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ORIGINAL PAPER

# A scientific analysis of cranial trepanation from an Early Iron Age cemetery on the ancient Silk Road in Xinjiang, China

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**Abstract** This study uses multiple scientific methods to analyse a case of trepanation from a cemetery located at the westernmost point along the ancient Silk Road in China dating back to the Early Iron Age. The skull of interest belonged to a middle-aged male; the opening is located on the left posterior side of the skull in the occipital bone. Computer tomography (CT) and microscopic observation show that the incision was unhealed, indicating an immediate death either during or after the operation. The procedure of trepanation might have been used to treat a depressed fracture from inflicted trauma on the individual's right parietal bone, suggesting the presence of surgical trepanation in early Western China.

**Keywords** Trepanation · Computer tomography · Early Iron Age · Silk Road · China

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## Introduction

Trepanation is a worldwide cultural tradition that has been practised for more than 5000 years, continuing until modern times (Lisowski 1967; Campillo 1984; Arnott et al. 2003; Weber and Wahl 2006; Han and Chen 2007; Han et al. 2007; Goodrich 2013, 2014, 2015; Brothwell and Sandison 1967; Roberts and Mckinley 2003; Rose 2003; Zanello et al. 2015). Trepanation was first discovered and identified in 1865 by E. George Squier, in Cuzco, Peru and later studied by Paul Broca, a neurologist famed for his investigations on trepanation (Broca 1867a, b; Finger and Fernando 2001; Andrushko and Verano 2008; Verano and Finger 2010). Later, examples of the practice of trepanation have been discovered in Europe, South America, Africa and Asia (Tello 1913; England 1962; Lisowski 1967; Campillo 1984; Zias and Pomeranz 1992; Weber and Wahl 2006; Han and Chen 2007; Han et al. 2007; Lv et al. 2013). In recent times, trepanations are still practised among several traditional ethnic groups from around the world, including Africa, several islands in the South Pacific and South America (Bandelier 1904; Hilton-Simpson 1922; Margetts 1967; Furnas et al. 1985; Bastien 1987; Mueller and Finch 1994). Both ante-mortem and post-mortem trepanations have been performed throughout history. Based on anthropological and ethnological evidence, there are two prevailing hypotheses regarding the purpose of trepanation: therapeutic after injury or ritual after death (Capasso and Tota 1996; Han and Chen 2007; Moskalenko et al. 2008).

In China, about 30 trepanation cases have been found from 15 archaeological sites ranging from 5000 to 2000 BP. All the individuals were found in normal cemetery burials with no indication of special or different social status. These trepanations can be divided into two broad categories: with and without healing margins. Cranial traumas have been observed in skulls of both types of trepanation, indicating that the

trepanation may be related to the therapeutic purpose despite some attempts failed (Han and Chen 2007; Han et al. 2007). However, historical record of the culture of these peoples and their medical knowledge is sparse (Zhang 2016; Ding 2011). The limited historical documents reveal that the ancient populations in Western China had been aware of trepanation as a surgical procedure for long. They not only recorded the trepanation in ancient Rome but also had primal methods in bone injury treatment (Yishakejiang 2005). The specimen, found from a cemetery at the Bietebasitao site and first reported by Linhu Zhang (Zhang 2016), is described and investigated in this study. It represents a case of trepanation from the westernmost point along the ancient Silk Road in China dating back to the Early Iron Age and offers a rare opportunity to learn about ancient customs and practices at that area.

The Bietebasitao site where this specimen was discovered is located in Nilka County, Ili, Xinjiang (Fig. 1). Historically, the site had abundant water and pasture and was an important settlement along the Silk Road. Between April and October 2003, during the preparation for the construction of a hydropower station on the Kax River, the Institute of Cultural Relics and Archaeology of Xinjiang conducted an excavation in the area (Zhang 2016). The site is located on the south bank of the Kax River. The tombs in the cemetery were built as either a single large mound or a mound surrounded by stones, and the vast majority of the tombs contained a single individual. The burial objects consisted of ironware, bronze ware and pottery, as well as metallic tools with knives and awls being the most common forms (Liu et al. 2004).

