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# RECONSTRUCTING EQUINE BRIDLES IN THE MONGOLIAN BRONZE AGE

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*Archaeozoological remains provide a key dataset for understanding horse control in Mongolia's Deer Stone-Khirigsuur (DSK) Complex, a late Bronze Age culture dating to circa 1300–700 BC. Although no horse tack has been recovered from DSK contexts, archaeological finds from nearby areas of East and Central Asia suggest that a bridle with a noseband, soft organic bit, and rigid cheekpieces was used by late Bronze Age Mongolian herders. Osteological data from a sample of 25 ritually interred horse crania corroborate these inferences. Deformation to the bridge of the nose on several archaeological specimens suggests that DSK bridles incorporated a noseband, while limited damage to the premolars or diastema is consistent with organic mouthpiece use. A preliminary comparison between archaeological and contemporary horses ridden with known bridle equipment implies that osteological changes to the lateral margin of the premaxilla, present in the DSK sample, might have been produced by a rigid cheekpiece. This study highlights the promise of combining multiple lines of skeletal evidence with other archaeological data to reconstruct ancient equine bridles and tack.*

**Keywords:** *horses, transport, osteology, Bronze Age, Mongolia*

## Introduction

The development of effective horse control revolutionized human societies in ancient Eurasia. As early as 3500 BC or before, domestic horses provided a source of milk, meat, and transport to people living in the steppes of western Central Asia (Outram et al. 2009). In the late third millennium BC, horse-drawn wheeled vehicles were interred in burials belonging to the Ural region's Sintashta culture, and by the middle of the second millennium, had become widespread across much of the Eurasian continent (Kelekna 2013:64). The spread of equine transport stimulated new forms of social organization (Anthony et al. 1991), prompted the expansion of trade networks (Christian 2000), and laid the foundation for new lifeways, such as nomadic horse pastoralism (Kuzmina 2003).

The domestic horse did not apparently arrive in the eastern steppes of Mongolia until the late Bronze Age, circa 1300 BC (Hanks 2010:475–76). At this time, some scholars hypothesize that innovations in horse transportation enabled the rapid development of mobile pastoralism in the region (e.g., Beardsley 1953:26). The earliest direct evidence for domestic horses in Mongolia comes from ritual inhumations found near stone monuments of the Deer Stone-*Khirigsuur* (DSK) Complex circa 1300–700 BC (Fitzhugh 2009a; Frohlich et al. 2009). Although mounted horseback riding is not clearly evident in Mongolia before the

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early first millennium BC (Hanks 2010:476–77; Honeychurch et al. 2009), many DSK horses predate this mark by several centuries (Fitzhugh 2009b). A growing body of evidence suggests that these horses were used for transport (Taylor et al. 2015). However, little is known about how they might have been controlled or bridled, or whether they were used in traction or mounted riding. Characterizing DSK horse use is thus an important step towards understanding the development of nomadic societies in the Eastern Steppe.

In this paper, we use historical and ethnographic data in tandem with zooarchaeological evidence to explore DSK bridling and horse control. We describe archaeological horse equipment from late Bronze and early Iron Age contexts in Mongolia, China, and South Siberia, which provide helpful analogs for DSK bridle technology. Next, we summarize the various ways in which halters and bridles may be identified through cranial osteology, including new evidence for deformation to the nasal bones caused by a noseband. Using a sample of well-documented contemporary and archaeological horses, we explore the potential osteological effects of bridle hardware on the premaxilla. Finally, we present results from an osteological study of 25 DSK horse crania, suggesting that DSK bridles incorporated a noseband for communication and braking, a soft organic mouthpiece, and a rigid cheekpiece for turning and lateral control. These initial results highlight the value of cranial osteology in the study of early horse equipment and provide a starting point for reconstructing the development of equine transport in the Eastern Steppe.

## Late Bronze Age Archaeology and Early Horse Use in Mongolia

Horses were an important component of subsistence and ritual in the DSK Complex. "Deer stone" is the term for anthropomorphic standing stones, which might have been memorials for warriors or particular ancestors (Fitzhugh and Bayarsaikhan 2011), while *khirigsuurs* are stone mounds that at least sometimes served a mortuary function. These monuments are commonly accompanied by ritually interred horse skulls, buried in smaller stone mounds surrounding deer stones or *khirigsuurs* (Fitzhugh 2009a). The distribution of DSK sites throughout the Mongolian steppe might suggest they played a role in the initial spread of horses into China (Honeychurch 2015:193-194), where chariots and horses appear in late Shang Dynasty burials circa 1180 BC (Kelekna 2013:136). Previous archaeozoological studies indicate that DSK horses were consumed for meat (Houle 2010:127) and were likely used for transport (Taylor et al. 2015). In this context, equine skeletal remains from the DSK period hold important clues about early horse use in eastern Eurasia.

