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SHORT REPORT

An Exceptional Case of Healed Vertebral Wound with Trapped Bronze Arrowhead: Analysis of a 7th–6th c. BC Individual from Central Kazakhstan

S. S. TUR,[a] **S. V. SVYATKO,**[b]* **A. Z. BEISENOV**[c] AND **A. A. TISHKIN**[d]

[a] *Museum of Archaeology and Ethnography of Altai, Altai State University, Barnaul, Russia*
[b] *[14]CHRONO Centre for Climate, the Environment, and Chronology, Queen's University of Belfast, Belfast, Northern Ireland, UK*
[c] *Institute of Archaeology n.a. A. Kh. Margulan, Almaty, Kazakhstan*
[d] *Department of Archaeology, Ethnography and Museology, Altai State University, Barnaul, Russia*

ABSTRACT Projectile injury caused by an arrow shot is a common skeletal marker of interpersonal violence in archaeological populations. The injuries of the spine were usually fatal. Only few reports on healing of the vertebra pierced by flint arrowpoint can be found in bioarchaeological literature. This paper presents an exceptional case of a healed trapped bronze arrowhead wound in the spine of a 7th–6th c. BC elite nomad from Central Kazakhstan. Computed radiography and tomography as well non-destructive X-ray fluorescence spectrometry provide detailed information about the context and mechanism of the injury. Copyright © 2015 John Wiley & Sons, Ltd.

Key words: arrow wound; arrowhead; Central Kazakhstan; Early Iron Age; spine

Introduction

Projectile injury caused by an arrow shot is a common skeletal marker of interpersonal violence in archaeological populations around the world (e.g. Lambert, 1997; Guilaine & Zammit, 2005). Arrowheads embedded in the human bones are generally very difficult to extract (Bill, 1862). If the vital organs were not damaged, the foreign object lodged in the bone usually gets obliterated, indicating total recovery (Wilson, 1901). The injuries of the spine were lethal in most cases (e.g. Rokhlin, 1965; Atkinson & Evans, 1978; Polos'mak & Molodin, 1981; Reuer, 1984; Stork and Wahl, 1988; Etxeberria *et al.*, 1992; Campillo *et al.*, 1993; Armendariz *et al.*, 1994; Schutkowski *et al.*, 1996; Lambert, 1997; Guilaine & Zammit, 2005; Jurmain *et al.*, 2009; Meyer *et al.*, 2009; Silva and Marques, 2010; Vegas *et al.*, 2012). Only few reports on healing of the vertebra pierced by flint arrowpoint can be found in bioarchaeological literature (Wilson, 1901; Jurmain, 2001; Jurmain *et al.*, 2009; Vegas *et al.*, 2012). This paper presents an exceptional case of a healed trapped bronze arrowhead wound in the spine.

* Correspondence to: Dr Svetlana Svyatko, [14]CHRONO Centre for Climate, the Environment, and Chronology, Queen's University of Belfast, Belfast BT7 1NN, Northern Ireland, UK.
e-mail: s.svyatko@qub.ac.uk

Material and methods

The anthropological material comes from kurgan 1 of the Koitas cemetery in Central Kazakhstan excavated in 2011 (Figure 1). Although the grave was completely plundered in ancient times, constructive and stratigraphic features of the barrow suggest that the kurgan belonged to the Early Saka nomadic aristocracy. Only few disarticulated human bones (a vertebra, ribs and fibulae) have been recovered from the filling of the burial pit (Figure S1). They have been accelerator mass

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Figure 1. Location map of the Koitas cemetery.

spectrometry radiocarbon dated to the 791–536 cal BC (UBA-23664; Beisenov *et al.*, in prep.).

Only the body of the vertebra, yet exposing sagittal cut made accidentally during the excavation process by a sharp tool, was available for the morphological analysis [Figure 2(a)]. Two ante mortem injuries can be observed macroscopically – the vertebral body was lodged by an arrowpoint and one rib has a well-defined callus of new bone, which usually forms around the fracture. Computed radiography (CR) and computed tomography (CT) were used for better visualisation of the arrowhead and detailed examination of the injury.