## Materials and methods

The specimen coded as YNBM: 53B with an opening on the rear of the cranium is preserved at the Research Centre for Chinese Frontier Archaeology at Jilin University, Changchun, Jilin, China. Carbon dating was conducted on a human phalanx and provided a date of 2170 ± 30 BP (Beta-409782) using the IntCal13 calibration curve (Ramsey 2009; Reimer et al. 2013). The dating result is in accordance with the archaeological cultural characteristics and falls within the Early Iron Age in Western China (Han 2007; Ding 2011; Tuohuti 1999).

The sex and age of the individual are determined based on the skeletal remains using the pubic symphysis, innominate and cranium (Brooks and Suchey 1990; Buikstra and

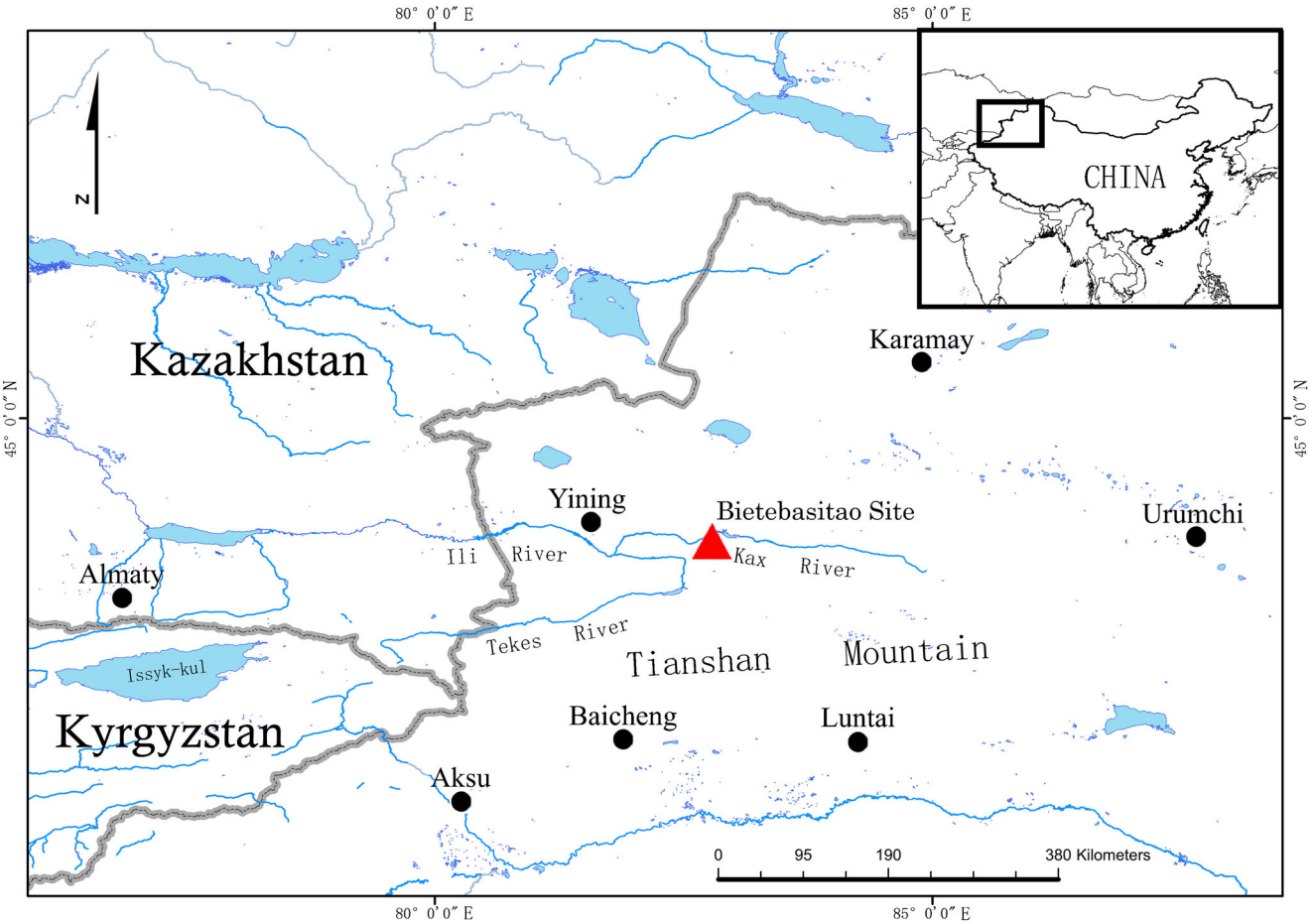


**Fig. 1** Geographic location of the Bietebasitao site

Ubelaker 1994). The cranium was examined using various scientific techniques. Macroscopic observation focused on the shape, dimensions, location and state of preservation. Microscopic observation focused on the edges and cut marks on the margin of the opening, attempting to detect the extent of healing, if any. The detail of the trepanation was observed directly using a three-dimensional deep-field microscope (VHX-2000 series, Keyence, Japan). In addition, computed tomography (9500 CBCT, KODAK, Japan; SOMATOM Sensation 64, SIEMENS, Germany) scan was used to obtain bone radiopacity for differentiating new bone from old and to obtain intracranial situation.