Prior to the first millennium BC, carts and chariots were an important means of horse transport in other Central Asian cultures. Coercing a horse to be ridden requires overcoming a host of obstacles, including the horse's physical discomfort and panicked flight response (Dietz 2003:190–91). When hitched to a chariot, the presence of another horse would have had a calming effect, the heavy restraints of draft equipment mitigating many other behavioral issues (Dietz 2003:190). At an earlier stage of domestication, such chariots might have been a more reliable form of transport than riding horseback (Dietz 2003:190; Drews 2004). Bronze objects connected to chariotry have been found in second

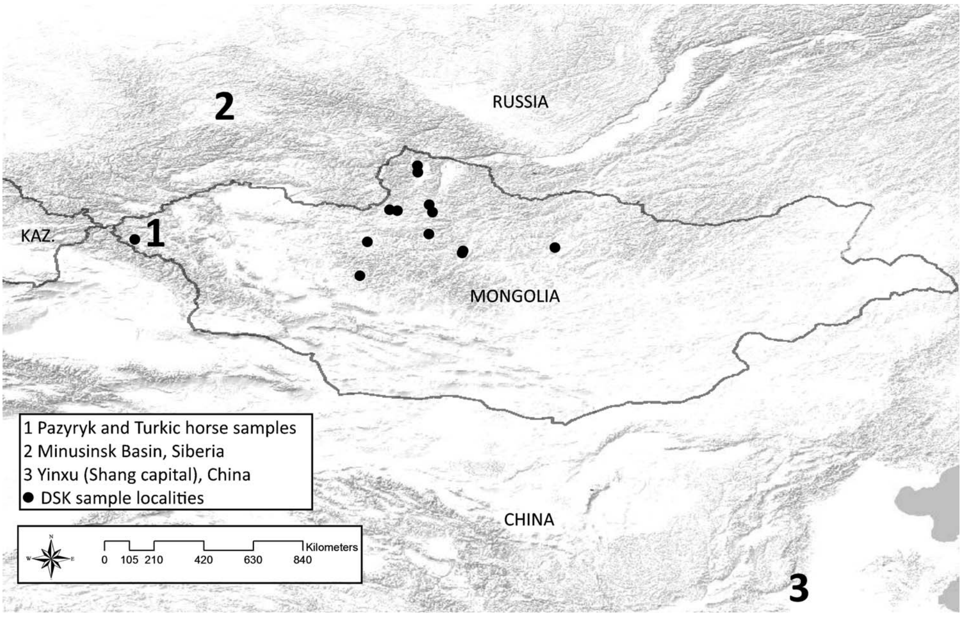


Figure 1. *Khirigsuur* and deer stone sites included in the study (filled dots), as they relate to contemporary political boundaries, the Minusinsk Basin in South Siberia, and Anyang, China (Shang Dynasty capital).

millennium BC archaeological contexts from the Minusinsk Basin, adjoining Mongolia to the northwest (Wu 2013:35–39; Figure 1:2). Although few artifacts were intentionally buried in DSK contexts (Frohlich et al. 2009), rock art carvings of chariots attributed to the late Bronze Age are common in central and western areas of Mongolia (Honeychurch 2015:192–94) and a few vehicles are even depicted on western Mongolian deer stones (e.g., Volkov 2002). This scenario raises the possibility that chariots were known and used by DSK people.

Beyond circumstantial evidence for chariots, people of the DSK Complex may also have been among the first in East Asia to use the horse for riding. In East Asia, nomadic groups likely began riding horses before sedentary peoples (Mair 2003:181). Herders in late Bronze Age Mongolia had extensive experience with equine management and seasonal mobility, experience which may have provided the necessary skillset to experiment with methods of horse control (Honeychurch 2015:148, 214). Archaeological tack found in Mongolian "slab burial" sites implicates mounted riding by the ninth century BC (Honeychurch et al. 2009:347), concurrent with later dates for deer stones and *khirigsuurs*. In short, despite a sparse material record pertaining to horse use, the DSK period encompasses a watershed period in the history of horse control—the emergence of sophisticated mounted riding and equestrian societies in East Asia. The archaeological record of other Bronze and Iron Age cultures in the region can help shed light on how DSK horses were bridled during this important transition.

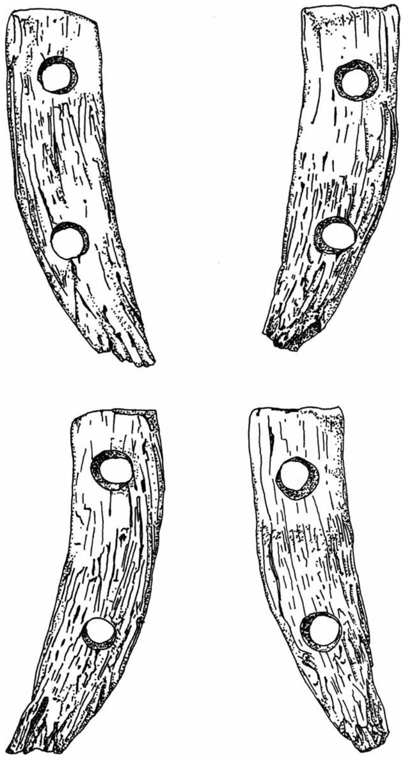

Figure 2. Interior and exterior views of antler tine bridle cheekpieces from the site of B-007 in Egiin Gol Valley, Mongolia, dated to circa 940–800 BC (Honeychurch 2015:129). Drawing by Dr. Joshua Wright, reprinted with permission. A mouthpiece would likely have been hemmed in between leather straps attached to the two holes, connecting to the bridle headstall.

