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Trauma analysis in bioarchaeology: a review and case study from Khuvsgul and the Tunka Valley

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Abstract. This article presents a review of trauma analysis in bioarchaeology. It starts with an introduction on what trauma is and what permanent markers it can leave on bones, even after recovery. Studies of trauma allow bioarchaeologists to evaluate the mechanism of injury and possibly reveal the cause of trauma, which may inform on individuals' interactions with their environments and sociocultural contexts. Trauma also can be incidental or intentional in origin, often reflecting cultural practices. Furthermore, this article focuses on the classification and interpretation of injuries in past populations, such as fracture, dislocation, ossification of soft tissues, and abnormal shape or contour of the bone. It describes different types of force trauma and defines dislocation and hematomas that may occasionally lead to ossification of adjacent soft tissues and can manifest as bony projections. This is followed by a case study utilizing trauma data to elucidate past human experiences. Human remains from twelve individuals excavated from Lake Khuvsgul, Mongolia, and three individuals from the adjacent Tunka Valley, Russian Federation, were examined. All skeletons were dated between the mid-11th and 14th centuries CE. Fatigue injuries on the spine were the most frequent, suggestive of strenuous activities, such as habitual horseback riding. There was some evidence of upper limb trauma, but limited lower body and violent trauma. A potential explanation of this pattern is that people in this area were frequently engaged in pastoral activities, but conflict rarely impacted their daily lives.

Keywords: paleopathology, trauma, bone, fracture, Khitan-Mongol period, northern Mongolia, pastoralism, horseback riding, Lake Khuvsgul, Tunka Valley

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Археология

Научная статья

Анализ травмы в биоархеологии: обзор и примеры исследований из Прихубсугулья и Тункинской долины

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Аннотация. Данная статья представляет обзор анализа травм в биоархеологии. Она описывает, что такое травмы и какие постоянные следы от них остаются на костях человека даже после их заживления. Исследование травм также позволяет биоархеологам оценить механизмы повреждений и, возможно, узнать их причины, что может дать информацию о взаимодействии людей с окружающей средой и социокультурным контекстом. Такие травмы могут быть случайными или преднамеренными по своему происхождению, часто отражая культурные традиции. Кроме того, в этой статье особое внимание уделяется классификации и интерпретации травм, таких как переломы, вывихи, отвердения мягких тканей и аномальные форма и контур кости, у древних населений. Описываются различные виды силовых травм и приводятся определения вывихов и гематом, которые иногда могут приводить к отвердению прилегающих мягких тканей и проявляться в виде костяных выступов. Приводятся примеры исследования травм на останках людей с могильников, расположенных на озере Хубсугул в Монголии (12 человек) и в Тункинской долине на территории России (3 человека). Останки людей датируются между серединой XI и XIV веков н. э. Наиболее частые виды травм на костях – это повреждения позвоночников, указывающие на требующую усилия активность, такие как постоянная езда на лошадях. Также зафиксированы случаи травм на руках и в меньшей степени на ногах. Повреждения в виде насильственных травм – очень редки. Возможное объяснение таких случаев связано с постоянным участием в скотоводческой деятельности. Конфликт редко был причиной повседневной жизни.

Ключевые слова: палеопатология, травма, кость, повреждение, Киданьско-Монгольский период, Северная Монголия, скотоводство, езда на лошади, озеро Хубсугул, Тункинская долина

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1. Introduction

Trauma is injury to living body tissues caused by external forces (Lovell, 1997; Lovell and Grauer, 2019). Some injuries, such as fractures, can leave permanent markers on bones even after recovery, allowing bioarchaeologists to evaluate their mechanisms. In turn, understanding the mechanism of injury can reveal the cause of trauma, which may inform on individuals' interactions with their environments and sociocultural contexts (Lovell and Grauer, 2019). This article will review trauma analysis in bioarchaeology (paleotrauma), including types of trauma and their interpretations. It will then present a case study to demonstrate how trauma analysis can contribute to understanding the past. The case study will focus on human remains excavated from four Lake Khuvsgul cemeteries (n=12) and two cemeteries from the adjacent Tunka Valley (n=3). All date to the Khitan-Mongol period (mid-11–14th centuries CE).

2. Trauma Analysis in Bioarchaeology

2.1 Types of Trauma

Because archaeological human remains are usually limited to skeletal tissues, paleotrauma typically reflects injuries present on bones (Judd and Rederfen, 2012). Ortner (Ortner, 2003. P. 120) proposed four types of bone injuries for archaeological remains: a partial or incomplete break, abnormal displacement of joints, disruption in nerve and/or blood supply, and artificially induced abnormal shape or contour of the bone. Lovell and Grauer (Lovell and Grauer, 2019) integrated this work with that of other scholars (Lovell, 1997; Ortner, 2003. P. 119-120; Roberts, 2006; Roberts and Manchester, 2007. P. 214-217) and introduced one of the most popular categorizations of paleotrauma: fracture, dislocation, ossification of soft tissues, and extrinsically induced abnormal shape or contour of the bone.

Fracture

Technically, the term “fracture” is broad, referring to any antemortem discontinuity of bone and encompassing breaks, blunt and sharp force trauma, and high-velocity projectile injuries (Christensen et al., 2019. P. 352-363; Galloway et al., 2014b). All fractures reflect both extrinsic factors, such as the direction, magnitude, and rate of force applied, and intrinsic factors, reflecting the bone’s ability to resist failure (e.g., tissue composition, bone geometry, individual age, and underlying pathological conditions; Brickley and Mays, 2019; Christensen et al., 2019. P. 343-345; Redfern and Roberts, 2019). Among these factors, the direction of the force can suggest the mechanism of injury. For instance, a direct collision between a rigid object and bone typically produces depressed, transverse, and comminuted (more than two fragments) fractures, with trauma location reflecting the impact site (Redfern and Roberts, 2019). In contrast, indirect forces, often resulting from twisting, tension, or compression, transform and propagate to affect other bone regions, commonly giving rise to oblique and spiral fractures, avulsion injuries (at tendon or ligament attachments), and fracture-dislocations (Lovell and Grauer, 2019; Redfern and Roberts, 2019).