Siding and sequencing of the isolated ribs being essential for determination of the exact location of the chest trauma, and for sex and age estimation of the individual was carried out according the morphological criteria by Dudar (1993), Jellema *et al.* (1993) and Mann (1993) and certain metric dimensions by Hoppa & Saunders (1998), Owers & Pastor (2005) and Cirillo & Henneberg (2012).

Sex and age at death of the individual were determined from the sternal extremity of the fourth rib (Işcan *et al.*, 1984; Işcan, 1985). The estimation of the stature of the individual was based on the length of fibula (Sjøvold, 1990).

In order to evaluate the risk of metal intoxication of the body, chemical composition of the arrowhead was determined by non-destructive X-ray fluorescence spectrometry applying the Innov-X Sistems portable analyzer. Three samples were measured from the arrowhead – two in the pure metal and one in the corrosion crust.

Results

Gross visual examination

It has been determined that the human remains belonged to a man of 25–45 years old, ca. 174 cm tall.

The majority of the ribs have been preserved, excluding right 11th and 12th and left 6th and 10th ribs (Figure S2). The fourth right rib demonstrates an ante mortem fracture.

Obviously, the vertebra shows an anatomical transition between the thoracic and lumbar patterns. The size and shape of the body are similar to those of the lumbar vertebrae. However, the body bears a single large costal facet on each side, extending on to the part of the pedicle [Figure 2(a)–(c)]. As such, the vertebra can be identified as T11 or T12. The two corresponding ribs available make it possible to determine more precisely the position of the vertebra. The left articular facet on the body of the vertebra is congruent with that of the 11th rib head but not of the 12th rib, which suggests that the considered element is T11.

Schmorl's nodes are located in both cranial and caudal vertebral endplates. The vertebra also exhibits slight horizontal lipping on the superior and inferior margins and a large osteophyte along the left anterolateral aspect, which has a characteristic shape of a 'bird's beak', with its free end directed to the nearest intervertebral space [Figure 2(a)].

On the left side of the vertebral body, near its lower edge and under the articular facet, there is a rounded deep cavity (6–7 mm in diameter) with smooth margins of remodelled bone and an end (presumably tip) of the

