Trepanations in the population of the Altai Mountains in the Vth—IIIrd centuries B.C.

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The history of trepanations beginning with the Mesolithic (10—12 thousand years ago) is known by means of findings in various parts of the world. The article describes three cases of intravital trepanation of skulls from the Pazyryk Culture graves in the Altai Mountains that had existed from the end of the 6th to the beginning of the 2nd century B.C. In two cases, trepanations were performed so skillfully that the operated patients had survived for a long time after the surgery, which was confirmed not only by microscopy but also by MSCT of the skulls. The article establishes causes of surgeries performed, reconstructs the technique of surgical manipulations, and evaluates them in terms of modern medicine. A comparative analysis of ancient trepanations performed by healers of different archeological cultures is provided. It is concluded that prehistoric cranial surgeries in the Altai Mountains had been performed for curative purposes.

Keywords: *neurosurgery, trepanation, skull injury, archeology, Pazyryk Culture.*

Traces of surgical intervention on the human head have been observed for a long period of human history [12], since at least the Mesolithic or the Early Neolithic (10—12 thousand years ago). Not all ancient manipulations can be considered as neurosurgical ones, i.e. aimed at operative treatment of diseases of the nervous system. In part, they might be related to the rituals, through which the operated person reached the altered states of consciousness required for religious and magical activities, because it is possible that behavior deviations observed after skull injuries were considered by the ancients as a manifestation of "divine madness". From this point of view, trepanation had to promote the emergence of new properties and qualities in a healthy, but specially chosen for some reason person [4]. Nevertheless, it should also be assumed that the main purpose of intravital trepanation was treatment of injuries and elimination of neurological symptoms in human patients.

The term "trepanation" is commonly understood as the process of removing a piece of the skull of a living person without damage to the skull contents [9, 17, 21, 32].

Interest in prehistoric trepanations arose as early as 1865, when Ephraim George Squier (an archeologist, ethnologist, and the representative of the United States in Central America) brought, from graves of the Incas in Peru, a skull with four incisions performed in the right half of the frontal bone perpendicularly to its surface that formed a rectangular opening of approximately one half inch in area [11]. Distinct signs of healing of the opening edges were observed that indicated the patient's survival, at least for a few weeks after the surgery. While this fact was confirmed by the famous French physician, anatomist and anthropologist Paul Broca, very few people believed in the possibility of successful trepanation under conditions of primitive ancient medicine [17, 24]. In addition to technical complexities of trepanation, the "surgeon" needed to provide effective anesthesia, control of bleeding from the amply perfused scalp soft tissues and bone as well as to prevent the development of wound infection. For example, even in the middle of the 19th century, survival of patients after trepanation at the best hospitals of Europe rarely exceeded 10%, which was associated with the extremely high risk of infectious complications and implementation of this operation only in very severe patients with traumatic brain injury [13].

We studied cases of intravital operative interventions in the head tissues in three skulls found in graves of the Pazyryk Culture that had existed on the territory of the Altai Mountains about 2.5 thousand years ago (from the end of the VIth to the beginning of the 2nd century B.C.). This chronological period is also called the Skythian Epoch, the Early Nomads Epoch, or the Early Iron Age. The southern boundaries of the Pazyryk Culture area covered the northern regions of East Kazakhstan and Mongolia. The leading sector of economy of the Altai Mountains tribes was nomadic herding.

Trepanations of the two skulls were performed so skillfully that operated people survived for quite a long time after surgeries. The article evaluates the performed operations in terms of modern medicine. The historical aspect of the study lies in the comparative analysis of trepanations performed by Pazyryk surgeons and healers from other archeological cultures, the information of which we obtained from publications. The fact that the Pazyryk Culture lifetime coincides with the flowering of medicine in ancient Greece and with the establishment and development of the