Depending on the size, shape, and velocity of objects generating the force, fractures can be classified into blunt force trauma (BFT), sharp force trauma (SFT), high-velocity projectile trauma, or combinations thereof (Christensen et al., 2019. P. 352). High-velocity projectile trauma pertains to injuries caused by bullets, a phenomenon that only emerged following the widespread use of firearms. BFT is typically caused by low-velocity forces delivered by broad and blunt surfaces and tends to propagate along paths of least resistance until the energy generated by the force has been dissipated (Spatola, 2015). BFT usually produces depression in the cranium and transverse fractures in the post-cranial skeleton (Christensen et al., 2019. P. 345-346; Galloway et al., 2014c). SFT resembles BFT but stems from intense compressive or shearing forces concentrated in a narrow area (Christensen et al., 2019. P. 360-361). Typical examples include cutmarks, penetrating wounds from projectile weapons (e.g., arrows and javelins), and stab wounds, all of which yield discernible modifications such as linear incisions, punctures, gouges, and clefts (Christensen et al., 2019. P. 360-361; Tur et al., 2018; Vanezis, 2021. P. 1). In addition, some objects, such as axes, can produce a combination of BFT and SFT reflecting a sharp cutting edge and substantial weight (Vanezis, 2021. P. 1-2).

Dislocation

Dislocation is the disruption of the normal connections between bones at their joints. Specifically, a dislocation, or luxation, refers to an entire displacement, while subluxation suggests that the joint is partially displaced but retains some contact (Lovell and Grauer, 2019). In bioarchaeology, dislocations can only be directly identified if they persist long enough for bone modifications to occur, such as the development of secondary joints. Such dislocations are most often documented on the hip because its socket is relatively deep and difficult to fully restore (McKenzie et al., 2022; Mitchell and Redfern, 2008; Plischuk et al., 2018; Traversari et al., 2016). Severe joint displacements may also be accompanied by fractures and damage to soft tissues that may be visible on bone. In addition, subluxation and chronic dislocation (e.g., of the shoulder joint) can cause secondary changes to joints and adjacent tissues, resulting in osteoarthritis, soft tissue ossification, and even ankylosis (joint fusion). In these cases, dislocations may be indirectly identified (Mitchell and Redfern, 2008; Nikitovic et al., 2012; Osterholtz et al., 2019; Toritsuka et al., 2007; Thompson, 2001; Zhang et al., 2022).

Ossification of Soft Tissues

Hematomas, or blood clots, usually form after traumatic injuries and facilitate bone healing. However, hematomas may occasionally lead to ossification (mineralization) of adjacent soft tissues, manifesting as irregularly shaped yet smooth bony formations or large bony projections (Redfern and Roberts, 2019;

Waldron, 2020. P. 80). In medical contexts, "myositis ossificans" (MO) is a general term used to denote the formation of bone within skeletal muscles (Walczak et al., 2015). When the condition is triggered by trauma, as is most common, it is referred to as "myositis ossificans traumatica" (MOT) or "traumatic myositis ossification" (Lovell and Grauer, 2019; Walczak et al., 2015). Unfortunately, since many ossifications do not adhere to adjacent bones, they can be easily overlooked during archaeological excavations (Redfern and Roberts, 2019).

Extrinsically Induced Abnormal Shape or Contour of the Bone

Chronic, low-grade compression can modify the normal shape or contour of bone (Redfern and Roberts, 2019). Such trauma can be either incidental or intentional in origin, often reflecting cultural practices. Intentionally induced alterations that produce discernible anatomical changes to bone morphology include cranial modification, foot-binding, and waist training. Such practices are usually initiated early in an individual's life, and these practices involve the sustained application of mild yet persistent compressive forces that ultimately lead to enduring morphological changes (Alfonso-Durrruty et al., 2015; Gibson, 2015; Mayall et al., 2017; Seguchi et al., 2023; Stone, 2012; Stone, 2020; Tiesler, 2012; Zhao et al., 2020).

Antemortem vs. Perimortem vs. Postmortem

Trauma can be categorized as antemortem or perimortem based on its association with the time of death. Antemortem trauma encompasses injuries that occurred before the death, while perimortem trauma transpired in proximity to the time of death and may bear direct relevance to the cause of death (Galloway et al., 2014a; Passalacqua and Rainwater, 2015; Redfern and Roberts, 2019). The primary indicator of antemortem trauma is evidence of bone reaction, such as the formation or removal of bone tissue in the days or weeks following the injury (Christensen et al., 2019. P. 347). In the absence of this, trauma is perimortem or postmortem. However, it is imperative to emphasize that postmortem 'trauma' is not genuine trauma because it reflects events that did not disrupt living tissues (Christensen et al., 2019. P. 341). Postmortem disturbances to dry brittle bone (typically years after death) can be identified by jagged, stepped, or irregular margins, flaked cortex, no plastic (smooth) deformation, and/or lighter hues of fracture margins (Christensen et al., 2019. P. 350-351; Klaus and Lynnerup, 2019; Redfern and Roberts, 2019).

2.2 Trauma Interpretation

The interpretation of paleotrauma primarily relies on contemporary medical and forensic research, and thereby bioarchaeologists must presume that the mechanisms and scenarios of injury in the past are similar to those today (Cheverko et al., 2020). Bioarchaeologists do not simply define an injury as "incidental" or "intentional." Instead, potential causes are suggested with consideration for anatomical regions, activity patterns, demographic factors, and archaeological or historical contexts.

Cranium

Cranial injuries commonly present as linear fractures, depressions, and penetrations (Galloway and Wedel, 2014a). Injuries to the vault and face are primarily caused by direct, high-velocity impacts, often resulting from assaults or accidental collisions (Barss et al., 1984; Scott and Buckley, 2010). The facial region is a common target in interpersonal conflicts, particularly in instances of domestic violence (Lovell and Grauer, 2019). Among facial bones, nasal fractures are the most prevalent due to the nose's prominent location and relatively fragile structure (Galloway and Wedel, 2014a). Conversely, trauma to the cranial base typically arises from forces indirectly transmitted from impacts to the face or nape (Galloway and Wedel, 2014a; Lovell and Grauer, 2019). In addition to fractures, acute dislocations of the mandible can occur from excessive stress during mastication, physical assaults, or falls where the chin absorbs the impact (Flensborg et al., 2019; Rando and Waldron, 2012; Shorey and Campbell, 2000; Toufeeq et al., 2019).