## Ancient East and Central Asian Bridles

The record of archaeological horse tack from Siberia, China, and Mongolia suggest that DSK bridles incorporated a cheekpiece. As used here, the term "cheekpiece" refers to a bar of metal or organic material situated against the sides of the horse's face, which helps to stabilize the mouthpiece and ensures its proper positioning in the mouth. Bridles with rigid cheekpieces have been recovered from many late Bronze and early Iron Age contexts in eastern and central Eurasia. In such bridles, when the reins are pulled on one side, the rigid bar would have been compressed against the opposite cheek, coercing the horse to turn in the desired direction (Littauer n.d.). Karasuk culture sites in Siberia's Minusinsk Basin have produced three-holed bone cheekpieces that probably date to between the eleventh and ninth centuries BC (Honeychurch 2015:257). Although few late Bronze Age chariot burials from China contain preserved bridle equipment, some have yielded rectangular bronze cheekpieces (Cooke 2000:88–89; Wu 2013:54). In Chinese bridles of the early first millennium BC, elongated cheekpieces of antler and bronze were common (e.g., Wu 2013:13).

Rigid cheekpieces are also known from first millennium BC, non-DSK archaeological contexts in Mongolia. At the slab burial site of B-007 in the Egiin

Gol Valley, antler cheekpieces (Figure 2) were found in association with equine skulls and bridle decorations (Honeychurch et al. 2009:347). Hard antler tines running along each cheek would have been secured to the bridle via straps, attached to the small holes visible at each end. A radiocarbon date from this burial feature places it between circa 940–800 cal yrs BC (Honeychurch 2015:129), coeval with later dates for DSK sites in other areas of Mongolia. These artifacts suggest that the cheekpiece was an important bridle element in East Asia during the late Bronze Age.

The archaeological record of Late Bronze and Early Iron Age bridles also raises the possibility that DSK bridles used an organic bit. When preserved wood, bone, or bronze cheekpieces are found in situ without a mouthpiece, the original presence of a bit of perishable material can sometimes be inferred (Drews 2004:84). In China, many second millennium BC horse burials have yielded in-place bridle decorations or cheekpieces, but no mouthpiece (e.g., Cooke 2000:88–89; Wu 2013:54). Bitless bridles are one important possible explanation for this scenario (Dietz 2003), but cheekpieces with a thin and flat central aperture probably once accommodated a soft leather strap or cord bit (Drews 2004:84). Several Karasuk cheekpieces from the Minusinsk Basin have such an opening (see Legrand 2006:857). Organic connecting straps can of course also be used to affix a separate, metal mouthpiece. However, this configuration became common in the first millennium BC (Dietz 2006:158), several centuries later than these Karasuk and early Chinese examples. As a result, it is likely that the scarcity of bits in these archaeological contexts reflects the degradation of organic mouthpieces.

Archaeological materials from the territory of Mongolia also indicate that organic bits were used in the region well into the first millennium BCE. At BG-007, the cheekpieces shown in Figure 2 were recovered with bridle decorations, but no accompanying mouthpiece (Wright 2006:275). Similarly, four sets of bronze cheekpieces were recovered from Jargalantyn Am Structure 3 in Central Mongolia, a slab burial built from repurposed deer stones (Turbat 2011; Volkov 1990). Each cheekpiece boasts three thin holes. According to the initial investigator, these artifacts were found in situ with remnant leather mouthpieces (Sanjmyatav 1993:34). Although the original faunal materials have been lost, a horse tooth recovered from site backfill dates these artifacts to between 790–542 cal yrs BC (2520 +/- 30 $^{14}$C BP, Beta #363202). In the context of other archaeological finds already noted, this constitutes compelling evidence that organic bits remained in use in Mongolia until at least eighth century BC.

Finally, these archaeological comparisons also suggest that DSK bridles incorporated a noseband. A noseband is a bridle strap that runs transverse across the nose of the animal. If attached to the reins, it places pressure on sensitive facial tissues, prompting the horse to instinctively lower its head and slow (Dietz 2003:192). As a means of braking, a key challenge of early horse transport (Drews 2004:88), the noseband was a major improvement over more rudimentary systems, such as the nose-ring (Littauer 1969). Although nosebands were phased out of some bridle systems after the invention of the jointed metal snaffle (Drews 2004:89), soft organic mouthpieces probably did not produce enough pressure for effective braking on their own (Drews 2004:83–86). In Mongolia and other parts

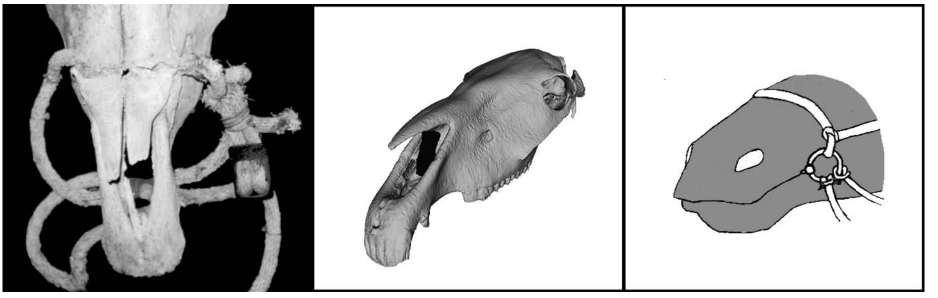

Figure 3. Left: adult horse with facial bones badly deformed around undersized halter, found in Wyoming. Photo courtesy of Dr. Danny Walker. Center: nasal deformation in a contemporary Mongolian riding horse. Right: diagram showing direct connection between reins and noseband in Mongolian bridles.

of Central Asia, nosebands have been used to control horses throughout antiquity (Brownrigg 2006:168). As a result, it is reasonable to hypothesize that DSK bridles probably incorporated a similar feature.