## Results

### General observations

The skeletal remains were nearly complete. Overall, various skeletal indicators, such as pubic symphyseal morphology, dental wear and cranial features, suggest that the individual is male and approximately 35 years old at the time of death.

The trepanation is located primarily on the left side of the squama occipitalis (*planum occipitale*), immediately below the highly fused lambdoid suture, with a small portion and surrounding cut marks crossing the midline (Fig. 2). Moreover, there is a roughly circular dark depressed fracture on the right parietal. The centre of the indentation is 41.2 mm from the coronal suture and 63.1 mm from the sagittal suture.

### A macroscopic observation of the trepanation

The trepanation is approximately rectangular in shape, with the longer sides running supero-inferiorly. The left long side is rugged and the right long side is slightly curved. The rectangular dimensions of the opening are 39.9 mm (superior–inferior) by 22.8 mm (medial–lateral), with an area of approximately 858 $mm^2$. Multiple deep, linear unremodelled grooves are visible on both the left and right sides of the ectocranial surface which may be related to the removal of the scalp. On the left side of the trepanation, there is a superficial removal of the ectocranial cortical bone, with dimensions of 15.3 mm × 6.8 mm. The open diploë on the superior, left and right sides are perpendicular to the edge of the opening, while there are some smooth sections, probably left by some kind of polishing process. While on the inferior side, a triangular-shaped endocranial defect can be observed instead of the perpendicular section. This may be due to that the uplift of the bone plate because of a leverage point which is the only notch on the section is found on the edge of the opening diagonally to the endocranial defect (Figs. 3 and 7).

### A microscopic observation

Microscopic observation provided additional detailed information. On the section towards the cranial base, the


**Fig. 2** Location of the opening on the skull. The opening in the cranium is located primarily on the left side of the squama occipitalis, with a small portion and surrounding cut marks crossing the midline. The depressed fracture was visible on the right parietal bone


**Fig. 3** Macroscopic observation of the opening. The trepanation is approximately rectangular in shape. Extra cut marks are visible on both the *left* and the *right sides* of the ectocranial surface

bone is thinned to a 2.42 mm thickness, and the ridge of the opening is sharp and distinct (Fig. 4). There are no apparent healing signs normally observed post-fracture/post-operation, such as tiny bony spurs or a smoothed, rounded bone surface. The defect presented sharp margins, and the porous diploë is visible around the edges. According to previous research on injuries and similar interventions, signs of bone healing and regeneration can appear within 1 week of the injury (Nerlich et al. 2003; Barbian and Sledzik 2008). The grooves surrounding the opening are vertical and unremodelled, showing no sign of bone healing, which suggested that the individual died immediately after the grooves were made. In addition, sharp and distinct crevices are observed on the depressed fracture area, another indication of the lack of healing (Fig. 5).

## CT scanning

The CT scan imaging analysis from the bone radiopacity confirmed both the characteristic cuttings and that there is no new bone growth on the edge of the lesion (Fig. 6). Sharp margins of defect can be seen with no bone regeneration. The usual irregular and more radiolucent bone reconstructions at the margins of the aperture that demonstrates the healing process are not observed. The cut angles are measured on the CT image, and most of the cut angles around the edges of the hole are near 90°. While on the inferior side, the unhealed lifted bony chip can be observed on the surface of the endocranial defect. The additional three-dimensional reconstruction methods provided three-dimensional pictures that made it possible to observe the endocranial defect (Fig. 7) and show that the right side of the trepanation is almost on the midline of the