Vertebrae

Cervical vertebral dislocations and fractures are typically caused by high-energy impacts, such as strangulation and decapitation (Galloway and Wedel, 2014c). Thoracic and lumbar vertebrae, the axis of the human body, are frequently engaged in various activities and therefore vulnerable to stress fractures, especially the more caudally they are positioned (Galloway and Wedel, 2014c; Jurmain, 2013. P. 170-172; Plomp, 2023; Toman et al., 2016; Waldron, 2020. P. 45 and 151). For example, spondylolysis, a cleft in the neural arch, often results from the repetitive impact of the inferior articular process of one vertebra on the arch of the vertebra below it (Hu et al., 2008; Plomp, 2023; Waldron, 2020. P. 151). Schmorl's nodes are characterized by the compression of the intervertebral disc by the vertebral endplate, leading to the prolapse of the disc's nucleus pulposus into the adjacent vertebral body (Faccia and Williams, 2008; Waldron, 2020. P. 45). Vertebral compression fractures refer to deformations of the vertebral body, distortion ranging from subtle deformation to substantial collapse, depending on the impact position (Genant et al., 1993). Although clinical research indicates that internal factors may predispose some individuals to these injuries, it also suggests that strenuous activities straining the lower back are the primary external factor of vertebral trauma (Bono, 2004; Swārd, 1992; Waldron, 2020. P. 45).

Thorax and Pectoral Girdle

The thorax and pectoral girdle include the shoulder (scapulae and clavicles), thoracic vertebrae, sternum, and ribs. Vertebral trauma was discussed above, so is not included here. The predominant cause of trauma to the thorax and pectoral region is blunt force. Rib fractures are most frequently linked to high-velocity collisions, falls, and interpersonal violence, with forces from the front or back generating oblique or transverse fractures on the midshaft or posterior ribs (Beshay et al., 2020; Galloway and Wedel, 2014c). In contrast, clavicles have reduced muscular support and are susceptible to injuries at the midshaft (Galloway, 2014a). Clavicular fractures typically result from compression forces during a fall, often accompanied by fracture-dislocations of the upper limbs and/or ribs (Faldini et al., 2010; Judd and Roberts, 1999; Kihlström et al., 2017). Trauma to the scapula primarily occurs in the shoulder joint (glenoid fossa and acromion process), often including dislocations, as the result of indirect forces such as falling onto an outstretched arm (Cole, 2017; Lovell and Grauer, 2019). Fractures of the scapular body and sternum are relatively uncommon among thorax injuries unless subjected to direct, high-energy impacts, usually produced by severe collisions and violent assaults (Cole et al., 2012; Galloway, 2014a; Galloway and Wedel, 2014b; Lovell and Grauer, 2019).

Upper Limb

Arms and hands make up our upper limbs, allowing us to participate in many daily activities. Direct blows can cause transverse or comminuted fractures, often on the humeral or ulnar shafts (Galloway, 2014a; Judd, 2008). The indirect forces generated by the forearm and hand can produce rotational or avulsive fractures and dislocations on the distal and proximal ends of bones, typically resulting from falls onto an outstretched hand or when using the arm to twist vigorously (Galloway, 2014a). As the distal ends of our upper extremities, hands are vulnerable to trauma because of their lower muscle mass and their use in manipulating objects and thwarting impacts on the body (Galloway, 2014a). Metacarpal shaft fractures are commonly incurred in modern populations through punching (Brickley and Smith, 2006), while phalangeal dislocations are usually associated with hyperextension of the palm after a fall, direct blows, or twisting (Chen and Kalainov, 2016). Wrist dislocations are often produced by tensile forces from high-energy impacts, causing hyperextension and dorsal (posterior) compression of the wrist (Apergis, 2013. P. 1).

Lower Limb

Given the density of the large lower limb long bones and the muscle mass of the thigh, leg injuries typically result from high-energy impacts. Severe collision accidents can transmit high-energy rotational forces from the knee to the hip, leading to femoral and pelvic fractures and dislocations (Galloway, 2014b; Lovell and Grauer, 2019; Roca et al., 2012). Lower leg trauma often manifests in the middle and distal sections of the tibia and fibula. Direct impacts, such as from high-velocity collisions, can cause transverse or oblique fractures to the tibial shaft and may extend to involve the fibula (Galloway, 2014b). Distal tibial fractures encompass a range of breaks above and within the ankle complex, frequently associated with rotational and compressional forces experienced in collisions and falls on steep slopes (Lovell and Grauer, 2019). Falls can also cause malleolar fractures, commonly occurring when the foot is anchored to the ground and the body lunges forward, resulting in oblique, transverse, or avulsion fractures and often accompanied by dislocations and ligament injuries (Bowyer, 2017). The feet support and propel our bodies, bearing and transmitting up to ten times our body weight when running and jumping (Bowyer, 2017). Fatigue fractures are the most common traumatic injuries documented on pedal bones, particularly affecting the metatarsals and their joints with the phalanges of the toes (Bowyer, 2017; Welck et al., 2017). Additionally, fractures of the toes and metatarsals are frequently caused by heavy objects falling on the foot, resulting in blunt force trauma (Bowyer, 2017).

Understanding Trauma Analysis and its Limitations

While the ultimate mechanisms behind paleotrauma cannot be definitively known (Judd and Redfern, 2012), the fundamental goal for bioarchaeologists is to consider all potential causes and provide the most plausible explanations. Violent trauma, for example, can be diagnosed through cranial and facial fractures, defence wounds on forearms, and weapon-induced injuries (Alvrus, 1999; Galloway and Wedel, 2014b; Judd, 2006; Lambert and Welker, 2019; Smith and Knüsel, 2014; Sołtysiak, 2017). However, it is often impossible to discern whether individuals with such injuries were simply victims of interpersonal conflict or warfare (i.e., non-combatants), or participants in such events (Judd, 2008). Conversely, accidental injuries are usually identified by avulsion, spiral, and oblique fractures on long bones (Alvrus, 1999; Judd and Roberts, 1999; Cole, 2017; Mant et al., 2021). Such injuries may result from accidents, such as a clumsy misstep, but they can also indicate that individuals were exposed to higher levels of hazardous circumstances, potentially influenced by occupations, social inequality, and structural violence (Alvrus, 1999; Bernbeck, 2008; Bright, 2020; Judd and Roberts, 1999; Lambert and Welker, 2019; Mant, 2019; Scott and Buckley, 2010).

