communities. Mortuary rituals and animal motifs on artifacts also indicated their relationship with the Pazyryk culture in the Altai Mountains (28, 29). The location of Shirenzigou and Xigou on the eastern side of the Tianshan corridor and their association with the first millennium BCE pastoral communities make this pair of sites particularly significant in terms of understanding economic, cultural, and social interactions between the East and the West.

Horse Assemblages from Shirenzigou and Xigou

We examined eight horses from burials (designated as "M") and affiliated sacrificial pits (designated as "K") at Shirenzigou (n = 6) and Xigou (n = 2) (Fig. 2). These horses were all excavated so far. Five primary burials contained a central pit, a chamber dug into the pit, and a stone mound above the ground. We recovered horses from within the central pit (M001, M002, M011, and M012 at Shirenzigou) or on the second-tier platform above the

Fig. 2. Horse skeletons from M012K2 at Shirenzigou (*Top Left*), M011 at Shirenzigou (*Top Right*), M1K1 at Xigou (*Bottom Left*), and M1 at Xigou (*Bottom Right*).

chamber (M1 at Xigou). Three sacrificial features shared a similar structure with these burials, and horses were recovered from central pits in these features.

Although the skull of one horse from Xigou (horse 8) and half of the maxilla of one horse from Shirenzigou (horse 6) were not present in the excavation, the skeletons of the other six horses were fairly complete, with excellent levels of bone preservation, enabling detailed osteological study. We estimated the age for each horse using epiphyseal fusion (30), dental eruption (30), incisor morphology (31), and crown-height measurements of premolars and molars (32). Estimation of sex was based on the presence and number of canines (31). Estimated age and sex for the horses are listed in Table 1. We then assessed each specimen for osteological features and pathologies informative of human activity, transport, and use.

We obtained direct radiocarbon dates for seven of these horses (Fig. 3). A single-phase Bayesian model with a uniform prior generated in OxCal provides a modeled start date for the studied burials at Shirenzigou of between 424 and 218 BCE (95.4% probability, with a median value of 337 BCE) and end date of ca. 348 to 129 BCE (95.4% probability, with a median value of 219 BCE) and an estimated span of activity of between 0 and 166 y (2-sigma calibrated range). Reconfiguring the model with a trapezoid prior produced a similar boundary estimate.

Osteological Analysis of Horse Remains

Vertebral Abnormalities. Of 243 vertebrae recovered from eight horses, 157 vertebrae exhibited abnormalities of varying degrees and characteristics. These abnormalities can be classified into four categories: hyperostosis, spinal fusion, horizontal fractures on epiphyses, and overriding/joining of dorsal spinal processes (*SI Appendix*, Table S3). We calculated the occurrence rate of abnormalities for individual vertebrae of all Shirenzigou and Xigou horses (Fig. 4) (33). Results showed that abnormalities most frequently occurred on the lower back between thoracic vertebrae 14 to 17, followed by the lumbar vertebrae 3 to 5, and a lower incidence from thoracic vertebrae 1 to 7. The occurrence rates of abnormalities in cervical vertebrae and the middle span of thoracic vertebrae were low.

We identified osteophytes (the excessive enlargement or growth of a bone) on and around the dorsal or lateral surfaces of spinal processes, as well as on articular processes and costal grooves of horse vertebrae from Shirenzigou and Xigou. Across the analyzed horse specimens, all vertebrae, except for cervical vertebrae 2 to 4, exhibited at least one instance of osteophyte formation. Osteophytes formed most frequently between thoracic vertebra 12 and lumbar vertebra 4 (the lower back) while the area between cervical vertebra 7 to thoracic vertebra 7 (the withers) also exhibited a high frequency of osteophytes (Fig. 5, 1–3).