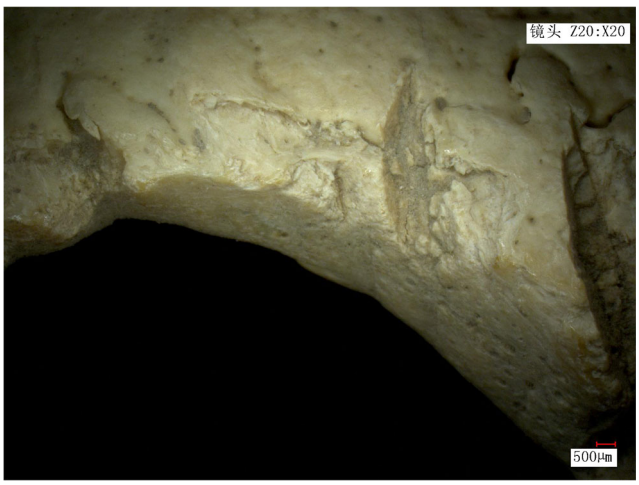


**Fig. 4** Margin of the opening with no apparent healing signs. Sharp and distinct margins of the opening with no apparent healing signs seen post-fracture/operation, for example, tiny bony spurs or a smooth, rounded bone surface

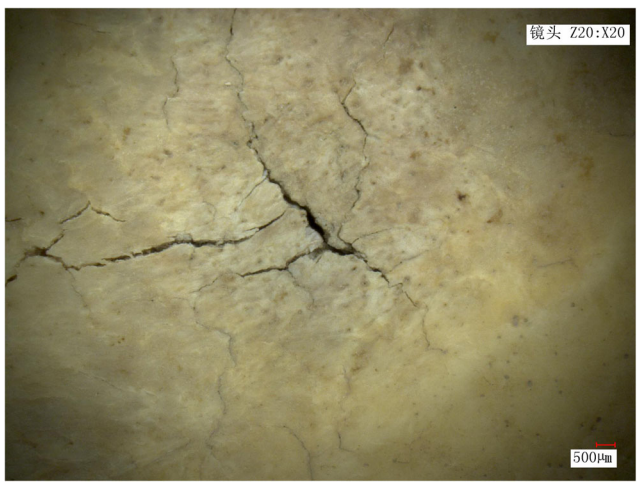


**Fig. 5** The depressed fracture in the right parietal bone. Sharp, distinct crevices can be observed on the depressed fracture area without signs of healing

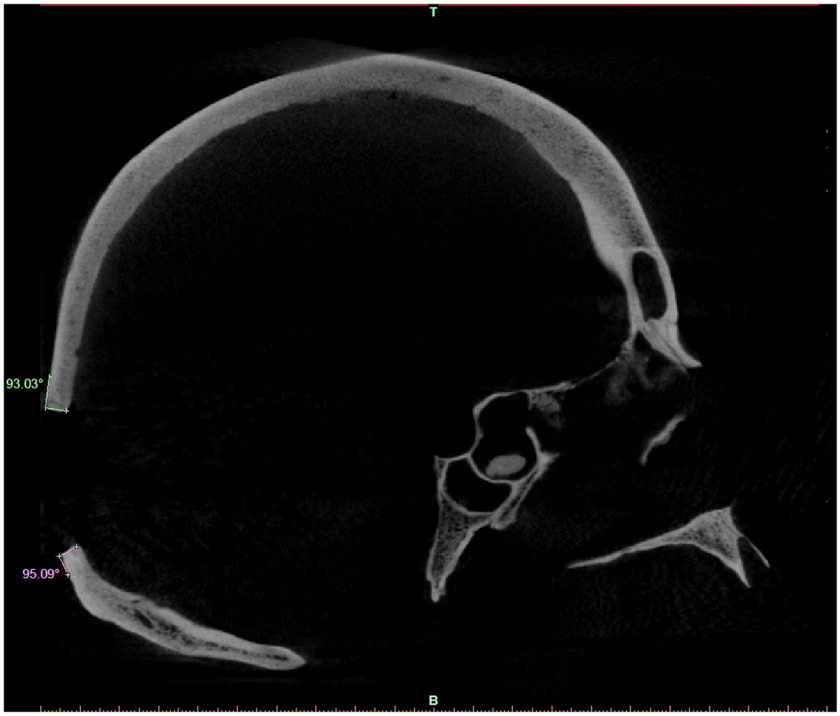


**Fig. 6** Parasagittal view of the skull passing through the perforation in CT images. The margin on the CT image shows no signs of the process of osteogenesis and the growth of new bone tissue

squamous part of the occipital bone where it is close to the superior sagittal sinus.