Moreover, occupational trauma is typically diagnosed by injuries caused by repetitive and/or strenuous activities, such as vertebral injuries, fatigue fractures on pedal bones, and specific types of trauma related to the social background, such as animal-related trauma in rural or pastoral populations (Berthon et al., 2023; Galloway and Wedel, 2014c; Glosten, 2015. P. 177-182; Karapetian, 2021; Mansfield and Wroten, 2021; Waldron, 2020. P. 45). It can be challenging to distinguish between trauma arising from exploitation associated with social stratification and that resulting from the burdensome demands of seeking out a livelihood to overcome environmental conditions (Klaus, 2012; Knüsel, 2000). Additionally, these injuries are usually nonfatal, making it difficult to accurately estimate the timing or sequence of these antemortem traumatic lesions if all are fully healed (Judd, 2008). Many other factors, such as aging (e.g., osteoporosis), genetic susceptibility, and malnutrition, can also contribute to injury, necessitating a more prudent interpretation of paleotrauma (Alghamdi et al., 2014; Cunningham et al., 2016. P. 32; Waldron, 2020. P. 118).

3. Case Study - Lake Khuvsgul and Tunka Valley Cemeteries

3.1 Materials and Methods

Can the analysis of paleotrauma help us understand Khitan-Mongol populations from northern Mongolia and the Tunka Valley? Here, we examine trauma on human remains excavated from the cemeteries of Nogoon Gozgor 1, Urd-Khiar 1 and 2, Zun Khiaryn Denzh 1, and Mondy 1 and 5. The first four sites, situated on the northeastern shore of Lake Khuvsgul, Mongolia (Figure 1), were excavated between the late 1990s and 2019 by researchers from Irkutsk National Research Technical University (INRTU) and Ulaanbaatar University (Kharinskii and Erdenebaatar, 2011; Kharinskii et al., 2020; Orgilbayar et al., 2018; Orgilbayar et al., 2019). Common grave goods include sheep bones and iron weapons and tools, and some individuals were found covered with birch bark or placed in wooden coffins (Kharinskii and Erdenebaatar, 2011; Kharinskii et al., 2020; Kharinskii et al., 2023; Kharinskii 2023; Orgilbayar et al., 2019). The Mondy 1 are 5 cemeteries are located on the west-

Fig. 1. Geographical locations of Lake Khuvsgul cemeteries (K) and Mondy 1 and 5 (M) in the Tunka Valley. *Graphed by Google Earth and ArcGIS*

Рис.1. Географическое местонахождение могильников на озера Хубсугул (К) и Монды 1 и 5 (М) в Тункинской долине. *Карта сделана с использованием Google Earth и ArcGIS* ernmost point of the Tunka Valley, Russia (Figure 1), ~20 km northeast of the Khuvsgul cemeteries. The cemetery was excavated in 2020–21 by scholars from INRTU (Kharinskii and Portniagin, 2021). The Tunka Valley served as an important corridor for migrations and trade between the Baikal Region and northern Mongolia since the late Pleistocene (Kozyrev et al., 2014; Losey et al., 2016; Shchetnikov et al., 2019). Indeed, artifacts from Mondy 1 are highly comparable with those from the Khuvsgul cemeteries, implying their close connection in the past (Kharinskii and Erdenebaatar, 2011; Kharinskii et al., 2020; Kharinskii et al., 2022; Kharinskii et al., 2023).

Twelve individuals were excavated from the Khuvsgul cemeteries, while three came from the Tunka Valley. All deceased were interred in burial pits dating to the Khitan-Mongol period, from the mid-11th through 14th centuries CE (Kharinskii and Erdenebaatar, 2011; Kharinskii et al., 2022; Kharinskii et al., 2023). Age at death estimations focused on cranial and palatal suture closure (Meindl and Lovejoy, 1985), traits of the pubic symphysis (Brooks and Suchey, 1990), and iliac auricular surface (Buckberry and Chamberlain, 2002; Meindl and Lovejoy, 1985) and, for non-adults, on skeletal development (Buikstra and Ubelaker, 1994; Schaefer et al., 2009). Sex estimation was mainly based on morphological features of the cranium, mandible and pelvis (Buikstra and Ubelaker, 1994; Phenice, 1969). Of the 15 individuals, 13 were adults (20+ years), and two were post-pubescent non-adults (15–20 years). Four were estimated to be females, eight to be males, and three were undetermined (Figure 2, Table 1). For each individual, bone representation indices were calculated after Dodson and Wexlar (Dodson and Wexlar, 1979). Trauma documentation was macroscopic and non-invasive. Following the guidance of Redfern and Roberts (Redfern and Roberts, 2019), lesion type, location, healing process, and other noteworthy observations were recorded (Table 1).

3.2 Results and Discussion

A total of 39 injured bones (Figure 3A) were identified from 10 individuals, including seven males, two females, and one of unknown sex. One individual was non-adult, one young adult (25–35 years), and eight were middle or older adults (35+ years). Vertebral lesions were the most prevalent, present on all 10 affected individuals. These vertebral injuries included two cases of spondylolysis, four vertebral compression fractures (VCF), and 24 cases of Schmorl's nodes (Figure 3B). No cranial trauma or perimortem injury was identified. Three individuals exhibited trauma in the thorax and pectoral girdle, two having healed clavicle fractures and the third healed fractures to five right ribs. Finally, two individuals had injuries to the limbs, one on the left radius and the second on a right metatarsal.