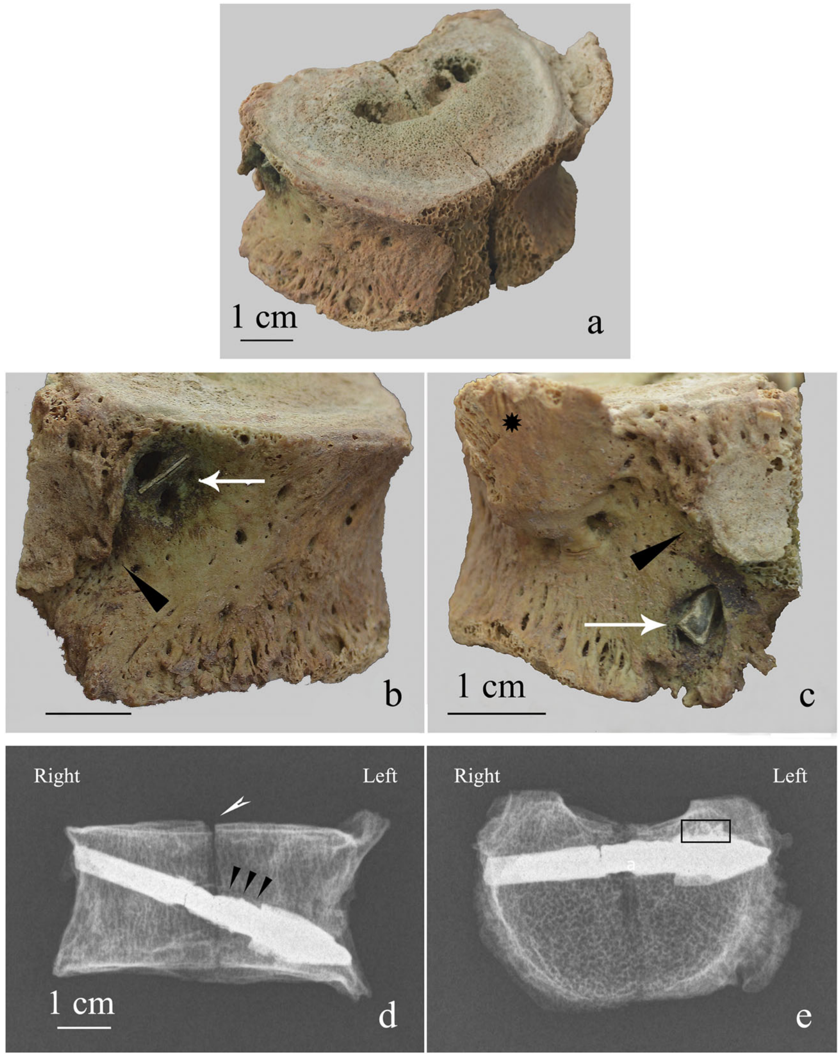

Figure 2. Photographs and computed radiography images of the vertebra from Koitas with trapped bronze arrowhead. Photo: (a) general view of the vertebra (note: the sagittal cut of the vertebra was made accidently during the excavation process), (b) right aspect, healed entrance hole (white arrow), the articular costal facet (black arrow), bar – 1 cm, (c) left aspect, rounded cavity with smooth margins of remodelled bone and protruded tip of the arrowhead (white arrow), the articular costal facet (black arrow) and the large osteophyte (black asterisk). Computed radiography images: (d) anterior-posterior projection, sclerotic reaction adjacent to the arrowhead only appears in a small area (black arrows), post mortem sagittal cut of the vertebral body (white arrow); (e) craniocaudal projection, damage of the warhead can be seen (framed). Figure 2(a)–(c) are available in colour at wileyonlinelibrary.com/journal/oa.

bronze arrowpoint inside. The other end of the arrowpoint is visible in the deepening on the right side of the vertebral body near its upper edge and immediately anterior to the articular facet. It is almost entirely covered with a new bony formation (Figure 2(b) and (c)). From the post mortem sagittal cut of the vertebral body, it also appears that the arrowhead is walled off from the cancellous bone by a thin solid bony layer [Figure 3(a)].

Computed radiography and tomography

The CR confirmed that the arrowhead pierced the vertebral body from right to left and from above (approx. at 21° angle), close to its dorsal surface. Clearly, it consists of a warhead, possibly damaged, and a tang. No osteolytic lesions related to the object are detected from the radiographs. The thin sclerotic rim immediately adjacent to the arrowhead is badly visible also [Figure 2(d) and (e)].

Computed tomography scans demonstrate that the warhead is triangular in cross section with its edges rolling in the narrow blades, and the tang, relatively wide and circular near the warhead, gradually tapers and flatters towards its free end [Figure 3(b) and (c)]. The arrowhead has the total length of 56 mm and the maximum diameter of 10 mm. The CT images further