Spinal fusion is the pathological fusion of spinal body, articular processes, and transverse process. We identified spinal fusion often on lumbar vertebrae of our examined horses, especially lumbar vertebrae 5 to 6 (Fig. 5, 6). Transverse horizontal fractures of the epiphysis occurred mainly on the lower back (thoracic vertebrae 13 to 18). The irregular, undulating fractures did not penetrate into the spinal body. The average length of these fractures was 22.8 mm, with a maximum width of 0.61 mm (Fig. 5, 3 and 4). We also identified overriding/joining of dorsal spinous processes (the interpressing or impinging of neighboring spinous processes) across the same region (thoracic vertebra 12 to lumbar vertebra 5) on several archaeological specimens, of which thoracic vertebrae 13 to 18 were most commonly affected (Fig. 5, 4 and 5). In some cases, the posterior portion of the front spinal process suffered serious deformation due to severe impinging (Fig. 5, 7–9).

In terms of absolute frequency, osteophyte formation was the most frequently occurring abnormality on vertebrae of horses from Shirenzigou and Xigou, followed by overriding/joining of dorsal spinal processes. Spinal fusion and horizontal fractures on epiphyses were the least common abnormalities but occurred on three and four of the eight horses in this study, respectively.

For individual horses, we identified instances of asymmetry in vertebral abnormalities, especially the portions of articular surfaces and costal foveae (*SI Appendix*, Table S4). A total of seven horses exhibited more severe abnormalities on the left side of the spine, while one specimen displayed no directional bias.

Cranial Changes. We identified premaxillary grooves associated with exertion and bridling on six horses with sufficiently preserved maxillae (*SI Appendix*, Table S5). Only two of these specimens (horse 3 and horse 7) retained both left and right portions of the premaxilla, while on four others, only a single side was preserved for analysis (Fig. 6). Results show that the medial groove depth ranges from 0.25 to 1.09 mm and the lateral groove depth ranges between 0 and 0.95 mm. All six crania had sufficient preservation of the rear of the skull to analyze for nuchal ossification (Fig. 7). Five of six analyzed horses had nuchal ossification scores of “3” or higher, while horse 7 had extremely pronounced changes (a score of “5”) that are rare in modern collections of unworked horses or those used for traction, but commonly found in ridden horses (34, 35).

Oral Pathologies and Dentition. The lower second premolars and diastemata of six horses were sufficiently preserved for analysis. Enamel or dentine exposure appeared on the anterior surface of these lower second premolars, with the exposed portion shaping as a thin vertical band or a flake with parallel sides (19) (Fig. 8) (*SI Appendix*, Table S6). In addition, horse 3 exhibited distinct, shallow and oval-shaped chips, with black staining, on the anterior surface of the two lower second premolars (Fig. 8). The chip on the right side measures 4.73×2.44 mm and that on the left side 3.54×2.25 mm (*SI Appendix*, Fig. S3).

Occlusal bevels to the lower second premolar are often associated with metal bit use (3, 36), but scholars have noted the necessity of considering malocclusion before attributing such

Table 1. Age and sex estimates for horses from Shirenzigou and Xigou

Horse ID	Field code	Site	Canines	Age (DE)	Age (IM)	Age (CH)	Age (EF)	Sex
1	06BSDM001	Shirenzigou	—	>4.5–5	14–16	17–19	>5	Likely female
2	06BSDM011	Shirenzigou	4	>4.5–5	9	9–11	>5	Male
3	06BSDM012	Shirenzigou	4	>4.5–5	11	>9	>5	Male
4	07BSDM012K2	Shirenzigou	0	>4.5–5	15–16	15.5	>5	Female
5	07BSDM012K3	Shirenzigou	4	>4.5–5	9–10	8.5–9.5	>5	Male
6	11XBSIM002JX3	Shirenzigou	3	>4.5–5	~6	6.5–9.5	~5	Male
7	12XBXM1	Xigou	4	>4.5–5	11–12	8.5–9.5	>5	Male
8	12XBXM1K1	Xigou	—	—	—	—	>5	—

DE, dental eruption; IM, incisor morphology; CH, crown height; EF, epiphysial fusion.