Given the limited sample size (n=15), discussion will focus on the interpretation of paleotrauma at the individual level. Clear evidence of violence, such as weapon-induced perimortem trauma and defence wounds, was not observed in this study. Historical records suggest that tensions among the tribes of the Mongolian steppe began to escalate in the early 12th century and persisted until 1206 CE, culminating in Chinggis Khan's victory and the establishment of the Mongol Empire (May, 2022; Togan, 2022a; Togan, 2022b). Therefore, the absence of violent trauma in the sample may imply that northern Mongolia and the Tunka Valley experienced less conflict compared to contemporaneous populations further south, and that this relative peace was maintained after the establishment of the Mongol Empire.

The only potentially violent event is suggested by the five fractured ribs of an individual from Urd-Khiar 1 (Figure 4). However, the mechanisms of rib trauma are complex and can result from collisions, falls, interpersonal conflict, and even pathological conditions (Beshay et al., 2020; Brickley and Smith, 2006; Lovell, 1997). Notably, high elevation falls and violent encounters typically result in multiple injuries to the cranium and extremities simultaneously (Judd, 2002; Petaros et al., 2013), a pattern not observed in

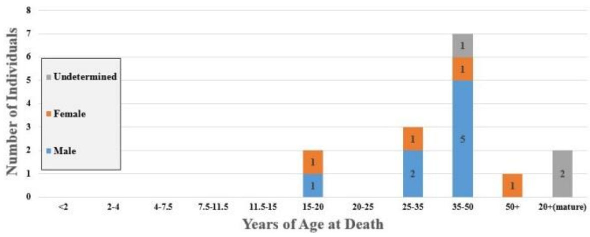

Fig 2. Demographic profile of the Khuvsgul and Tunka Valley cemeteries (n=15)
Рис. 2. Демографические данные по могильникам с побережья озера Хубсугул и Тункинской долины (15 человек)

Table 1. **Bioarchaeological information for the Khuvsgul and Tunka Valley cemeteries**
Таблица 1. **Биоархеологическая информация с Хубсугульских и Тункинских могильников**

Site and Individual/ Burial (B)	**Age at Death (in years)**	**Sex**	**Bone Representation Index †**	**Trauma Documented**
Mondy 1 B.1 (Tunka Valley)	17–20	M	0.51	Six L vertebrae; L6 vertebra: bilateral spondylolysis
Mondy 1 B.2 (Tunka Valley)	20+	*	0.03	
Mondy 5 B.1 (Tunka Valley)	25–35	M	0.32	L clavicle: healed fracture of acromial shaft; one L vertebra: Schmorl's node and compression fracture
Nogoon Gozgor 1 B.3 (Khuvsgul)	20+	*	0.06	
Nogoon Gozgor 1 B.4 (Khuvsgul)	25–35	M	0.55	
Nogoon Gozgor 1 B.5 (Khuvsgul)	45–60	F	0.37	Distal L radius shaft: healed fracture; T12–L1, and L5 vertebrae: Schmorl's nodes
Nogoon Gozgor 1 B.6 (Khuvsgul)	16–18	F	0.26	
Urd-Khiar 1 B.9 (Khuvsgul)	35–50	M	0.79	Five R rib shafts (second rib and four mid-level ribs): healed fractures (bony spurs on three); T8–T11 and L1 vertebrae: Schmorl's nodes
Urd-Khiar 2 B.21 (Khuvsgul)	40–50	M	0.61	L5 vertebra: bilateral spondylolysis; three T vertebrae: Schmorl's nodes
Urd-Khiar 2 B.23 (Khuvsgul)	25–35	F	0.65	
Urd-Khiar 2 B.24 (Khuvsgul)	35–50	F	0.74	R clavicle: healed fracture of acromial shaft; one T and one L vertebrae: Schmorl's nodes
Urd-Khiar 2 B.26 (Khuvsgul)	35–50	M	0.42	C6 vertebra: compression fracture with fusion of C5–7; T7–8 vertebrae: Schmorl's nodes
Zun Khiaryn Denzh 1 B,1 (Khuvsgul)	35–50	M	0.72	T11–12 vertebrae: compression fracture; T12 vertebra: Schmorl's node
Zun Khiaryn Denzh 1 B,2 (Khuvsgul)	40–50	M	0.45	T9 vertebra: Schmorl's node
Zun Khiaryn Denzh 1 B.9 (Khuvsgul)	35–45	*	0.35	R metatarsal 2: healed fracture of proximal shaft; four T and L4–5 vertebrae: Schmorl's nodes

Sex: M, male; F, Female; * undetermined. **†** Bone Representation Index: the absolute presence or absence of individual skeletal elements compared to the number of elements if fully preserved (Dodson and Wexlar, 1979). For example, an index of 1.0 would represent a skeleton with all elements present (though not necessarily complete). Trauma Documented: L, left side; R, right side; C, T, and L vertebrae: cervical, thoracic, and lumbar, respectively.

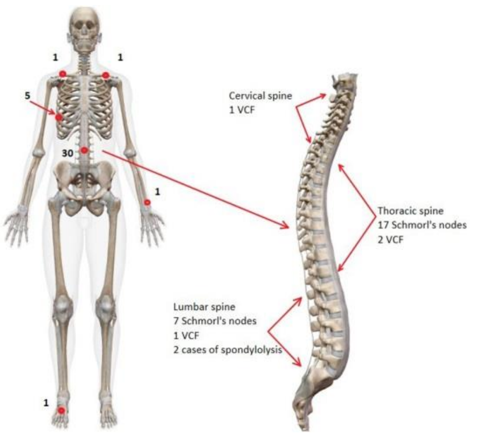

Fig. 3. Locations of observed traumatic lesions within the sample, with number of affected skeletal elements indicated and types of vertebral trauma and their distributions. *VCF: vertebral compression fractures. Images were produced by Visible Body Suite (Version 4.31; 2023). Retrieved July 18, 2024, from www.visiblebody.com*

Рис. 3. Расположение травматических поражений у анализируемых индивидуумов с указанием количества поражений и видов травм и их распределение. *VCF: vertebral compression fractures (позвоночный компрессионный перелом). Рисунок сделан 18 июля 2024 г. с помощью Visible Body Suite (версия 4.31; 2023), www.visiblebody.com*

this skeleton. Therefore, it is more likely that a sudden high-energy collision caused the rib fractures. Given that mounted pastoralism was the fundamental subsistence strategy for the Khitan-Mongol populations, interactions with domestic animals, such as being crushed or kicked by large livestock or falling from a galloping horse, could be responsible for such an injury. Contemporary medical records reveal that strikes and kicks from large livestock are common causes of animal-related injuries, with chest trauma being a frequent consequence (Bury et al., 2012; Busch et al., 1986).