**Reconstructing Ancient Bridles Through Equine Osteology**

This review of archaeological tack raises the possibility that DSK bridles incorporated three key components—a noseband, an organic bit, and a rigid cheekpiece. Because of historical variability in bridle design and the absence of organic components due to poor preservation, bridle reconstructions based on incomplete artifacts sometimes yield controversial results (Dietz 2003:193–97; Drews 2004:15–19). A clear understanding of DSK horse control thus requires consideration of other forms of evidence. One promising line of inquiry comes from faunal remains. Recent studies (e.g., Anthony and Brown 1998; Anthony et al. 2006; Bartosiewicz 2014:135; Bendrey 2007, 2008; Taylor et al. 2015) indicate that various osteological changes to the skull and mandible accompany the use of the horse for transport. Here, we outline several changes to the equine cranium that help identify components of DSK bridle technology.

**Noseband Use and Nasal Remodeling**

Deformation to the bridge of a horse's nose occasionally accompanies the use of a halter or bridle noseband. When present, such deformation can be used to identify this bridle component in the archaeological record. In the horse, very little tissue covers the bone at the bridge of the nose, facilitating osteological changes to this area of the skull. As one example, tight haltering of developing juvenile animals can cause the bone to deform as the horse matures (Scott Bender, personal communication, February 12, 2015). An extreme example is illustrated here by the skull of a horse who grew to maturity while wearing an undersized halter (Figure 3, left). As the animal's head grew larger, the halter placed consistent pressure on the nasal bones, resulting in grotesque deformation. In less dramatic fashion, the skulls of constantly bridled or haltered adult animals may also deform under pressures from regular use (Bartosiewicz 2014; Takács 1985). For example, we discovered a pronounced nasal depression in the skull of several adult male Mongolian riding horses (Figure 3, center). Unlike most western

Figure 4. Top: nasal depressions on working horses in the Altai of Xinjiang, China.Bottom: Altai horses in traction work, showing long reins looped through a body harness and attached to bridle headstall. Photos courtesy of Nils Larsen, Altai Skis.

bridles, the traditional Mongolian bridle still uses a noseband that is directly connected to the reins (Figure 3, right). In cases of chronic use, this configuration alone might be enough to prompt bone remodeling.

Nasal divots such as those described above are also common in a group of modern horses from the Altai of western China, who are controlled with a bridle nearly identical to its Mongolian counterpart (Figure 4, top; see also Jenkins 2014:77). The Kazakh horseman who owns the animals, Mr. Norbek, suggests that nasal remodeling observed in his horses may be a result of traction work and *jugen* cart racing (Nils Larsen, personal communication, January 29, 2015). When long reins are looped through "terrets" or other harness parts which break the line of the reins (Figure 4, bottom), this likely increases leverage and magnifies the driver's original pressure (Littauer 1969:290). Paired with a direct attachment between reins and noseband, chronic traction work with long reins is thus one possible explanation for the Altai horse patterns. Whether nasal deformation relates to chronic bridling, traction work, or other factors, in all cases this osteological feature provides clear evidence of noseband or halter use.

**Bit/Mouthpiece Use and "Bit Wear"**

Dental and lower jaw anomalies can shed light on bit/mouthpiece use in antiquity (Bendrey 2007; Outram et al. 2009). A unique pattern of dental wear, commonly referred to as "bit wear," consists of changes to the lower second premolar from interaction between tooth and mouthpiece (Anthony and Brown 1998, 2003; Anthony et al. 2006). According to Anthony and Brown (1998, 2003), riding horses with a mouthpiece regularly produces measurable beveling to the