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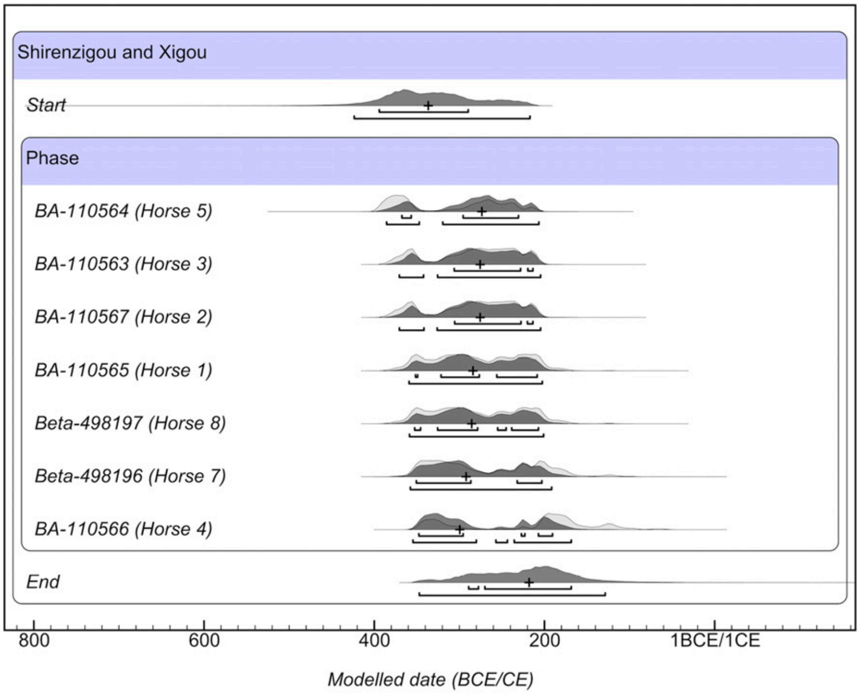

Fig. 3. Calibrated radiocarbon dates for seven horses from Shirenzigou and Xigou, along with posterior modeled start and end boundaries using a uniform phase model in OxCal. See details in *SI Appendix*, Tables S1 and S2.

changes to human activity (19, 37). The occlusal surface (both enamel and dentine) of lower second premolars of five horses in our dataset had been worn into a "flat"-profiled bevel (*SI Appendix*, Table S6). When we examined the mandible and the crania together in an occlusal view, horse 3 and horse 5 still exhibited discernable bevels on both the lower and opposing upper second premolars that cannot be attributed to natural malocclusion. Horse 6 could not be assessed for malocclusion because of the absence of its opposing upper second premolar. This dual upper and lower wear has been previously noted in Iron Age riding horses from East Asia (38). Importantly, none of these horses exhibited the "Greaves effect"—the uneven loss of enamel and cementum caused by natural dental wear (39). Consistent with other assemblages from Bronze and Iron Age Central Asia (38), no specimen exhibited pronounced osseous changes to the diastema. Only one horse (horse 1) in our dataset showed continuous slight osseous changes [score "2" in the classification scheme devised by Bendrey (19)] and two horses (horse 3 and horse 4) exhibited faint roughening of the diastema (score "1"). No discernable changes were identified on diastemata of the other four horses (score "0").

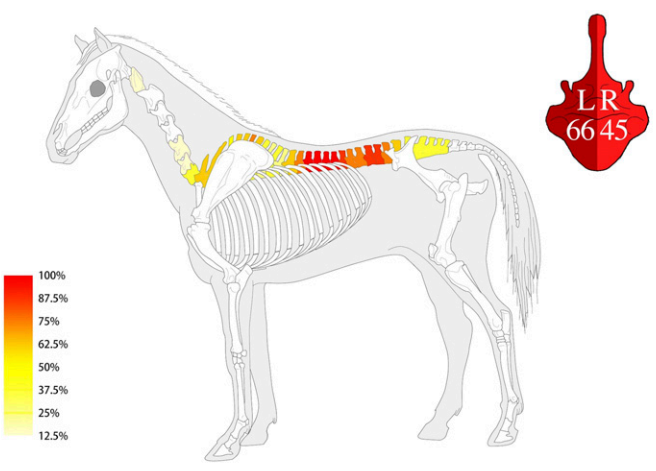

Fig. 4. The occurrence rate of abnormalities for individual vertebrae [modified from pl. 6 in Barone (33)] and the left/right asymmetry in abnormalities.