The Urd'-Khiar 1 individual's rib fractures are fully healed, indicating that they occurred at least several months before death. While it's not possible to say whether they reflect one or more traumatic events, three of the four mid-level ribs have two fractures each on the same region of their anterior midshafts, suggesting a single severe occurrence. Rib trauma is often accompanied by damage to the respiratory and circulatory systems, which can lead to difficulty breathing and vascular disruption, resulting in hemothorax and pneumothorax (Brickley and Smith, 2006;

Fig. 4: Multiple healed right rib fractures, Urd'-Khiar 1, Burial 9, anterolateral views. Red arrows indicate fracture calluses. Note that three mid-level ribs each have two fracture calluses on their anterior midshafts (close-up images on the right)
Рис. 4. Множественные сросшиеся переломы правых ребер с Урд-Хяр 1, погребение 9 (антерио-латеральные проекции). Красные стрелки указывают затвердения переломов. Обратите внимание, что середина каждого из трех ребер имеет по два затвердения от переломов на антериальной стороне (изображения крупным планом справа)

Morgan et al., 2022; Oyetunji et al., 2013; Tumler et al., 2019). Medical records indicate that breaking more than three ribs in a single event is usually associated with severe visceral trauma and even death (Shkrum and Ramsay, 2007. P. 428). Therefore, the presence of healed fractures on five ribs—at least three of which may have occurred simultaneously—suggests that this person received considerable treatment and care from others over an extended period.

Lower limb trauma, a healed metatarsal fracture, was observed on only one individual. Injuries in the lower limbs are typically caused by spiral and bending forces resulting from strenuous activities such as jumping, slipping, kicking, and running (Bowyer, 2017; Galloway, 2014b; Lovell and Grauer, 2019; Roca et al., 2012). Archaeological and historical records indicate that horseback riding was a significant aspect of daily life on the eastern Eurasian steppe since the Bronze Age (Eng, 2016; Honeychurch, 2013; Honeychurch et al., 2021; Kradin, 2011; Taylor et al., 2015), with most equestrian injuries today and in the past occurring on the upper body (Anđelinović et al., 2015; Ball et al., 2007; Berthon et al., 2021; Paix, 1999; Wentz and de Grummond, 2009). Therefore, the low prevalence of lower limb trauma in the skeletal assemblage is consistent with mounted pastoralism and may suggest that horseback riding reduced the risk of injury to the lower body. The single metatarsal fracture could be a fatigue injury, resulting from overexercise, or a blunt force injury, such as from a heavy falling object or a large animal hoof (Bowyer, 2017). Both bioarchaeological and modern clinical studies report cases of animal-induced trauma to pedal bones (Lee and Steenberg, 2008; Pedersen et al., 2019; Watts and Meisel, 2011).

Falls are among the most common causes of fractures and dislocations in bioarchaeology and modern medicine (Alvrus, 1999; Lovell, 1997; Lovell and Grauer, 2019; Unguryanu et al., 2020). In this research, two clavicle fractures and one radius fracture were likely caused by falls. The radius fracture, occurring on the distal shaft (Figure 5), is probably a Colles' or Smith's fracture, because of the dorsal angulation of the bone's distal end. Although it is difficult to determine which because bone remodelling has obscured the fracture line, both types are caused by a strong shearing force against the wrist, typically associated with a fall onto an outstretched or flexed hand (Judd, 2008). Clavicle fractures typically reflect compression forces resulting from falls where forces impact the shoulder (Judd and Roberts, 1999; Kihlström et al., 2017). It is possible that these three injuries reflect horseback riding accidents. Falling from a galloping horse will throw the rider forward, making the upper body the first to make contact with the ground. While clavicle and facial fractures are the most common, they are followed by trauma to the forearm (Altgärde et al., 2014; Ball et al., 2007; Berthon et al., 2021; Lee and Steenberg, 2008; Wentz and de Grummond, 2009).

All ten injured individuals exhibited vertebral trauma, with seven of them having more than one affected vertebra. Schmorl's nodes (Figure 6.1) were the most frequent type of injury, affecting 17 thoracic and seven lumbar vertebrae in nine individuals. The etiology of Schmorl's nodes is complex. While genetics, age, vertebral shape, and body weight can predispose certain individuals, the primary cause is repetitive and strenuous movement (Jurmain, 2013. P. 165–167; Plomp et al., 2015; Plomp, 2023). Schmorl's nodes typically occur in the lower thoracic and lumbar vertebrae, with activities involving extensive use of the waist and back muscles, such as lifting, loading, and military training, being direct triggers (Burke, 2012; Waldron, 2020. P. 45; Zhang et al., 2017). Additionally, habitual horseback riding may contribute to the high prevalence of Schmorl's nodes in skeletal samples. Experienced riders lower their center of gravity to maintain balance on a galloping horse, causing repetitive hyperextension and rotation of the lower back and hips. This posture can result in the lower spine bearing around 65 % of the rider's weight, making it susceptible to fatigue injuries, such as Schmorl's nodes (Anđelinović et al., 2015; Berthon, 2019; Berthon et al., 2019; Glosten, 2015. P. 177-182).

