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Case study

Multi-level spondylolysis at Egiin Gol: A case from Xiongnu period Mongolia

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ABSTRACT

Objective: This paper presents and discusses the aetiology of an extreme case of multi-level spondylolysis with unique presentation.
Materials: The affected individual is an adult male from Xiongnu period (209 BCE to 93 CE) Egiin Gol, northern Mongolia.
Methods: Analyses were limited to macroscopic and non-invasive methods.
Results: Seven complete spondylolytic clefts were documented on four vertebrae between T12 and L4, with only one located on L4, where most cases of spondylolysis occur, and four defects had atypical morphology. Evidence of spondylolisthesis was also observed.
Conclusions: Congenital susceptibility to spondylolysis, combined with a physically demanding lifestyle, likely account for the condition's unusual manifestation.
Significance: The significance of this case its severity (one of the most extreme documented from archaeological contexts) and unusual presentation (location of the clefts and their atypical morphology).
Limitations: Only a small sample (< 30) of Xiongnu period human remains were available for comparison.
Suggestions for further research: Interpretations from this case study would benefit from a more extensive analysis of spondylolysis, biomechanical stress, and acute trauma on the nomadic pastoral populations of northern Mongolia, including those pre-dating and post-dating the Xiongnu.

1. Introduction

Spondylolysis, a vertebral condition unique to humans, is a separation of the neural arch at the *pars interarticularis* (between the superior and inferior articular processes; Aoki et al., 2020; Gagnet et al., 2018; Mays, 2007a; Merbs, 1996a, 2002). Lower lumbar vertebrae (those caudal to L3), especially L5, are involved in 85–95 % of cases, with prevalence decreasing the more cranial the vertebral position (Aoki et al., 2020; Gagnet et al., 2018; Fibiger and Knüsel, 2005; Kalichman et al., 2009; Lessa, 2011; Mays, 2007a; Merbs, 2002; Stewart, 1953). The aetiology of spondylolysis appears to be multifactorial and linked to human bipedalism. In the lower lumbar region, the condition is generally thought to originate as a stress fracture reflecting repetitive biomechanical forces. In more cranial elements, its low prevalence and unique presentation, along with reduced biomechanical stress, suggest a congenital origin (Mays, 2007a; Merbs, 1996a). To be clear, most scholars do not consider the clefts themselves to be congenital (but see Mann et al., 2018), but rather to occur on congenitally "weakened" arches. Underscoring this, no cases of spondylolysis have been documented on individuals who never walked (Gagnet et al., 2018; Merbs, 1996a). The dual role of congenital and biomechanical factors is supported by skeletal shape analyses revealing that vertebral morphology may influence susceptibility to spondylolysis (Plomp et al., 2020; Ward et al., 2010).

Spondylolysis is not rare, but its prevalence varies widely, from 3–19 % among modern people (Kalichman et al., 2009; Kyei et al., 2015; Roche and Rowe, 1951) to as high as 54 % in historic or archaeological groups (Arriza, 1997; D'Angelo de Campo et al., 2017; Fibiger and

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Knüsel, 2005; Karapetian, 2021; Lessa, 2011; Mays, 2006; Merbs, 1989, 2002; Pilloud and Canzonieri, 2014; Simper, 1986; Suzuki, 1998; Tipper et al., 2023; Waldron, 1991b). It appears to have been especially common among premodern Arctic peoples (e.g., Merbs, 2002). Today spondylolysis is most likely to develop during childhood and early adolescence (Aoki et al., 2020; Gagnet et al., 2018), but its peak period of onset was later, during late adolescence and early adulthood, for many past populations (e.g., Lessa, 2011; Mays, 2007b; Merbs, 1996a, 2002; Tipper et al., 2023). The severity of spondylolysis also varies. Most instances involve single vertebrae, but double cases with four complete bilateral defects are known (Arriza, 1997; Karapetian, 2021; Mays, 2006; Yarube et al., 2017). Multi-level spondylolysis involving more than two vertebrae is exceedingly rare (Al-Sebai and Al-Khawashki, 1999; Liu et al., 2015; Merbs, 2002; Park et al., 2009; Wieckowski, 2021). Most cases—and all archaeological ones—affect elements caudal to L1.