Discussion

Distinguishing Ridden and Chariot Horses Using Vertebral Paleopathology. While distinguishing between horses used for riding and traction is a difficult task, ancient ridden horses exhibit more abnormalities on lower thoracic vertebrae and lumbar vertebrae than their modern unridden counterparts (40). Comparing horses used for riding with chariot horses from high-ranking burials at the site of Sunjianantou in Shaanxi, China, dating to the seventh century BCE, Levine (41) found that abnormalities on ancient ridden horses occurred at high frequency on the lower thoracic vertebrae and the lumbar vertebrae, which would have borne the most stress from human riding. In contrast, fissures on epiphyses and the impinging of dorsal spinal processes were either insignificant or completely absent on Sunjianantou horses found in chariot burials. More importantly, the lower thoracic vertebrae of these chariot horses, i.e., the area where saddles and human riders would sit on the horse's back, did not exhibit well-developed abnormalities—a significant difference from ridden horses. All horses from Shirenzigou and Xigou exhibited severe vertebral abnormalities on their lower thoracic and lumbar vertebrae, indicating their use in riding.

Osteological Evidence for Horseback Riding at Shirenzigou and Xigou. Vertebral abnormalities on lower thoracic and lumbar vertebrae in our analyzed assemblage are severe and similar to those associated with horseback riding in early Eurasian archaeological contexts (40, 42). In particular, all horses from Shirenzigou and Xigou suffered from osteophytes and six of them exhibited overriding/joining of dorsal spinal processes. The development of these abnormalities can be influenced by aging, congenital

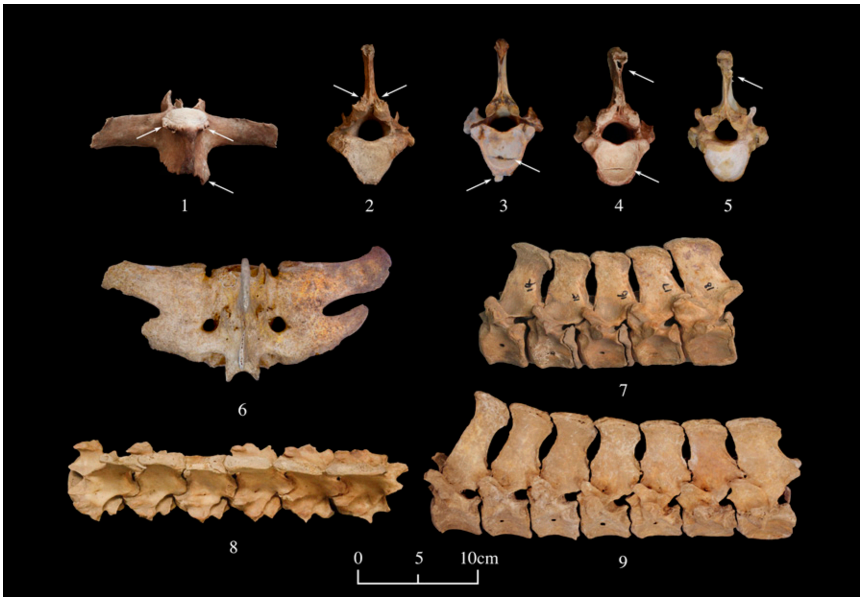

Fig. 5. Vertebral abnormalities on horses from Shirenzigou and Xigou (T, thoracic vertebra; L, lumbar vertebra). See *SI Appendix*, Fig. S2 for close-ups of the abnormalities. 1) Horse 8, L1, ventral view, osteophytes (ventral part of vertebral body); 2) horse 8, T16, caudal view, osteophytes (posterior articular process); 3) horse 2, T13, caudal view, osteophytes and horizontal fracture (posterior articular surface of vertebral body); 4) horse 8, T15, caudal view, horizontal fracture (posterior articular surface of vertebral body), overriding/joining of dorsal spinous processes (spinous process); 5) horse 2, T16, cranial view, overriding/joining of dorsal spinous processes; 6) horse 4, L5–L6, dorsal view, spinal fusion; 7) horse 6, T14–T18, left lateral view, impinging of spinal processes; 8) horse 5, T13–T18, dorsal view, impinging of spinal processes; 9) horse 7, T12–T18, left lateral view, impinging of spinal processes.