Moreover, the bone fractures caused by a strike to the right parietal involved the entire thickness of the cranial wall and are visible in CT images (Fig. 8). From the coronal, sagittal and axial views, a less radiopaque triangular area appeared as darker colour can be observed. Fractures are normal to the surface, either breaking both the cortical and diploë layers or running parallel to the surface within the diploë, thus implying a potential blow to the intracranial tissues. The indentation is also visible in the internal surface of the right parietal as seen in the 3D rendering of the CT images (Fig. 9). Given such a traumatic event, it is likely that the middle meningeal arteries would have raptured, causing an intracranial haematoma.

## Discussion

### A case of unsuccessful trepanation after a trauma

Little is known about trepanation practices in historical populations living in Xinjiang, Western China. This is the first

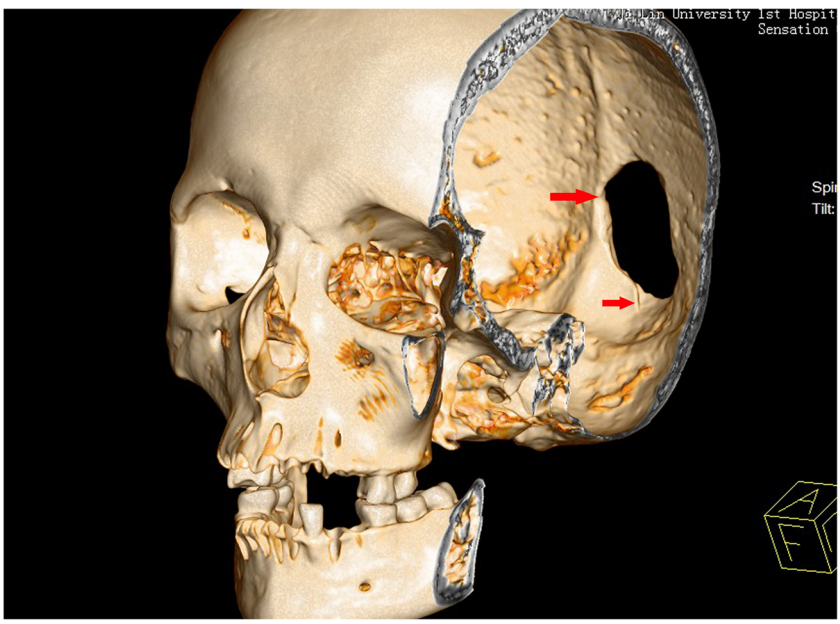


**Fig. 7** Three-dimensional reconstruction of the skull. The perforation is located in the postcranial fossa above the groove of the transverse sinus, slightly lateral to the groove of the superior sagittal sinus

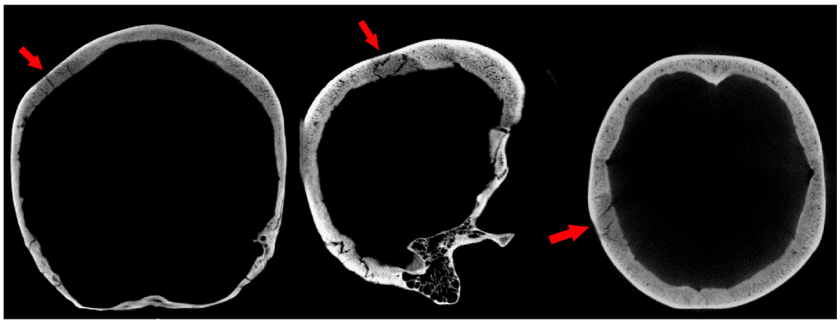

**Fig. 8** The transverse section of the skull viewed from coronal, sagittal and axial view (*left* to *right*). Fractures are visible in the right parietal bone, breaking both the cortical and diploë layers

known human cranium with an obvious sign of trepanation from Western China during the Early Iron Age. The dimensions and morphological features of the opening on the skull indicate that the perforation is intentional. The edge of the defect shows a clear form and definite shape, suggesting the intentional removal of bone. The operation could have been performed by an incision with a type of sharp metal instrument that was frequently discovered among the burial objects (Fig. 10).