Here we present an extreme case of multi-level spondylolysis involving four vertebrae between T12 and L4. Of significance is not only the severity of the condition but also its unusual presentation, both the location of the clefts and their atypical morphology. The affected skeleton, Individual EG-1-018, was an adult male from northern Mongolia, recovered from the site of Ereen Khailaas in the Egiin Gol Valley. His remains revealed degenerative changes and multiple traumatic injuries in addition to the spondylolytic defects. These lesions, the nature of the clefts, and the broader archaeological context highlight the multifactorial—congenital and biomechanical—aetiology of spondylolysis.

2. Materials and methods

Ereen Khailaas was excavated by a team of Mongolian archaeologists, including co-authors (IT and OS), as part of the Eg River Hydroelectric Power Plant project in 2014–2015. The site is located on the west bank of the Eg River (Egiin Gol), 3 km southeast of Khantai Bag in Bulgan Province of northern Mongolia (Fig. 1). Excavations at Ereen Khailaas revealed 13 Xiongnu period (209 BCE to 93 CE) ring burials and 14 other stone features. Ring burials are characteristic of Xiongnu commoners; while varying in terms of the number and quality of grave accompaniments, they are distinct from the massive terrace tombs of the Xiongnu elite (Brosseder and Miller, 2011; Kradin, 2005; Miller et al., 2018; Wright et al., 2009; Wright, 2021). Over 500 archaeological sites have been identified in Egiin Gol (Wright et al., 2009, Wright et al., 2023) and these include 14 Xiongnu cemeteries containing at least 145 individuals. Remains of 28 individuals from six Egiin Gol Xiongnu sites, including 12 of the 13 from Ereen Khailaas, were examined by co-authors in 2023. Documentation was limited to macroscopic and non-invasive methods.

A typical Xiongnu ring burial, Individual EG-1-018 was a single inhumation in extended and supine position. Placed in a stone coffin, the deceased was interred in a pit overlain by a circular arrangement of stones on the surface. Grave goods included iron artifacts (arrowheads, horse bits, belt hooks), ceramic fragments, bone chopsticks, bow fragments, and horse, bovid and sheep skulls, along with other faunal material (Iderkhangai et al., 2014). The human remains were generally well preserved, with good representation of post-cranial elements (Fig. 2). While the cranium was missing, the mandible and complete vertebral column were recovered. It's worth noting that grave structure, body position and preservation, and burial accompaniments for Individual EG-1-018 were not distinct in any way from those of other Xiongnu interments at the site. Age at death and biological sex estimation were based largely on the morphology of the pelvis and mandible (Brooks and Suchey, 1990; Buckberry and Chamberlain, 2002; Buikstra and Ubelaker, 1994: 16–21; Meindl and Lovejoy, 1989).

3. Results

Individual EG-1-018 was assessed as a male aged 35–50 years. Multiple antemortem traumatic injuries were noted on the postcranial skeleton, specifically healed fractures to the distal shafts of the left ulna and left fibula, healed fractures to three right ribs, and—the subject of this paper—multi-level spondylolysis. Degenerative joint changes were also present on the upper limbs and vertebrae, including Schmorl's nodes on T12–L3. No other pathological conditions were observed on the skeleton, apart from dental disease.

Clefts in the neural arch at the *pars interarticularis* were present on four vertebrae (Fig. 3): T12 (unilateral left side), L1 (bilateral), L2 (bilateral), and L4 (bilateral, with the posterior neural arch missing postmortem). All seven defects were complete. Four were 'atypical,' their infero-lateral aspects characterized by discrete areas of smooth flat bone on the opposing surfaces, reminiscent of facets and suggesting the presence of synovial joints (Mays, 2007a; Merbs, 1996a; Nathan, 1959; Stewart, 1953). They also exhibited stepped or "dog-leg" morphology, being more or less horizontal supero-medially, in most cases extending through the superior lamina, and vertical infero-laterally (Mays, 2007a; Merbs, 1996a; Nathan, 1959). These "facetted" clefts were observed on T12 (left side), L1 (right side), and L2 (bilateral), though that on the T12 was obstructed by postmortem damage (Fig. 4). The other three defects (left side on L1 and bilateral on L4) were more typical, with adjoining surfaces of rough, porous cortical bone. Those on L4 were relatively straight and more remodelled (smoother and less irregular) than that on L1 (Fig. 4), possibly reflecting their earlier formation (Mays, 2007a).

Fig. 1. Map of Mongolia with Ereen Khailaas (Egiin Gol) indicated. Map (edited by A. Lieverse) by NordNordWest via Creative Commons, available at https://commons.wikimedia.org/wiki/File:Mongolia_location_map.svg.