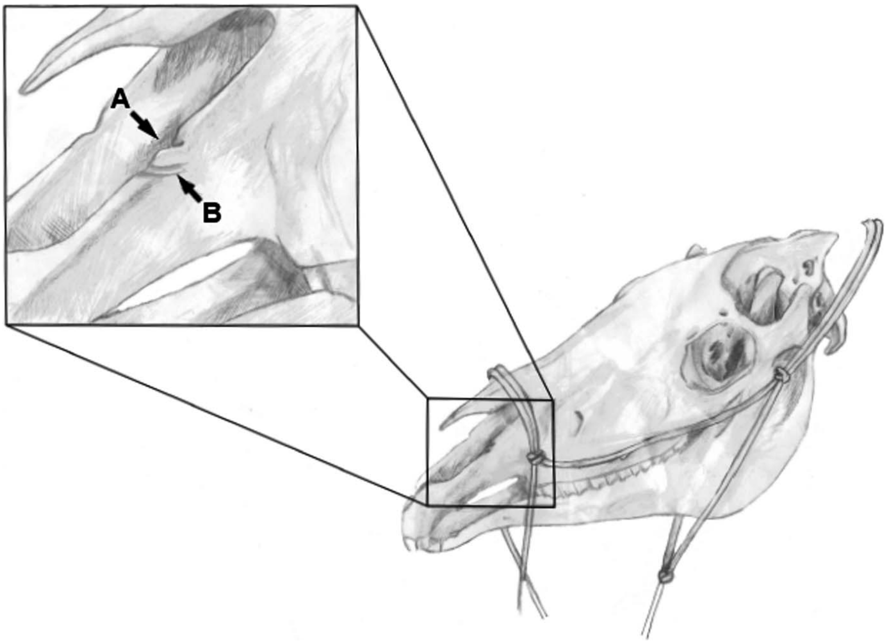


Figure 5. Diagram showing remodeling to the medial (A) and lateral (B) aspects of the equine premaxilla. Illustration by Rebecca Tuccillo.

occlusal surface of the LP2, and wear of more than 3 mm in magnitude can be taken as evidence of bit use. Unfortunately, without careful control over factors such as malocclusion and abrasion, these occlusal bevels can be an unreliable measure of human influence (Bendrey 2007; Olsen 2006). Nonetheless, other changes to the second premolar, including anterior enamel exposures on the LP2 as well as damage and new bone formation on the diastema, may also be useful for the identification of bitted horses (Bendrey 2007).

**Cheekpieces and Premaxillary Remodeling**

Recent research links two separate changes to the equine premaxilla with horse transport, and may help to identify the use of bridle cheekpieces. The first feature, a groove forming along the medial aspect of the premaxilla, is probably caused by hypertrophy of the *lateralis nasi* muscle and its accessory cartilage, which are involved in nasal dilation (Perez and Martin 2001; Vanderwegen and Simoens 2002; Figure 5:A). Referred to hereafter as "medial remodeling," this groove appears to be more severe in captive and ridden domestic animals, and is plausibly linked to heavy breathing from stress or exertion during transport (Taylor et al. 2015:863–66).

The second feature occurs along the lateral aspect of the same bone (Figure 5:B). Referred to here as "lateral remodeling," this groove is associated with an internal nasal branch of the infraorbital nerve (Perez and Martin 2001). This feature could also be developmentally related to heavy exertion, wherein the rigid *lateralis nasi* on a heavily worked horse presses the nerve against the

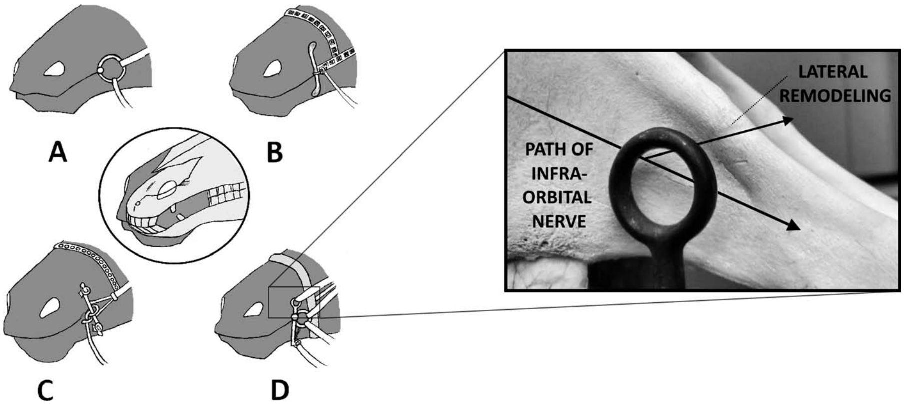


Figure 6. Left: equipment of horses analyzed for premaxillary remodeling. A) simple loose ring snaffle, B) Turkic-era snaffle bit with S-shaped iron cheekpiece, C) Pazyryk snaffle with wooden cheekpiece, and D) Weymouth bridle under rein pressure. Right: US Cavalry curb bit similar to equipment used on *Kidron*'s Weymouth bridle, with dashed line indicating the path of the infraorbital nerve in area of lateral remodeling.

premaxilla and causes remodeling to avoid nerve compression (Perez and Martin 2001). Unlike medial remodeling, however, lateral remodeling appears inconsistently, even among some extensively ridden animals (Taylor et al. 2015:866), and is often highly asymmetric in specimens we observed. One possible explanation for this pattern is that lateral remodeling is exacerbated by bridle equipment. The internal nasal branch of the infraorbital nerve is situated near the facial exterior, where it lies in close proximity to the margin of the premaxilla (Figure 5, B). For those horses bridled with a hard cheekpiece, chronic pressure on this area could exacerbate remodeling of the premaxilla to prevent nerve compression. If so, the presence of this feature would be especially valuable for the reconstruction of ancient horse control technology.