Second, the bone healing process following trepanation can be described as the closing of the diploë, the smoothing of the margins and the occasional development of osteophytes or bone spicules (Lisowski 1967). However, no indicators of healing were clearly observed in this skull. The fresh appearance of the cuts and the exposed spongy bone along one margin of the opening, along with a lack of porosity or necrotic bone around the margins of the opening, suggests that the patient did not survive the surgery or died shortly thereafter. Moreover, the dark depressed fracture area is due to the blood infiltrated into the bone tissues as the result of diploë bleeding and peri-osteal vessels damage when the strike occurred, which is often associated with haematoma. This is an important criterion in the confirmation of peri-mortem damage (Huo and Liu 1994; Zhang and Liu 1990).

There are several possible explanations for why the trepanation was unsuccessful. First, the opening is not of a shape often observed in other successful cases, in which the opening of the external cortical layer is wider than the opening of the internal cortical layer, indicating an "unconventional" operation. In most of the rim, the wall is nearly vertical. However, in the inferior rim, there is a bony chip of the internal cortical bone with a triangular shape that is detached from the skull, and a bony chip at the left side of the external cortical bone is also lost. Additional cutting marks on the right side can be obviously observed. Second, the trepanation site is not often observed in the practice of trepanation. Normally, the site is away from the trauma site, which is also the case in the procedure described here. However, the trepanation location is often the left parietal bone (Verano 2003), and the opening site in the occipital bone is not often observed. Moreover, the operation site is too close to the superior sagittal sinus, a very dangerous location to conduct a trepanation on a living

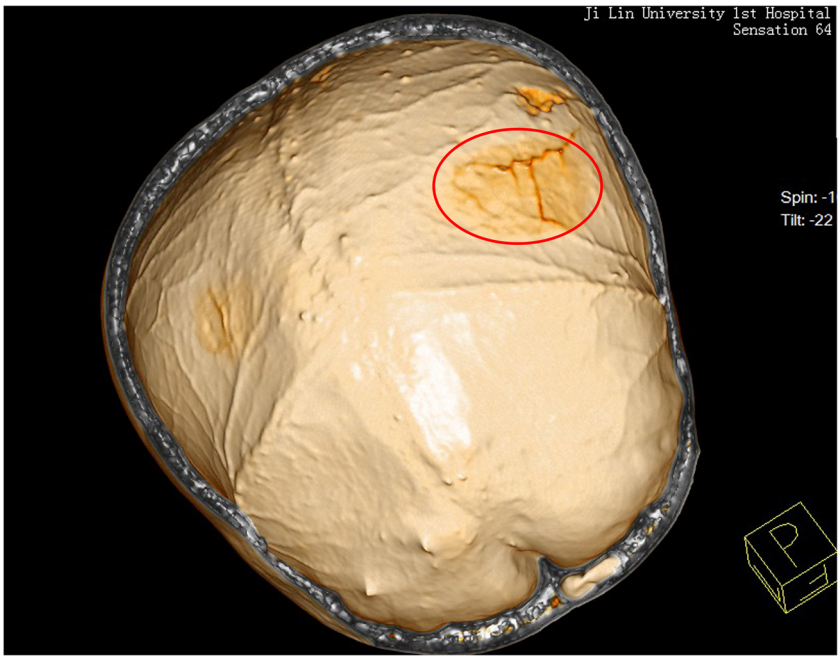


**Fig. 9** Visible fractures from the reconstructed intracranial view

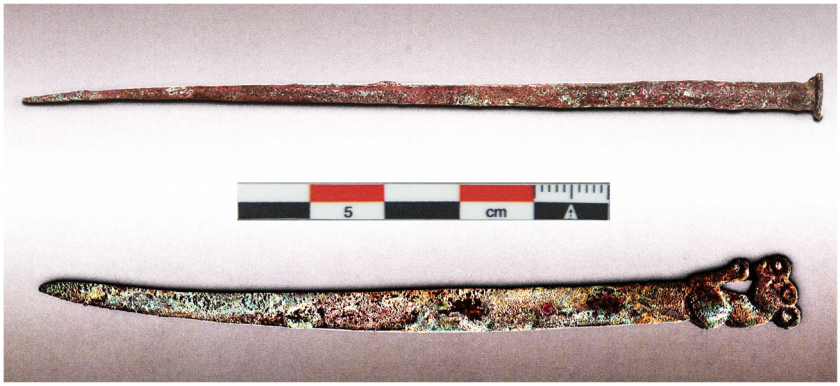


**Fig. 10** Common awl and knife discovered from this region. These two tools were discovered separately from Hutubi Shimenzi Cemetery and Changji Nuerjia Cemetery in Xinjiang during the Early Iron Age

person. All of these characteristics might indicate a botched operation, leading to unintended damage to intracranial structures and causing immediate death.