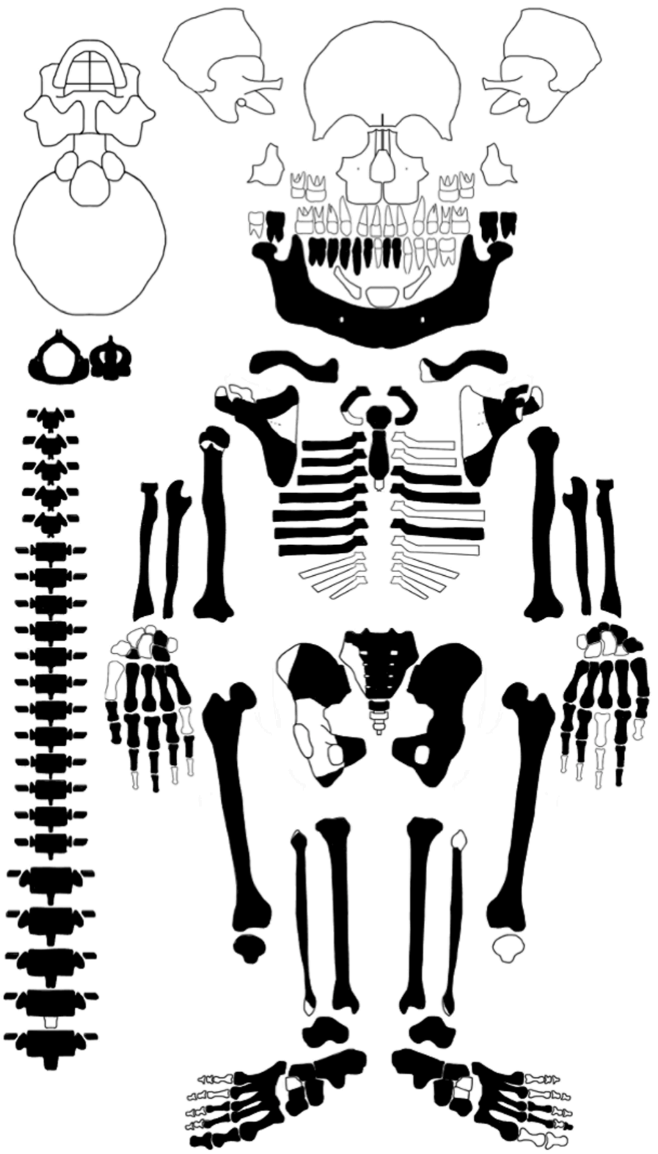

Fig. 2. Diagrammatic skeletal/dental inventory of Individual EG-1-018. Elements/fragments present indicated in black. Image by A. Lieverse. Template from Roksandic (2003).

In addition to the neural arch defects, degenerative changes were observed on the centra of L2 (inferoanterior), L3 (superoanterior), L4 (inferoposterior), and L5 (superoanterior). These changes included osteophytosis, irregular new bone formation, pitting, and porosity of the vertebral endplates (Fig. 5). Vertebral osteophytes, initiating as horizontal outgrowths near joint margins on the centrum, typically reflect degeneration and/or displacement of intervertebral discs (Burt et al., 2013:57; Roberts and Manchester, 2005:139–140; Rogers et al., 1987). New bone formation, porosity, and pitting are also indicative of disc degeneration (Roberts and Manchester, 2005:139–140; Rogers, 2000), the former likely instigated by migration of the centrum (Lewis, 2019). These changes are consistent with isthmic spondylolisthesis (IS) of L2 and L4, the anterior displacement of their centra relative to L3 and L5, respectively (Gagnet et al., 2018; Mays, 2006; Merbs, 1996a, 2001, 2002). Note that IS can only occur on vertebrae with bilateral arch defects (Gagnet et al., 2018).