Premaxilla morphology in a small sample of contemporary and archaeological horses, ridden with documented equipment, support the idea that these features of bone remodeling relate to use of bridle cheekpieces. If cheekpieces are involved in lateral remodeling, this feature should be limited or absent from unridden horses, and reduced in horses ridden with bridles that use less exterior pressure. The loose-ring snaffle bit, for example, relies primarily on pressure at the corners of the mouth and unless very large connecting rings are used, places minimal hardware in the relevant areas of the cheek (Figure 6, bridle A). Five historical American racehorse specimens, most of which were definitively ridden with a loose-ring snaffle, exhibit limited lateral remodeling depths (0.6 mm or less, Figure 7, top). We also observed minimal lateral remodeling in definitively unbridled wild equids. Eleven paleontological specimens (late Pleistocene *Equus scotti*, 30–75 ka; Pliocene *Equus simplicidens*, 3.5 Ma: and Pliocene *Equus stenonis*, 2.8 Ma) all lacked measurable lateral remodeling. Only shallow lateral remodeling was observed in three wild *Equus hemionus* skulls from Mongolia and this feature was uncommon among wild and feral equids examined in a prior study (Taylor et al. 2015; Figure 7, top).

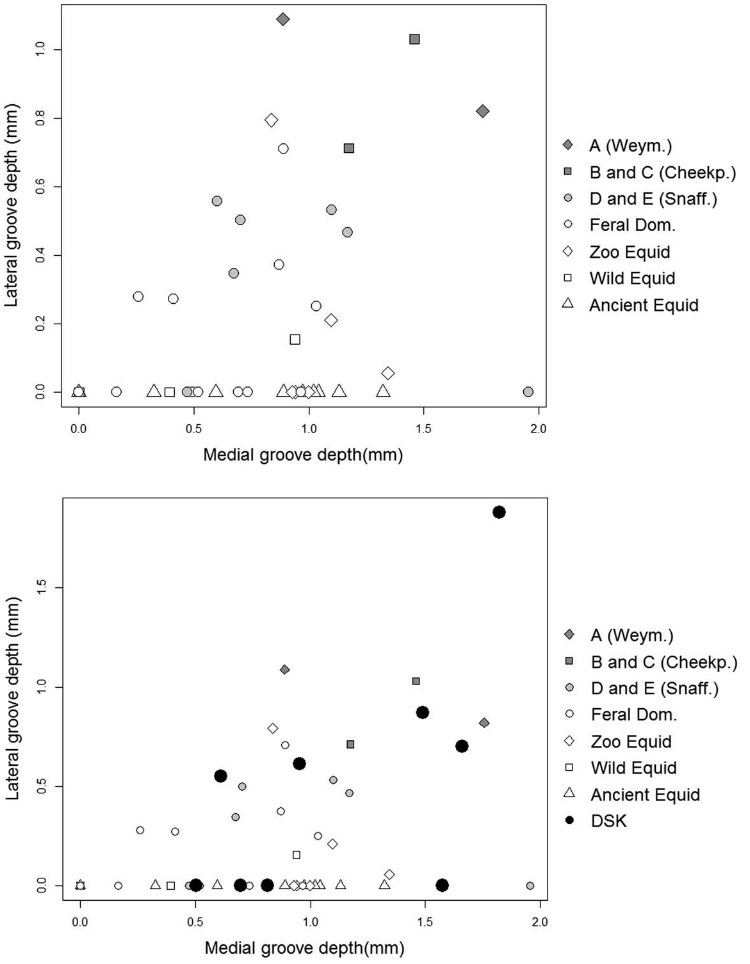


Figure 7. Top: lateral vs. medial remodeling depth across a sample of wild extant and fossil equids, feral domestic horses, captive *E. przewalskii*, and ridden horses with documented equipment (A- simple loose ring snaffle, B and C- archaeological snaffle with rigid cheekpiece, D- Weymouth or double bridle). Bottom: lateral vs. medial remodeling depth for DSK horses (black) as compared to a sample of wild extant and fossil equids, feral domestic horses, captive *E. przewalskii*, and ridden horses with documented equipment (A- simple loose ring snaffle, B and C- archaeological snaffle with rigid cheekpiece, D- Weymouth or double bridle).

In contrast, bridles using "full cheeks" place more pressure on the sides of the face (Draper et al. 2014:427) and horses ridden with such bridles should exhibit heavier premaxillary remodeling. Historical bridles used by Pazyryk (circa 600–300 BC) and Turkic Khaganate (circa 600–700 AD) cultures used a large rigid cheekpiece, which ran perpendicular to the mouth (Figure 6, bridles B and C). Two Pazyryk and Turkic horses from western Mongolian burials exhibited comparatively deeper lateral remodeling (0.7 and 1 mm in depth, respectively). Similarly, two twentieth century specimens (including General John Pershing's warhorse *Kidron*) were ridden with a Weymouth bridle, a style of tack that

Table 1. Osteological features of the skull and their potential significance for equine harness equipment.

| Feature | Anatomical mechanism | Equipment implications |
|---|---|---|
| Premolar beveling | Contact between mouthpiece and lower premolars<br>OR<br>Dentistry/malocclusion | Presence of a mouthpiece<br>OR<br>None |
| Diastema bone formation | Contact between mouthpiece and bars of the mouth | Presence of a mouthpiece |
| Nasal bone depression | Downward pressure on the nasal bones during development OR chronic work | Presence of a bridle noseband or tight halter |
| Medial remodeling to the premaxilla | Hypertrophy of *lateralis nasi* and accessory cartilage (due to heavy exertion and stress) | None hypothesized |
| Lateral modeling to the premaxilla | Developmentally related to medial remodeling<br>OR<br>Lateral pressure on the premaxilla at point of contact with a branch of infraorbital nerve | Unknown, possibly exacerbated by chronic use of a rigid cheekpiece |

amplifies rein pressure using an arm or shank attached to the reins (MacFarland 2013:105). This bit's primary action is on the roof of the horse's mouth, but the dorsal portion of this shank is situated near the area of contact between the premaxilla and the infraorbital nerve (Figure 6, bridle D). These two specimens exhibited marked lateral remodeling (Figure 7, top).