Four cases of vertebral compression fractures (VCF; Figure 6.2–6.3)—one cervical, two thoracic, and one lumbar—were observed in three individuals. Similar to Schmorl's nodes, VCF often occur in thoracolumbar vertebrae and have multiple etiologies, including age, sex, and pathological conditions such as osteoporosis. However, high-energy trauma that exerts excessive strain on the spine is the primary external cause (Curate, 2014; Genant et al., 1993; McCarthy and Davis, 2016). Contemporary medical records indicate that osteoporosis is the most common cause of

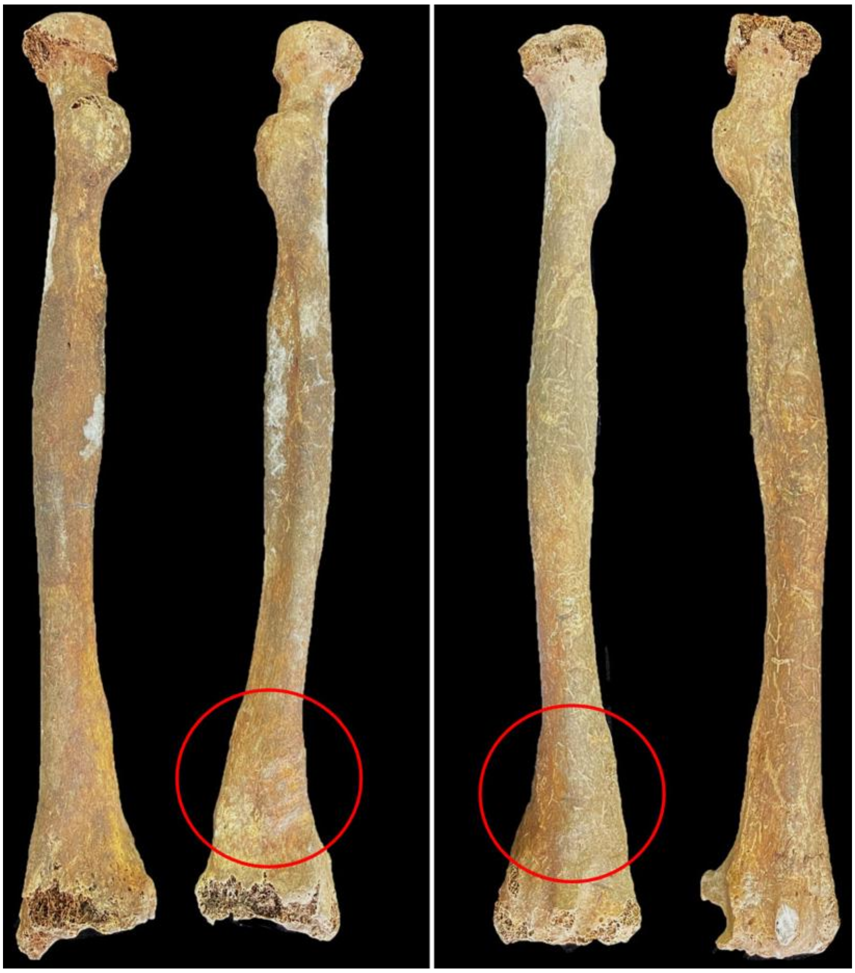

Fig. 5: Anterior (left) and posterior (right) views of the left and right radii of Nogoon Gozgor 1, Burial 5. The left radius exhibits a healed fracture of the distal shaft (indicated by the red circles); the right radius is unaffected
Рис. 5. Антериальный (слева) и постериальный (справа) виды левой и правой лучевых костей с Ногоон Гозгор 1, погребение 5. На левой лучевой кости зафиксирован заживший перелом на дистальной части диафиза (обозначен красными кружками); правая лучевая кость без повреждений

VCF, particularly in females. Among patients younger than 80 years, most VCF result from falls and collisions (Donnally et al., 2023; Hoyt et al., 2020). In bioarchaeology, VCF in non-elderly individuals, especially males, are typically attributed to strenuous activities and prolonged mechanical stress unless relevant pathological conditions are also observed (Jiménez-Brobeil et al., 2010; Kubo et al., 2024; Thomsen, 2022). The three individuals diagnosed with VCF in this research are males aged between 25 and 50 years. Therefore, external forces such as hyperextension, falls, and lifting are more likely to account for the VCF in these cases.

Notably, one case of VCF was observed on the sixth cervical vertebra on an individual with fused C5–7 (Figure 6.3). Cervical compression fractures are rare due to their anatomical shape, low weight bearing, and increased range of motion (Zmurko et al., 2003). Modern clinical reports indicate that most cervical VCF are caused by hyperflexion or hyperextension during falls and collisions (Galloway and Wedel, 2014b; Leng et al., 2010; Okereke et al., 2021; Zmurko et al., 2003). A plausible explanation for this case is a horseback riding accident. An investigation into equestrian injuries revealed that approximately 25 % of riders who sustained head injuries also had neck injuries (Sandiford et al., 2013). The fusion of the vertebrae is likely a complication following the compression fracture, where blood enters the joint and increases the risk of ankylosis (Waldron, 2020. P. 146), or through ligamentous ossification or abnormal new bone formation during the healing process (Klaus and Lynnerup, 2019). It's also possible that certain joint diseases caused the vertebral fusion, whether related to the injury or not (Sieper et al., 2002; Waldron, 2020. P. 57-59).

Finally, two individuals exhibited spondylolysis (Figure 6.4) on the L5 and L6 vertebrae, respectively.