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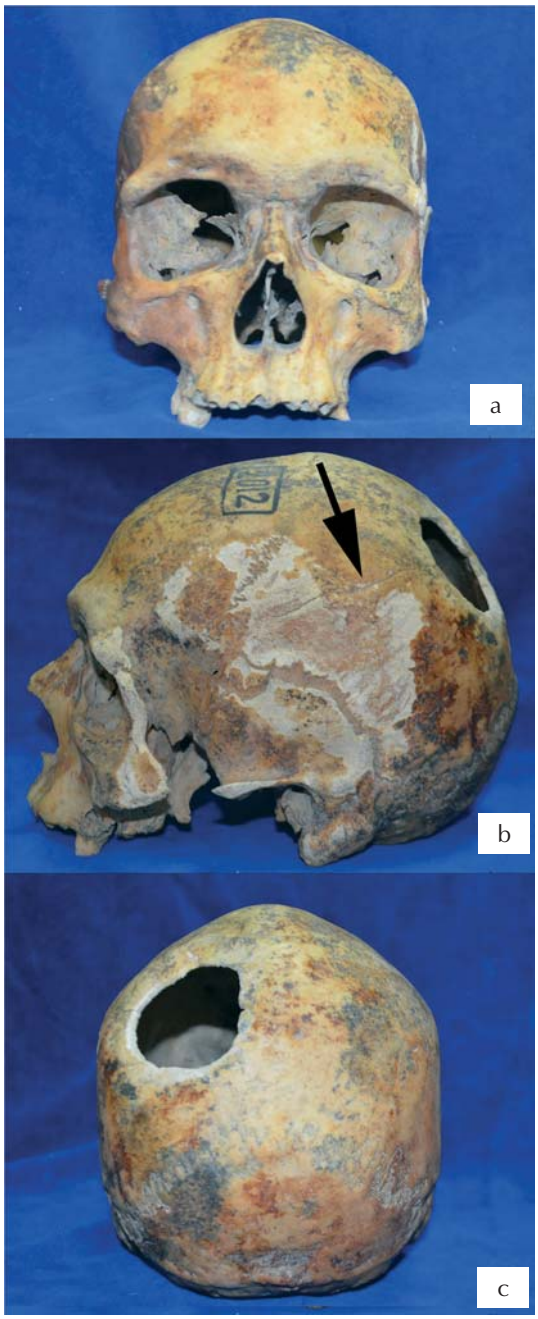

Fig. 1. **The skull of a male from the mound 3 of the Kyzyl-Dzhar-V burial mounds.**

a — frontal projection; b — lateral projection (arrow points at the linear fracture); c — occipital projection.

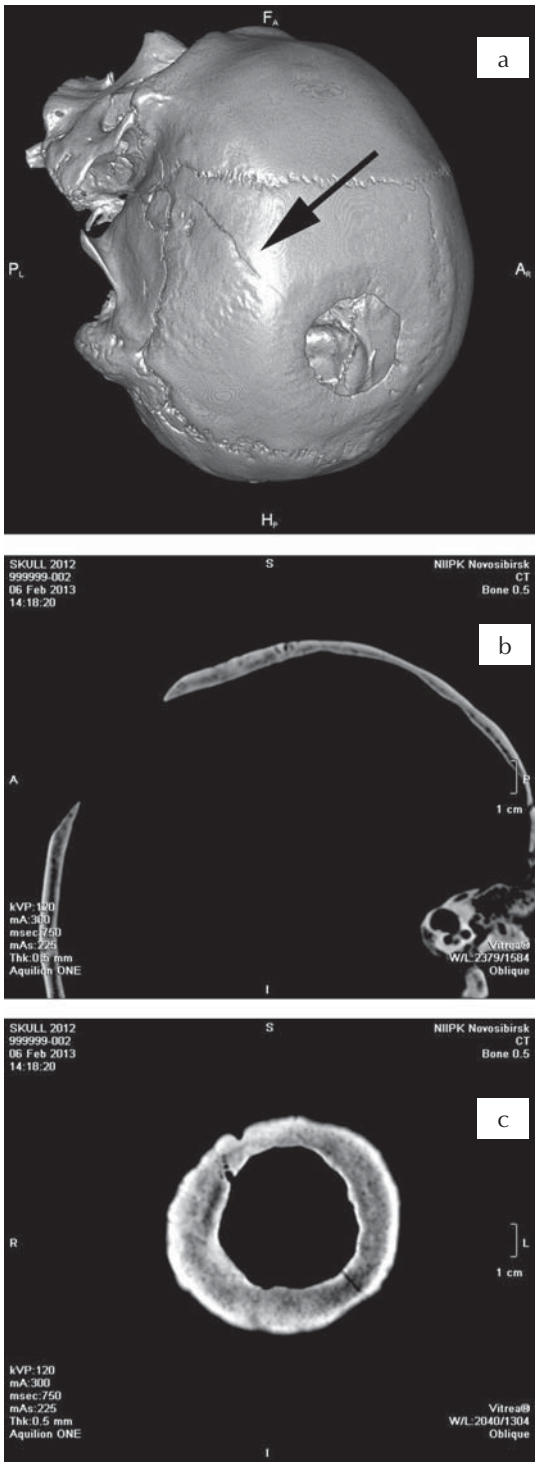

Fig. 2. **MSCT of the skull of a male from the mound 3 of the Kyzyl-Dzhar-V burial mounds.**

a — 3D model of the skull (arrow indicates at the linear fracture); b — slice through the trepanation defect in the lateral projection; c — horizontal slice through the surface of the trepanation defect. Clear signs of bone regeneration at the defect edge are present.

school of the great Greek physician Hippocrates (460—377 B.C.) is of particular interest.