A larger comparative sample is necessary to confirm the validity of these patterns and assess the impact of potentially confounding variables, such as a horse's age, horsemanship or riding style, and work history. However, these preliminary data raise the possibility that a bridle cheekpiece exacerbates lateral remodeling of the premaxilla. As such, this feature is useful to consider in tandem with other lines of osteological evidence to evaluate late Bronze Age equine bridling in Mongolia (summarized in Table 1).

## Methods

To test the hypothesis that DSK bridles incorporated a noseband, rigid cheekpiece, and soft organic bit, we analyzed a sample of 25 horse crania for evidence of nasal depression, bit wear, and premaxillary remodeling. Although the majority of these skulls were badly fragmented, two skulls had complete preservation of the upper nasal area. We scanned these at a resolution of 2000 DPI with a NextEngine 3D Scanner, visually inspecting them for recesses related to noseband use. To identify whether bitting damage affected DSK horses, we assessed lower premolar beveling following the protocol outlined by Anthony and Brown (2003). Excluding deciduous or broken specimens, teeth from 13 individual horses remained for analysis. For each LP2, we measured bevel depth

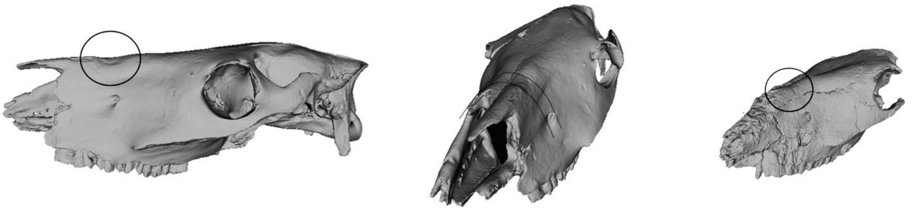

Figure 8. 3D model showing facial deformation from noseband use in a specimen from the site of Khushuutiin Gol (left, center) radiocarbon dated to 2910 +/- 40 $^{14}$C BP (1224–980 cal yrs BC), and possible deformation in a young horse from Tsatstain Khushuu (right, 2920 +/- 40 $^{14}$C BP).

at the anterior-most border of the tooth perpendicular to the occlusal surface, using scale profile photographs in the open-source measurement program, ImageJ. When measurable bevels could be identified, we compared tooth row morphology of both upper and lower jaws to identify malocclusion-related causes. For each LP2, we also analyzed the anterior morphology for exposed cementum or enamel following Bendrey (2007). In cases of exposed enamel, we sought to identify parallel-sided wear exposures that might be indicative of bit use and compared anterior exposures with the lingual sides of the tooth to rule out natural tooth wear. For DSK specimens with sufficient preservation (n = 8), we scored diastema bone changes according to the categorical ranking system provided by Bendrey (2007). Finally, we compared previously published digital measurements of nine DSK premaxillary fragments (Taylor et al. 2015) with data from the documented specimens outlined above in order to explore implications for cheekpiece use.

## Results

One of two horses with sufficient preservation for morphological study provided unequivocal evidence of a bridle or halter noseband (Figure 8, left). This specimen, an elderly animal of indeterminate sex from the site of Khushuutiin Gol, in northern Mongolia, was radiocarbon dated to 1224–980 cal yrs BC (Fitzhugh 2009b). The animal's skull exhibits a deep recess to the bridge of the nose, situated above the third premolar. This depression is similar to pathologies identified by Takàcs (1985) in sixteenth century AD specimens from Hungary, as well as the animals from contemporary Xinjiang and Mongolia discussed above. While the second complete horse exhibited no deformation, a third partially complete specimen, a juvenile between 2–2.5 years in age from the site of Tsatstain Khushuu, exhibits thinning and possible deformation to the nasal bones (Figure 8, right). Unfortunately, taphonomic damage reduces confidence in this assessment. Nonetheless, at least one specimen provides compelling evidence that DSK horses were controlled with a noseband.

Diastema and premolar form revealed no diagnostic evidence of bit wear in the DSK sample. Among adult LP2s (n = 13), eight lacked a measurable bevel and only one specimen produced a value greater than 3 mm (Supplementary online material, Appendix B). When fitted with the opposing upper jaw, this feature was clearly attributable to malocclusion, caused by a badly impacted upper molar. Anterior premolar wear and diastema bone formation were also nearly absent from the DSK sample. Ten DSK LP2 specimens show some form of anterior cementum or enamel loss. However, most instances of apparent enamel wear also affected other portions of the tooth beyond the anterior edge, and none exhibited the parallel sides that are characteristic of metal bit wear. As a result, it remains unclear whether this anterior wear is entirely natural or relates to the use of a softer bit. In any case, none of the seven DSK specimens with diastema preservation demonstrated more than faint bony changes to the diastema, falling within the range of variation observed by Bendrey (2007) in unbitted horses.