defects, and—most importantly—the consistent application of external forces associated with mounted horseback riding (43–46). Similar to Pazyryk horses found at Ak-Alakha in Russia (40), the caudal and cranial portions of dorsal spinal processes of horses from Shirenzigou and Xigou were seriously deformed, to an extent not previously documented in the zooarchaeological literature.

The most severe cases of spinal fusion are sometimes referred to as the "bamboo spine," wherein a number of thoracic and lumbar vertebrae fuse into a single block (42, 47). A previously excavated ca. fifth to sixth century CE horse from Hungary exhibited discernable bamboo spine formation, with 17 vertebrae fused together (42, 48). While other factors can play a role, fusions of the transition region between thoracic vertebrae and lumbar vertebrae in relatively young horses are most likely caused by repetitive strain associated with riding. In addition, the archaeological occurrence of horizontal fractures on vertebral epiphyses is also strongly associated with horseback riding (49, 50). For instance, early Iron Age horses from Ak-Alakha 5 (40) and Arzhan 2 (51) exhibited this type of abnormality on lower thoracic vertebrae.

We suggest that asymmetric patterning in these abnormalities in the horses from Shirenzigou and Xigou relates to differences in load bearing associated with riding. More specifically, frequent mounting from the left side and controlling the horse from the left with the reins—known to have been an important tradition in some areas of Central Asia (22, 52)—may explain the apparent leftward bias in vertebral pathologies of horses in our dataset.

Several lines of cranial osteological evidence also indicate heavy exertion and riding of horses at Shirenzigou and Xigou. Horses used for transport appear to develop deeper and more frequent grooves to the medial and lateral margins of the premaxilla, caused by soft tissue changes linked to heavy exertion and perhaps stimulation or pressure from bridle equipment (35). Our measured values of 0.25 to 1.09 mm for medial grooves on the premaxilla of horses from Shirenzigou and Xigou (*SI Appendix*, Table S5), likely generated by heavy exertion, were within observed ranges for both feral and ridden specimens reported previously (35). However, we observed deep lateral grooves of 0.65 mm or more—which are uncommon on unridden animals and also caused by heavy exertion or bridle equipment (35)—on some specimens at Shirenzigou and Xigou. Pronounced ossification of the nuchal ligament attachment site of horses 4 and 7 in our assemblage may also be indicative of riding when other evidence is considered (34). Our inference of mounted horseback riding at Shirenzigou and Xigou from equine skeletal remains is further supported by the presence of riding-associated skeletal abnormalities in at least one of the humans interred alongside horses (*SI Appendix*, SI Text and Fig. S4).

Although the eight horses we examined are the only complete horse skeletons that have been excavated from the two sites in recent years, preliminary observations of horses from Tuobeiliang in this region contemporary with Shirenzigou and Xigou suggest that a tradition of funerary inhumation of horse remains—along with evidence for riding and archery—reflects a broader trend across the region during the fourth century BCE.

Inferring Horse Equipment from Osteological Features. One piece of iron bit—a jointed metal snaffle—was unearthed from the chamber of burial M001 at Shirenzigou (*SI Appendix*, Fig. S5). The horse deposited in this burial exhibited distinct rectangular enamel/dentine exposure on the anterior surface of upper second premolars as associated with metal bits by Bendrey (19), and we found similar damage on all other specimens we analyzed. Similarly, shallow chips on the lower second premolars of horse 3 appear to indicate traumatic contact with a metal bit. Although we found no meaningful diastema damage in our horse assemblage, the lack of such damage is consistent with other Bronze, Iron Age, and even modern assemblages from East Asia—and likely reflects a bit design that uses very little leverage on the mandible (19, 22). Together, these data indicate the use of metal mouthpieces at Shirenzigou and Xigou. Severe lateral grooves on the equine premaxilla found in our horse assemblage might also reflect the use of a rigid bridle cheekpiece (35).