4. Discussion

To the best of our knowledge, this is one of the most severe cases of multi-level spondylolysis documented in the paleopathological or clinical literature. Seven complete *pars interarticularis* clefts were present on four vertebrae, most (five clefts on three vertebrae) being cranial to the lower lumbar region. Spondylolysis involving upper lumbar (L1–L3) or thoracic vertebrae is uncommon, occurring in approximately 5 % of modern cases (Aoki et al., 2020; Kalichman et al., 2009) and 5–15 % of archaeological ones (Fibiger and Knüsel, 2005; Lessa, 2011; Mays, 2007a; Merbs, 2002; Tipper et al., 2023; Stewart, 1953; Waldron, 1991a). Affectation of more than two elements is exceptionally rare, with only a handful being documented from archaeological contexts. In an extensive examination of Canadian Inuit remains, Merbs (2002) identified two individuals with three affected vertebrae and three individuals with four. However, it's unclear how many clefts were present on these individuals, whether they were complete, or even if they involved the *pars interarticularis*. In Merbs' (2002) sample, 19 % of defects (38/198) were unilateral, 20 % (40/198) were incomplete, and 5 % (10) did not occur on the *pars*. In fact, just 52 % of affected elements were "classic" cases, that is lumbar vertebrae exhibiting complete bilateral clefts at the *pars interarticularis*. Earlier studies on some of the same Inuit remains by Merbs (1983, 1995), together identifying four individuals with spondylolysis on more than two vertebrae, demonstrated that no individual had more than five defects, nor more than three that were complete separations at the *pars.* Another archaeological case, a 19th century immigrant to Peru (Wieckowski, 2021), exhibited spondylolysis on three vertebrae (L2–L4), all being bilateral and complete (six defects). With seven complete defects, EG-1-018 may represent the most extreme example reported to date.

What might explain the severity of the case presented here? First and foremost, spondylolysis is a stress fracture resulting from repetitive vertebral loading, especially in hyperextension (Gagnet et al., 2018; Merbs, 1996a). Lower lumbar elements—particularly the *pars interarticularis*—bear the brunt of biomechanical stress and are thus most susceptible to fracture (Gagnet et al., 2018; Mays, 2007a). Today prevalence is highest among young athletes, especially those engaging in repetitive hyperextension (e.g., gymnasts and weightlifters) or rotation (e.g. rowers, baseball players; Ciullo and Jackson, 1985; Gagnet et al., 2018; Greene et al., 1994; Selhorst et al., 2019). In archaeological contexts, spondylolysis is considered a general marker of strenuous and physically demanding lifestyles (Arriza, 1997; Mays, 2007a; Merbs, 1983; Tipper et al., 2023; Waldron, 1991a). For example, its high prevalence among Arctic peoples has been attributed to posture and repetitive activities such as wrestling, paddling, weightlifting, and throwing (Merbs, 1983, 1996b, 2002; Stewart, 1953). Multi-level spondylolysis is also normally associated with intense physical activity (heavy labour, sports) or trauma (Liu et al., 2015; Wieckowski, 2021).

Many Xiongnu were mounted nomadic pastoralists who established the first empire of the eastern Eurasian steppes (Brosseder and Miller, 2011; Di Cosmo, 2002; Honeychurch, 2013; Wright, 2021). They are often depicted as fierce warriors, skirmishing with other nomadic entities and neighbouring states such as China (e.g., Zhang et al., 2021). Despite this, most Xiongnu commoners appear to have been herders, farmers, and craftspeople (Brosseder and Miller, 2011; Di Cosmo, 1994; Kradin, 2005), those in Egiin Gol employing a mix of agropastoralism supplemented with wild foods (Wright et al., 2009, Wright et al., 2023: 209). Bioarchaeological research on the Xiongnu, especially commoners, is limited, with few studies focusing on lived experiences and activity (Bemmann et al., 2015; Eng, 2013, 2016; Machicek,2011; Machicek and Beach, 2013; Machicek and Zuboa, 2012). Some research suggests that skeletal changes associated with a mounted pastoral lifestyle (e.g., high mobility and habitual horseback riding)—rather than violent conflict—dominate (Eng, 2013, 2016; Wright, 2021). These include long bone fractures from falls and other accidents; degenerative changes to joints absorbing heavy or repetitive loads, particularly in the vertebrae, upper limb, and hip; entheseal robusticity of upper limb and hip muscles; and, especially relevant here, spondylolysis and Schmorl's nodes reflecting biomechanical stress and chronic trauma to the lumbar