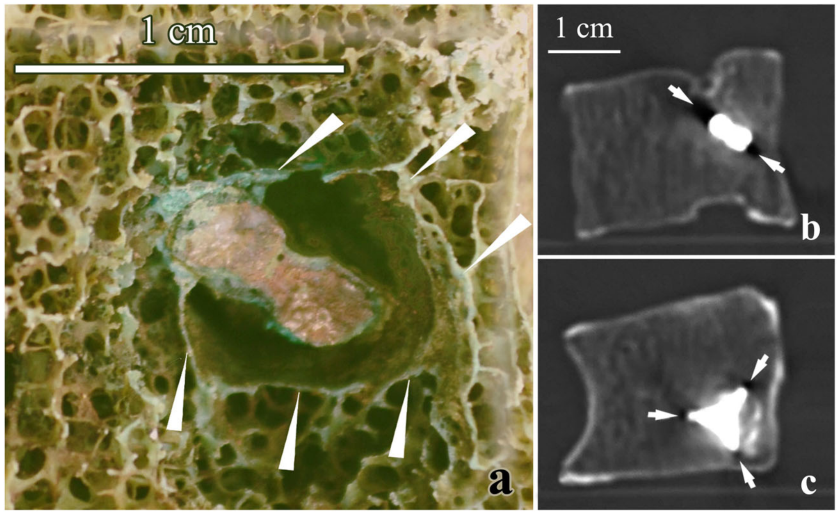

Figure 3. Photograph and computed tomography images of the vertebra from Koitas with trapped bronze arrowhead. Photo: (a) sagittal post mortem cut of the vertebral body (white arrows show cavity and sclerotic rim around the arrowhead). Computed tomography images of cross sections of the arrowhead: (b) tang and (c) warhead; common metal artefact is mostly due to beam hardening, producing dark streaks along the lines of greatest attenuation (arrows) and bright streaks in other directions (Boas & Fleischmann, 2012). Figure 3(a) is available in colour at wileyonlinelibrary.com/journal/oa.

show that the very point of the warhead is broken, and the outer layer of the warhead flakes off in some places [Figure 4(a)]. Graphical reconstruction of the arrowhead was made based on the CT scans [Figure 4(b)].

Archaeologically, the arrowhead is dated to the second half of 7th–first half of 6th c. BC (Čugunov *et al.*, 2010).

X-ray fluorescence spectrometry

The results of X-ray fluorescence analysis indicate that the arrowhead is made of copper alloy with high tin content; lead and iron, being impurities, constitute in average 0.12 and 0.23 wt%, respectively (Table 1); no presence of other elements has been detected. The outer corroded layer consists of pure copper (99.85%) with traces of iron (0.15%).

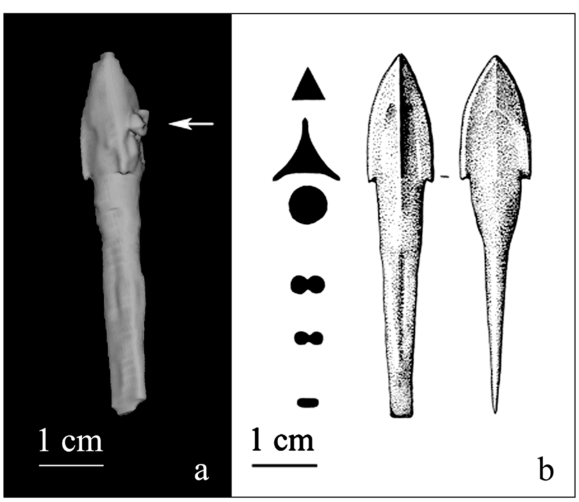

Figure 4. The arrowhead lodged in the vertebra: (a) computed tomography generated 3D model, damage of the warhead can be seen (white arrow); (b) graphical reconstruction based on computed tomography cross sections (by A. L. Kungurov).

Discussion

The penetrating and destructive effect of a projectile depends primarily on its velocity, weight and design. The arrowhead lodged in the thoracic vertebra of the individual from the elite kurgan of the Koitas cemetery belongs to a military form – it is made of bronze with high level of tin, which is hard and can produce very sharp blades, and has widening of anterior part of the tang, increasing the kinetic energy and, consequently, the penetration power of an arrow.

Removing arrowheads was often a difficult task, partly because of the construction of the arrows. The tanged arrowhead usually fit into a slot at the end of the shaft and was tied with narrow animal tendons and sinews. When the arrow penetrated the body, the

Table 1. Chemical composition of the arrowhead

Sample no.	Cu (wt%)	Sn (wt%)	Fe (wt%)	Pb (wt%)
1	80.98	18.74	0.23	0.05
2	78.99	20.61	0.22	0.18
3	99.85	0	0.15	0

tendon got wet from its contact with blood and other bodily fluids and was lengthened, as a result of which, the arrowhead would become loosened and readily detached. It was left within the victim's body if the shaft of the arrow is pulled out (Bill, 1862).