Extreme vertebral pathologies in the lower back, common in our assemblage, are most likely the result of chronic use of a pad

Fig. 6. Photos showing grooves on the right side of the maxilla of horse 5 (*Top*) and that of horse 3 (*Bottom*).

saddle in horseback riding. Prior to the invention of the frame saddles, early Central Asian saddles consisted of two leather cushions and one unpadded strip of leather, seated directly over the animal's thoracic vertebrae. This design caused the lower back to bear a great deal of stress from the riders, as evidenced by extreme damage to the vertebral column of Pazyryk horses (40). One such leather saddle was unearthed from the site of Subeixi in Turpan, which, although as yet undated, appears roughly contemporaneous and close to Shirenzigou and Xigou on the basis of associated material culture (53). Vertebral pathology and archaeological comparisons suggest that similar pad saddles would have been in use at Shirenzigou and Xigou.

Finally, we found 15 bone arrowheads (single tanged or double tanged) under the right hand of the male deceased in burial M013 at Shirenzigou. The length of arrowheads ranged between 53.42 and 86.67 mm, with an average of 66.4 mm (*SI Appendix*, Fig. S6). This suggests that horsemen interred at Shirenzigou may have engaged in mounted archery. Bone arrowheads of similar types have also been found at contemporaneous sites in the eastern Tianshan Mountain area, but the number of published, well-preserved finds is very small (54). While bronze arrowheads, indicative of earlier practices of archery, have been recovered from the region, such sites have not yielded direct evidence for horseback riding (55, 56).

In the absence of historical records, osteological and material datasets from Shirenzigou and Xigou provide direct evidence that early horsemen in this region controlled their animals with metal bits, perhaps in conjunction with hard cheekpieces and soft pad saddles—and may have already practiced mounted archery prior to the first documentation of horseback riding in imperial records during the terminal fourth century BCE.

Conclusion

Despite fragmentary archaeological findings and historic records pertaining to the emergence of equestrian technologies on China's imperial frontier, our results demonstrate that horseback riding was an established component of lifeways in the eastern Tianshan Mountain area of China by the late first millennium BCE. Osteological changes to skeletons indicate that horses at Shirenzigou and Xigou were ridden, bridled, and heavily exerted, while archaeological contexts indicate that these early riders also engaged in mounted archery. Our data suggest that the eastern Tianshan Mountain area was a crucial location on the route for the spread of equestrian technologies from the Altai region into the heartland of northern China, where emergent military cavalry—which depended on access to quality horses and knowledge of horsemanship—crystallized the formation of the first unified empires. The equestrian technologies also facilitated the expansion of imperial power and the development of sustained exchanges between settled and pastoral communities along the northwest frontier, laying the groundwork for the formalization of extensive trade and communication across the Silk Road.

Materials and Methods

Osteological and Zooarchaeological Analysis. The studies of horse vertebrae and teeth, as well as three-dimensional (3D) scanning of horse skulls, were conducted in the Zooarchaeology Laboratory of the School of Cultural Heritage at Northwest University.

We identified, documented, and analyzed abnormalities on vertebrae that relate to horseback riding and transport, using references from Bartosiewicz and Gál (47), Levine (21), and Levine et al. (40). For each vertebra, we calculated the occurrence rate of abnormalities expressed as a percentage of

Fig. 7. Photos showing new bone formation at the nuchal ligament attachment of horse 5 with a score of "3/2" (*Top*) and that of horse 7 with a score of "5" (*Bottom*).