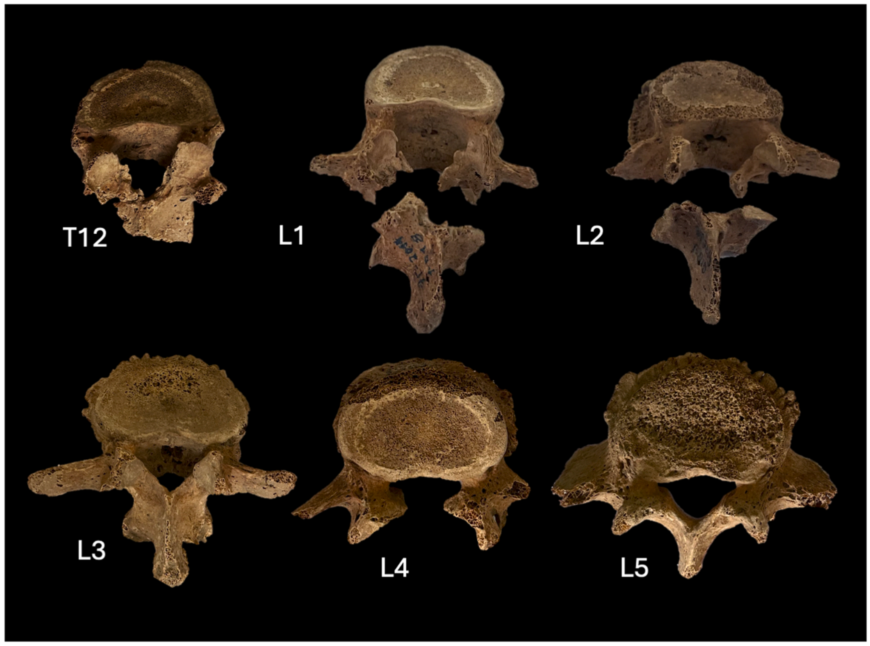

Fig. 3. Superior views of T12–L5 vertebrae. Images by A. Lieverse.

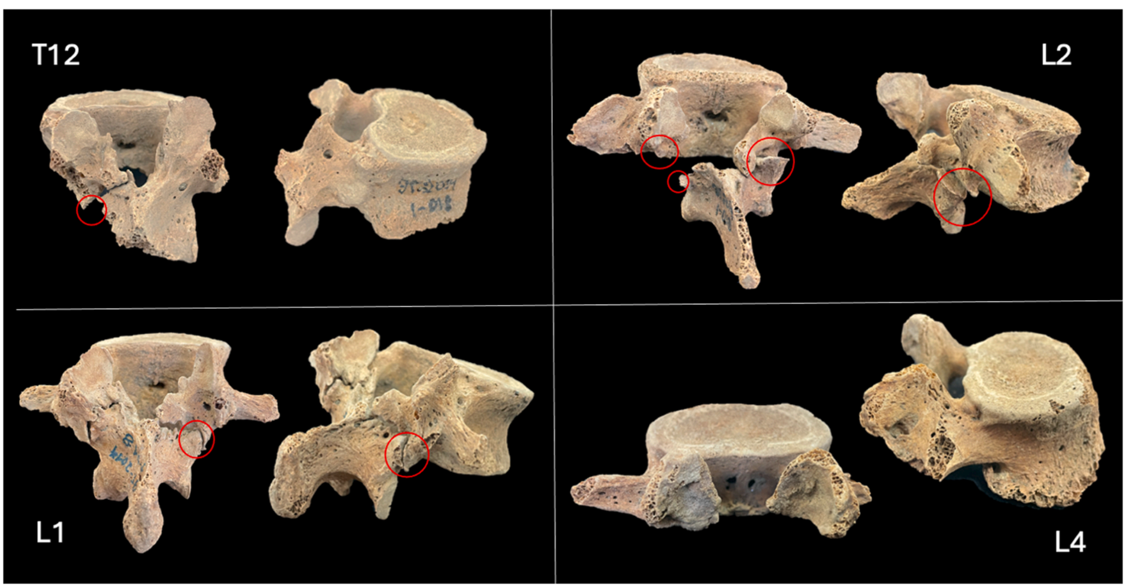

Fig. 4. Posterior (left) and right lateral (right) views of the four spondylolytic vertebrae. Red circles indicate the "facetted" surfaces on T12 (left side), L1 (right side), and L2 (bilateral). Images by A. Lieverse.

region (Eng, 2013, 2016; Fuka, 2018; Machicek, 2011; Machicek and Beach, 2013; Wright, 2021). Even during periods of warfare or conflict, time spent on horseback would have likely increased (Eng, 2016), exacerbating these skeletal changes.