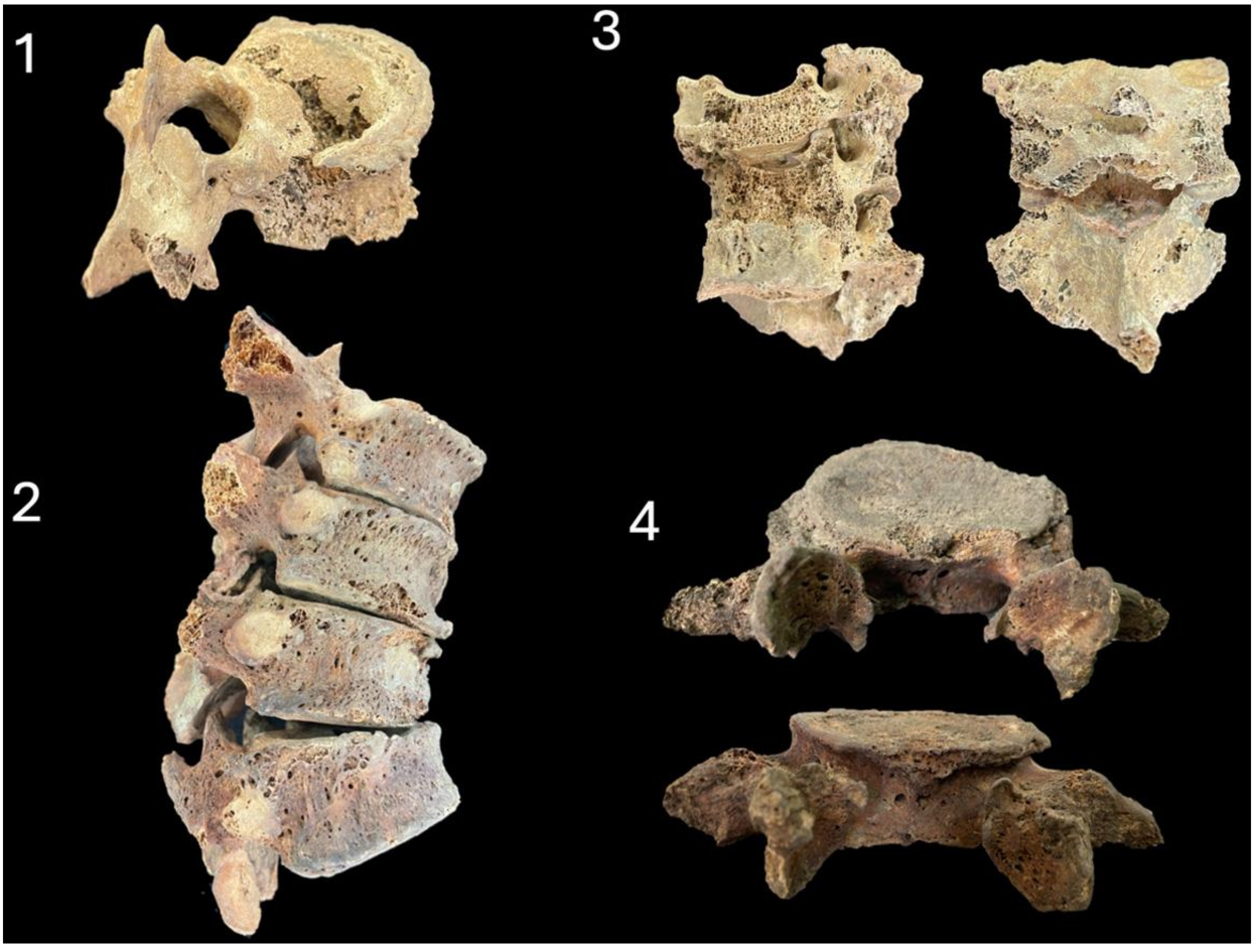

Fig. 6. Examples of vertebral trauma: *1) large Schmorl's node on the superior centrum of T7 vertebra, Urd'-Khiar 2 Burial 26 (right superior view); 2) T9–12 vertebrae, Zun Khiaryn Denzh Burial 1, with compression fracture of T12 (right lateral view); 3) C5–7 vertebrae, Urd'-Khiar 2, Burial 26, with compression fracture of C6 and fusion of C5–7 (anterior left view on left, posterior view on right; 4) L5 vertebra of Urd'-Khiar 2, Burial 21, with complete bilateral spondylolysis and posterior arch missing postmortem (posterior view with superior centrum up in top image and inferior centrum up in bottom image)*

Рис. 6. Примеры травм позвоночника: *1) крупный узел Шморля на верхнем центре позвонка T7 с Урд-Хяр 2, погребение 26 (вид сверху и справа); 2) T9–12 позвонки с Зун Хярын Денж, погребение 1, с компрессионным переломом T12 (вид справа и сбоку); 3) C5–7 позвонки с Урд-Хяр 2, погребение 26, с компрессионным переломом C6 и сращением C5–7 (вид слева и спереди, справа и сзади); 4) позвонок L5 с Урд-Хяр 2, погребение 21, с полным двусторонним спондилолизом и отсутствием постериальной дуги (вид сзади: верхний центр вверху на верхнем изображении и нижний центр вверху на нижнем изображении)*

Spondylolysis is a condition associated with human bipedalism, triggered by repetitive habitual or strenuous movements involving lateral flexion and hyperextension of the lower back (Hu et al., 2008; Plomp, 2023; Waldron, 2020. P. 151). This type of trauma is prevalent across various societies, including agrarian, foraging, and industrialized communities, and can be caused by a wide range of activities (Fibiger and Knüsel, 2005; Lessa, 2011; Karapetian, 2021; Tipper et al., 2023). Although modern clinical research has not demonstrated a positive correlation between habitual horseback riding and spondylolysis (Kraft et al., 2009), falling from a horse can trigger such an injury (Karatas et al., 2016), providing additional explanations for its occurrence.

Additionally, the traumatic injuries discussed above may have been caused by various other labour-intensive activities, including seasonal cultivation and metallurgy, which can be traced back to the first millennium BCE (Honeychurch et al., 2021; Hsu et al., 2020; Svyatko et al., 2017; Wilkin et al., 2020). Construction activities may also contribute to the observed trauma, given that some earlier habitation sites in the central Mongolian steppe began to urbanize into sedentary centers following the establishment of the Mongol Empire in the 13th century CE (Kradin et al., 2016; Erdenebat et al., 2022). These factors should be considered alongside pastoral activities as potential causes of occupation and accidental trauma. Finally, it is worth pointing out that, despite our small sample sizes, males were more likely to exhibit traumatic lesions (7 out of 8, or 88 %) than were females (2 out of 4, or 50 %). This is consistent with both bioarchaeological and clinical research indicating that trauma is more common among males, especially young males, reflecting their more frequent engagement in high-risk activities and occupations (Bono, 2004; Karapetian 2021; Mansfield and Wroten, 2021; Swārd, 1992; Waldron, 2020. P. 45).

4. Conclusion

In summary, this paper reviewed the classification and interpretation of paleotrauma on human remains, demonstrating its value as a tool for better understanding the past. In the case of the Khuvsgul and Tunka Valley cemeteries, results indicate that stress fractures on the spine are the most frequently documented lesions. These injuries likely reflect prolonged and strenuous activities. Pastoralists often engage in habitual horseback riding, long-distance movement, and the repeated construction of temporary camps, which could be the origins of the observed vertebral trauma. Most other injuries were concentrated on the upper body, many being consistent with animal-induced accidents such as from horseback riding. No weapon-induced or other violent trauma was identified, and all acute injuries were healed, suggesting a peaceful social environment and care during convalescence.

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