Several of the DSK horses yielded lateral remodeling depths similar to those observed in horses bridled with a rigid cheekpiece. Four of the DSK specimens with measurable premaxillae had no lateral remodeling (that is, levels comparable to feral horses and other wild equids). However, five DSK premaxillary fragments had measurable external grooves of greater than 0.5 mm (Figure 7, bottom). In particular, the Khushuutiin Gol specimen, previously noted for its noseband depression, had pronounced lateral remodeling of nearly 2 mm in depth. Two other DSK specimens fell between 0.7 and 0.9 mm, measurements comparable to those observed in the Pazyryk, Turkic, and modern Weymouth bridle specimens.

## Discussion

Remodeling of the nasal bones in at least one DSK horse skull corroborates the inference of a noseband or halter, with several possible modes of formation. In contemporary Mongolia, young foals are often haltered and tied for long periods during the summer, when the mares are milked to produce *airag* (fermented horse milk; Figure 9). Young horses that will be used for riding also begin their training at around one year of age (Enkhtuvshin and Tumurjav 2011:173–74). Either of these practices could produce chronic pressure to the bridge of the nose, at an age when the nasal bones would be developing and thus particularly sensitive to deformation. The extreme deformation on the specimen from Khushuutiin Gol probably indicates that DSK bridles used a direct connection between reins and noseband, as seen in the Altai and contemporary Mongolian examples. An additional possibility is that traction work using long reins (i.e., chariotry or carts) increased the pressure on this point of the skull.

The absence of appreciable diastema or LP2 damage to sample DSK specimens may reflect organic bit use. While experimental efforts have come to conflicting conclusions about the effect of softer organic bits on equine dentition (Anthony et al. 2006; Brownrigg 2006), a less abrasive mouthpiece of leather or hemp could have a reduced effect on the diastema and LP2 (Bendrey 2007:1048). It should be noted that the absence of bitting damage in our sample does not necessarily rule out use of a metal bit; factors such as bridle design and style of horsemanship probably alter the skeletal impact of even hard metal mouthpieces (Bendrey et al. 2013:98). DSK horsemen could also have used a bitless bridle, a technology that remained common throughout the Bronze Age (Dietz 2003).

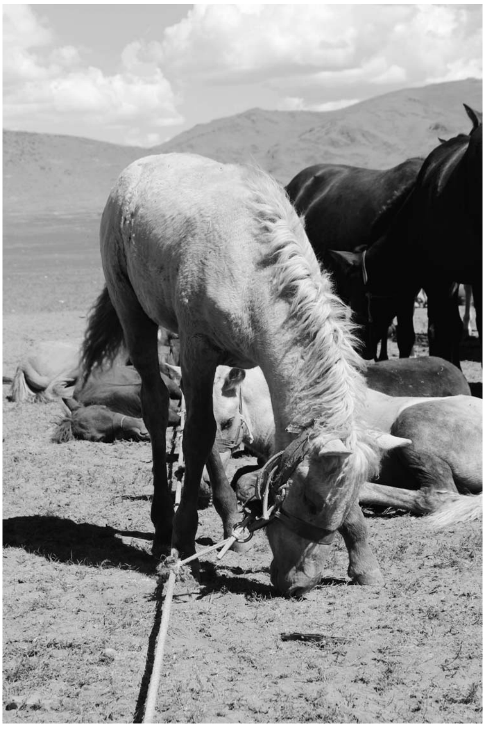

Figure 9. Young foal haltered and tied to a rope line with other foals during summer milking season, Bayankhongor province, Mongolia.

However, as archaeological tack demonstrates the use of organic bits well into the first millennium BC in other Mongolian archaeological contexts, we suggest that the minimal bitting damage in the DSK sample reflects the use of leather, wood, or bone mouthpieces.

If future study validates the link between osteological changes to the premaxilla and lateral bridle pressure, our sample would also support the presence of a rigid cheekpiece in DSK bridles. Grooving to the lateral margin of the premaxilla in DSK specimens is similar to contemporary horses ridden with a Weymouth bridle and archaeological specimens controlled with a rigid bar cheekpiece. Bars of metal, bone, or wood situated along the sides of the horse's face were an important element of Mongolian bridles for centuries following the DSK period and would have enabled DSK riders or charioteers to turn the horse effectively.

## Conclusion

Several key challenges complicate the osteological study of equine bridles. Foremost among these are the difficulty of acquiring specimens with suitably detailed histories and the complex and continuous nature of osteological remodeling processes in the equine skull. However, our results indicate that osteology can be used to identify particular bridle components when skulls are preserved in the archaeological record, even in the absence of preserved tack. Drawing on both osteology and analogy, we argue that DSK bridles incorporated a noseband, organic bit, and hard cheekpieces. This style of bridle could have been used to drive chariots/carts or for experiments in early horseback riding (Bokovenko 2000; Honeychurch 2015:128). In either case, DSK bridle technology would have been critically important for ancient nomadic activities, and may have facilitated the development and spread of mobile pastoralism in the Eastern Steppe. With an improved understanding of osteological formation processes, the cranial changes identified here may one day be useful for evaluating temporal patterns in bridle technology across the late Bronze Age. This approach will help to clarify the changing role of the horse in ancient societies, as well as the ways Mongolian nomads may have affected the transition from chariotry to mounted horseback riding in East Asia.

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