Clinical and paleopathological research on the impact of horseback riding on the human skeleton is abundant, demonstrating increased risk of both repetitive stress lesions and acute trauma (e.g., Ball et al., 2007; Berthon et al., 2021, 2023; Eng,2016; Tsirikos et al., 2001). Among the anatomical regions most affected by biomechanical stress is the lumbar segment of the vertebral column (Berthon et al., 2023; Kraft et al., 2009; Mason and Greig, 2020; Tsirikos et al., 2001), which experiences substantial loading in extension (Auvinet,1999; Ginés-Díaz et al., 2019; Pugh and Bolin, 2004). Studies of horseback riding in the past have frequently documented its effects on the lumbar spine, including degenerative joint disease (DJD), Schmorl's nodes, and spondylolysis (Anđelinović et al., 2015; Berthon et al., 2021, 2023, Eng, 2013, 2016; Gresky et al., 2016; Karstens et al., 2018; Pálfi and Dutour, 1996; Sandness and Reinhard, 1992; but see Hosek et al., 2024). However, some research on the Xiongnu (Eng, 2013, 2016) suggests that they experienced high levels of vertebral DJD and Schmorl's nodes, but low levels of spondylolysis, compared to earlier Bronze Age populations (i.e., predating the transition to mounted pastoralism). This is consistent with our preliminary findings: of 13 adult Xiongnu individuals from Egiin Gol (nine from Ereen Khailaas) with at least three preserved lumbar vertebrae, five exhibited Schmorl's nodes and seven lumbar DJD, but only Individual EG-1-018 had spondylolysis.

Current equestrian activities have a high risk of acute trauma, usually from falls, but also from being crushed, kicked, or stepped on (Ball

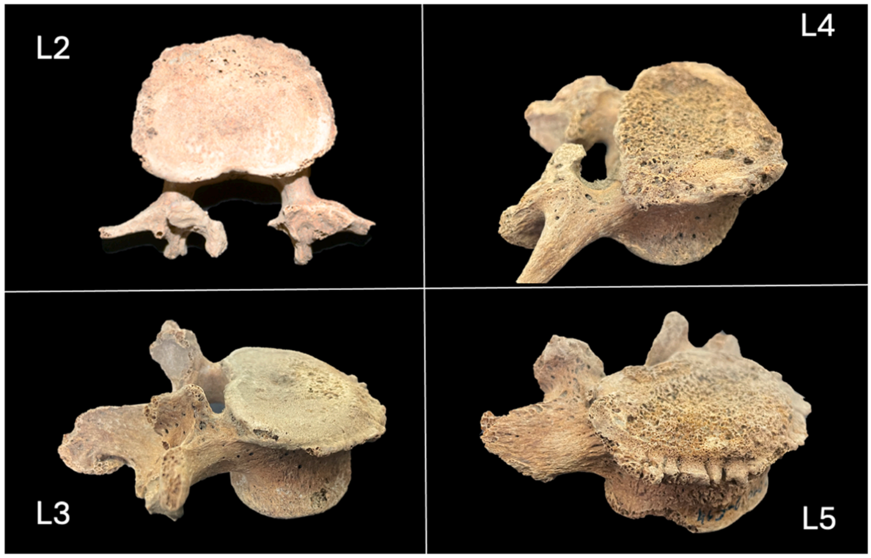

Fig. 5. Degenerative changes (osteophytosis, irregular new bone formation, pitting, and porosity) of L2–3 (left) and L4–5 (right) centra. L2, inferior view; L3, right lateral view; L4, left infero-lateral view; L5, right antero-superior view. Images by A. Lieverse and R. Losey.

et al., 2007; Paix, 1999). Most injuries occur on the upper body (head, torso, and upper limb), a pattern that is similar in archaeological horse-riding populations (Anđelinović et al., 2015; Berthon et al., 2021; Wentz and de Grummond, 2009). Despite having multiple healed injuries, largely on the upper body, Individual EG-1-018 does not appear to have been unique. Our preliminary data indicate that traumatic lesions were common at Egiin Gol: of 20 Xiongnu individuals (10 from Ereen Khailaas) whose remains were at least 50 % complete, 80 % (16) exhibited evidence of antemortem trauma, most (11) having injuries limited to the upper body. Furthermore, while almost half of individuals (nine) exhibited multiple injuries, only three had lesions consistent with intentional violence. Therefore, most individuals at Egiin Gol appear to have been at high risk of injury, probably associated with horseback riding or other aspects of their nomadic pastoral lifestyle, rather than conflict. Whether incidental or intentional in origin, acute trauma is probably not responsible for the spondylolytic defects exhibited by Individual EG-1-018. Fractures of the *pars interarticularis* due to severe trauma (e.g., falls, motor vehicle accidents), rather than repetitive stress, have been documented in clinical contexts, but they are uncommon and typically occur alongside other vertebral (pedicle, facet, centrum) or pelvic fractures (Hilibrand et al., 1995; Merbs, 1996a; Ver et al., 2019) that are not present here. If they occur alone on archaeological human remains, however improbable, they are indistinguishable from the more common stress fractures (Merbs, 1996a).