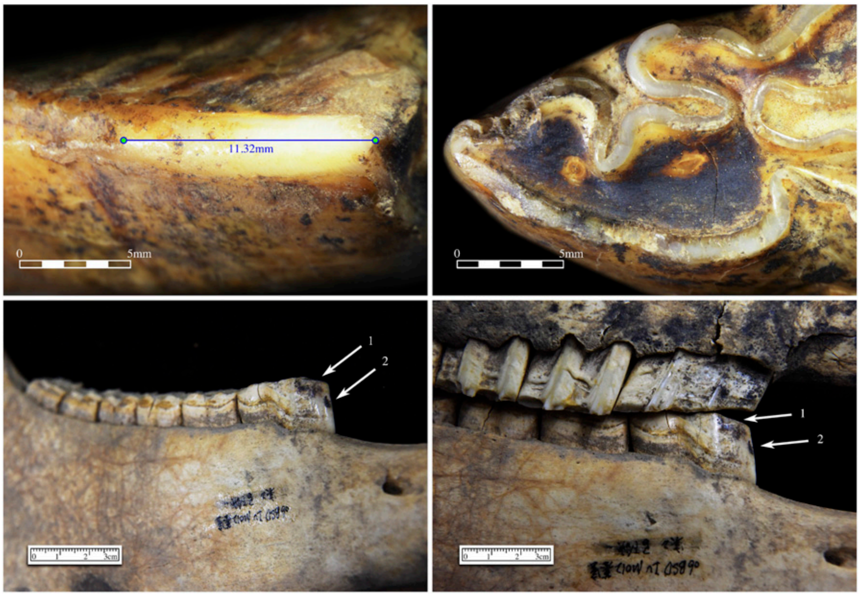

Fig. 8. (*Top*) Enamel/dentine exposure on the left lower second premolar of horse 7. (*Bottom*) Enamel/dentine exposure on the right lower second premolar of horse 3: occlusal bevel (arrow 1) and distinct black-colored shallow chip on the anterior surface of the tooth (arrow 2). See *SI Appendix*, Fig. S3 for a close-up of the shallow chips.

the total assemblage. With respect to the instances of asymmetry in vertebral abnormalities, we recorded only vertebral pathologies with discernable directional bias in severity (*SI Appendix*, Table S4).

The cranium of each specimen (including occiput, nasal bones, and premaxilla) was analyzed for osseous changes linked to bridling and transport. We scanned and created 3D models of all available skulls using a NextEngine3D scanner at a resolution of 2,000 dots per inch. We documented visible grooves on nasal bones and measured the maximum depth of lateral and medial grooves on both sides of the premaxilla following the procedure outlined in Taylor et al. (35). As values were produced for both left and right sides, we used the maximum depth value in further comparisons (*SI Appendix*, Table S5). Based on the shape and size of new bone formation at the nuchal ligament attachment, we assigned a score (from 1 to 6) to each horse using the criteria proposed by Bendrey (34). The results were compared with published reference data from wild and domestic horses.

We analyzed the remodeling of lower second premolars according to procedures described by Anthony et al. (36) and Brown and Anthony (57). The measurements of occlusal bevels were made from the projected intersection of the lower second premolar unmodified occlusal surface and the unmodified anterior margin of the lower second premolar following Anthony et al. (36). Enamel/dentine exposure on lower second premolars was photographed and measured using a NIKON SMZ25 Research Stereo Microscope. Diastemata of horses with preserved mandibles were observed for potential osseous changes using a scoring system developed by Bendrey (19), which described the different degrees of new bone formation and bone loss (*SI Appendix*, Table S6).

Radiocarbon Dating. Radiocarbon dates for horses from Shirenzigou (horses 1 to 5) were generated at the Accelerator Mass Spectrometry Dating Laboratory of Peking University. Radiocarbon dates for horses from Xigou (horses 7 and 8) were generated at Beta Analytic Radiocarbon Dating Laboratory. Calibration of dates and the Bayesian modeling were conducted in OxCal v4.3.2 (58) using IntCal13 as the calibration curve (59) (*SI Appendix*, Tables S1 and S2).

Data Availability. All horse skeletons unearthed from Shirenzigou and Xigou were collected on site during the excavations and are currently housed in the Zooarchaeology Laboratory of the School of Cultural Heritage at Northwest University, as part of permanent collections for teaching and research. All data are available in the main text and *SI Appendix*.

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