## The motive for trepanation

The motive for trepanation can be deduced from various features of the skull. Based on evidence from other regions, trepanation may serve therapeutic and ritual purposes (Alt et al. 1997; Capasso and Tota 1996; Moskalenko et al. 2008; Standen and Arriaza 2000; Horsley 1888; Clower and Finger 2001). In the present case, a lack of healing around the opening may be due to death either during or soon after the trepanation (Kaufman et al. 1997). Considering the existence of an unhealed blunt force blow to the right parietal bone and bone fracture, the trepanation is most likely a result of surgical intervention carried out to treat discomfort inside the cranium incurred by trauma, such as coma or intracranial haematoma. The conclusion that trepanation is a surgical practice, albeit an unsuccessful one, is based on several pieces of evidence.

First, many trepanned specimens yield evidence of bone fracture on or near the locations operated upon (Steinbock and Stewart 1976; Erdal and Erdal 2011). The frequent co-occurrence of skull fractures and trepanations has been noted worldwide, especially in the early studies of Peruvian trepanned skulls (Tello 1913; Hrdlicka 1914; Verano and Finger 2010). In a study based on the largest-ever sample of central highland Peruvian trepanned skulls, 26.2% of 457 trepanations were directly associated with visible skull fractures, thus indicating a high incidence of trepanation as a kind of surgical intervention to treat head trauma (Verano 2003). In addition, modern ethnographic examples from the Kisii of Kenya show that patients with recurring headaches continue to receive multiple trepanations as treatment (Furnas et al. 1985). Therefore, it makes sense to suppose that in ancient times, trepanning was performed to relieve intracranial pressure following skull fractures (Moodie 1929; Popam 1954; Jorgensen 1988; Rifkinson-Mann 1988; Verano 2003).

Second, there are both practical and documentary evidences of medical treatment in China since the Neolithic Age. At least six successful clinically trepanned cranial specimens from five Chinese archaeological sites ranging from 5000 to 2000 BP have been studied (Han and Chen 2007). Among the specimens, the borders of the openings are relatively smooth and the growth of tiny bone spurs is observed, which indicates that the individuals had lived for a while after the trepanation. Moreover, signs of bone fracture and trauma can be observed on or near the trephine, which supports the hypothesis that the trepanation was performed for a therapeutic purpose (Han et al. 2007; Lv et al. 2013). The ancient Roman records of trepanation for treatment in ancient Chinese documents indicate that ancient Chinese people were aware of and understood the principle of trepanation. Moreover, procedures for fracture treatment played an important role in the ancient Western medical category—Uyghur medicine. The ancient western populations had a rich experience in orthopaedics treatment; the protocols are still used in modern times (Yishakejiang 2005). There are no signs connecting this case to a post-mortem trepanation for ritual purposes. Empirically, a lack of healing around a trephine may relate to both peri-mortem and post-mortem behaviour. In Western Europe, some of the trepanations described by Prunieres are thought to be practised post-mortem to obtain bone rondelles. Prunieres gathered some of these crafted rondelles and postulated that they most likely served as amulets or good luck charms (Prunieres 1874). Indeed, pieces of skull rondelle also have been found archaeologically—sometimes they remain associated with the skull, but more commonly, they appear as perforated amulets, which indicate that some trepanations are related to magical/religious purposes (Piggott 1940; Verano and Finger 2010). However, no single piece of crafted rondelle has been found in any archaeological sites in Xinjiang or throughout China nor were there no other trepanation cases found in this huge cemetery, suggesting that the practice of post-mortem trepanation was not a common cultural custom in ancient China; rather, like in the current case, it was most probably related to the trauma treatment on some occasional discoveries.

## Conclusion

The case presented here showed an opening on the skull that demonstrated the practice of trepanation after a head trauma. However, there is no apparent healing signs post-fracture/operation, suggesting that the individual did not survive the trauma of the trepanation. The case of trepanation is the first scientific analysis using advanced imaging techniques. It presents clear evidence that the operation was performed by human hands to a victim of head trauma. Though not successful, this discovery suggests an important therapeutic trepanation tradition in the region along the ancient Silk Road dating back to the Early Iron Age in Western China.

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