Given the apparent rarity of spondylolysis among the Egiin Gol Xiongnu, despite abundant evidence of repetitive vertebral stress and acute trauma, it's unlikely that this case can be solely attributed to biomechanical factors, whether related to a pastoral lifestyle or not. Skeletal lesions suggest that Individual EG-1-018 lived a physically strenuous life, but this appears to have been typical, as was his mortuary treatment. Instead, the location and presentation of some of the neural arch clefts may support a congenital aetiology: five of the seven are cranial to the lower lumbar region and four exhibit atypical morphology as described above. Not only are spondylolytic defects considerably less common on vertebrae cranial to L4, but they are also more likely to be unilateral and to have a “facetted” and “dog-leg” appearance (Mays, 2007a; Merbs, 1996a; Nathan, 1959; Stewart, 1953). While most scholars attribute their unique presentation to congenital factors, citing the reduced biomechanical stresses experienced by the upper lumbar spine (Merbs, 1996a; Miki et al., 1991; Nathan, 1959), their aetiology and nature remain poorly understood. For example, the “facetted” surfaces are reminiscent of movable synovial joints, but their restriction to the infero-lateral aspects of clefts and their common unilateral manifestation mean that most movement would be limited (Mays, 2007a; Merbs, 1996a, 1996b). Furthermore, if the clefts are truly congenital, reflecting errors in skeletal development (Stewart, 1953; Mann et al., 2018; Merbs, 1996a; Miki et al., 1991), then it is difficult to explain why none have been identified on fetuses, young infants, and non-ambulatory adults (Fredrickson et al., 1984; Mays, 2007a, 2007b; Rosenberg et al., 1981; Wiltse, 1962). As such, what is ‘congenital’ about spondylolysis appears to be its predisposition (Mays, 2007a; Merbs, 1996a; Plomp, 2023), rather than the defects themselves. Various aspects of vertebral morphology, such as posterior wedging of the centrum and narrow inter-facet distances, have been associated with its increased risk (Plomp et al., 2020; Ward et al., 2010; Roussouly et al., 2015). While an analysis of lumbar morphology and comparisons with the broader Egiin Gol population are beyond the scope of this study, it's likely that morphology played a role, alongside biomechanical stress, for Individual EG-1-018. The severe manifestation of spondylolysis in this case is likely a reflection of both a physically demanding lifestyle and an underlying congenital susceptibility. In addition, anterior slippage (IS) of L2 and L4 may have further reduced stability in the lumbar region, exacerbating spondylolysis risk.

5. Conclusions

The Egiin Gol Xiongnu appear to have experienced high levels of biomechanical stress and trauma, consistent with a mounted pastoral lifestyle, but Individual EG-1-018 was the only individual with spondylolysis. The significance of this case is its severity and unique presentation. With seven complete clefts on four vertebrae, this is one of the most extreme examples documented in either the clinical or paleopathological literature. Furthermore, while up to 95 % of spondylolytic defects occur on lower lumbar elements, most of those here are cranial to L4; in fact, three- or four-level spondylolysis involving T12 and L1 has not been previously recorded from archaeological contexts. Finally, four of the seven clefts have atypical morphology that is more common on upper lumbar vertebrae and typically attributed to congenital factors. Thus, it's likely that a congenital susceptibility to spondylolysis, combined with a physically demanding lifestyle, can account for the condition's unusual manifestation here.

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CRediT authorship contribution statement

Tumur-Ochir Iderkhangai: Writing – review & editing, Resources, Data curation. **Lieverse Angela:** Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Conceptualization. **Nomokonova Tatiana:** Writing – review & editing, Funding acquisition. **Samdantsoodol Orgilbayar:** Writing – review & editing, Resources, Data curation. **Losey Robert:** Writing – review & editing, Funding acquisition.

Declaration of interest

None.

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