As CT scans have shown, the warhead was damaged. It was probably broken by the contact with the bone at the moment of an impact. Although high-tin alloy can produce very sharp blades for cutting the soft tissues, the downside is that it tends to be more brittle at the hit in hard tissues. Mechanical damage of the warhead appears to have accelerated the corrosion of metal, which usually occurs *in vivo* (Jacobs *et al.*, 1998).

Arrow wounds to the thoracolumbar spine are at risk for life-threatening damaging the heart, lungs, major blood vessels and bowel. They were usually fatal because of immediate massive haemorrhage or subsequent peritonitis. The incidence of septic complications was significantly higher in the lumbar spine than in thoracic one. The pathway of an arrow within a body is important – if a projectile perforates hollow viscus before entering the spine, there is a higher risk of developing secondary spinal infections (Romanick *et al.*, 1985; Isiklar & Lindsey, 1998; de Barros Filho *et al.*, 2014). Besides, bacteria could be further carried into the wound by contaminated arrowhead itself. In the analysed case, the arrow might have penetrated the lower part of the right lung. Medical experience suggests that, when arrow penetrates the lung, if a patient luckily avoids internal haemorrhage leading to almost immediate death, and if the arrowhead is not lodged in the lung tissue, the prognosis is favourable, as the consecutive inflammation is not severe (Bill, 1882).

As expected, the arrowhead embedded in the vertebra induced an inflammatory reaction that led to a resorption cavity associated with peripheral sclerotic formation (osteomyelitis). However, the cavity surrounding the foreign body can only be observed visually on the sagittal cut of the vertebra. Both CR and CT failed to identify the bone injury as cavitation. Unfortunately, at presence of metallic foreign bodies, CT images are often obscured by artefacts and conceal details (Boas & Fleischmann, 2012). The entrance hole on the right side of the vertebra was affected by the sclerotic healing process, whereas the opening on the opposite side appeared as a drainage sinus. The inflammatory reaction may have occurred in response not only to mechanical irritation and bacterial contamination of the arrowhead but also to its corrosion product (Roy *et al.*, 2012).

Metal projectile retained within the body can lead to both systemic and local intoxication of tissues. The location of the projectile is crucial. Animal studies have demonstrated that copper can cause a severe local necrosis of both brain and spinal cord tissues but only if located intradurally (Cushid & Kopeloff, 1968; Tindel *et al.*, 2001). A number of cases of systemic lead poisoning, also known as plumbism, have been reported in the medical literature for patients with retained bullets in the spine (Machle, 1940; Linden *et al.*, 1982). Bullet in close proximity to facet joints or the intervertebral disc is more likely to develop this complication (Machle, 1940; Grogan & Bucholz, 1981). However, low lead concentration in the copper alloy of the analysed arrowhead, as well as its location in the vertebral body without contact with the spinal cord, seems to have excluded the risk of metal intoxication in the individual from Koitas.

Besides the arrow wound of the spine, the analysed individual also demonstrated a well-healed fracture of the fourth right rib. These traumas could have been suffered at the same or different times. Rib fractures may result from accidents during daily activities or interpersonal aggression (Lovell, 1997).

Conclusion

The cause of death of the individual from an elite burial of the Koitas cemetery cannot be securely established; it may have no association with the vertebral wound. As an evidence for the fact that a person can live with a trapped arrowhead in their body for a long time, an interesting case, documented in the medical literature, may be brought. A chief of the Kiowa Indians, wounded by an arrow, quickly recovered and, in few weeks, was able to go for a buffalo hunting without any inconvenience, yet with the iron arrowhead still remaining in his torso. He had sought medical help only 6 years later at least, and the foreign body was extracted (Bill, 1882; Wilson, 1901).

More archaeological cases of healed wounds with arrowhead lodged in human bones need to be described in details in the bioarchaeological literature.

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