Material and methods

Three skulls were thoroughly examined. Two skulls were found in the Kyzyl-Dzhar burial mounds located in the high-mountain valley of the Kyzyl-Dzhar mountain area, 7—8 km away from the Beltir village of the Kosh-Agach district of the Gorny Altai Republic [5]. Both

skulls have been stored in the anthropological collection of the Tomsk State University.

1. Kyzyl-Dzhar-V (mound 3, #KA TGU — 2012): a buried male died at the age of 40—45 years. 2. Kyzyl-Dzhar-V (mound 2, #KA TSU — 2009): a buried female died at the age of about 30 years. The third skull (male, age-related changes at the level of 50—60 years) was found in the mound 3 of the Bike-III burial located in the Bike Mountain area, investigated by V.D. Kubarev [2], in the middle reach valley of the Katun River. This skull has been stored in the anthropological collection of the Institute of Archeology and Ethnography of the Siberian Branch of the Russian Academy of Sciences. According to the authors of the excavation, it may be concluded that all three individuals were living in the 5th—3rd centuries B.C.; descended from the social environment of ordinary commoners and belonged to different ethnic and tribal groups of the Pazyryk archeological culture.

Reconstruction of the treatment process was carried out on the basis of a careful macroscopic examination of the skulls combined with standard osteometric measurements of the trepanation area using surgical optics and multislice computed tomography (MSCT). The latter was performed on a Toshiba Aquilion ONE (320-row 0.5 mm detector, with implementation of VTR and MRR); magnetic resonance imaging was carried out on a GE Signa Infinity (1.5T) device placed on the skull base. CT is known to detect much more clearly the changes in the bone tissue compared to craniography in this kind of studies [8].

Results and discussion

The skull from the Kyzyl-Dzhar-V (mound 3, #KA — TSU 2012), which belonged to a 40—45-year-old male, has a linear fracture (result of injury?!) the left temporal and parietal bones that goes to the sagittal suture **(Fig. 1)**. The fracture-sagittal suture intersection is 80 mm away from the coronal suture and 90 mm away from the occipital protuberance. In constructing the Kronlein scheme, the fracture line is close to the central sulcus. The fracture resulted, with a high probability, from a blow to the left parietal-temporal area by a right handed opponent. Investigators of ancient trepanations have found in most cases openings performed in the left parietal bone. It is assumed that this resulted from interpersonal conflicts with right hander opponents [22, 30].

In the left parietal bone, 12 mm away from the middle line, a rounded skull defect with an internal size of 40×41 mm is identified. The defect edge is bevelled due to dislocation of part of the outer table. Thus, the overall size of the bone defect is 63×64 mm. The bone thickness at the defect is 3 mm. Signs of bone growth are visually defined both at the defect edge and along the fracture line. Healing of a linear skull fracture is known to take many years [3]. MSCT demonstrated good regeneration and healing of the bone **(Fig. 2)**. By the nature of the fracture that goes to the sagittal suture, under which the sagittal sinus is located, it is very likely to suspect the development of an epidural hematoma due to the traumatic rupture of the sinus edge. With allowance for the proximity of the injury to the central motor area, it may be assumed that the affected person had not only cerebral symptoms such as headache, nausea, vomiting, and disturbances of consciousness but also movement disorders in his right leg, and to a lesser extent, in the hand. The clinical picture might also manifest with the development of partial (tonoclonic spasms in the right extremities) or generalized epileptic seizure.

It is curious that the trepanation made by the Pazyryk surgeon was carried out in strict accordance with the recommendations of Hippocrates who believed that bone injuries near the sutures require trepanation in most cases. In this case, Hippocrates warned to avoid trepanning over a suture. "The sutures should be avoided of trepanning, the operation should be performed at some distance in the nearest bone" [1, p. 590; 23]. Hippocrates does not mention sinuses or any vascular structures located under sutures [21]. Sutures were regarded as the weakest bone areas dangerous for injury to the intracranial contents with a trephine of Hippocratic times.

One of the strange Hippocrates recommendations concerned the trepanation technique. He always advised to leave a thin bone layer covering the dura mater without making cephalotomy to the end: "... when the bone became mobile, leave this operation to let the bone part separate spontaneously.... what is left is already sufficiently fine" [1 p. 597]. Later, this statement roused a suspicion that the author was not familiar with the trepanation technique [20]. However, it really is not surprising. Hippocrates nowhere indicated that trepanation is performed for evacuation of hematomas and abscesses or for other intracranial interventions. Hippocrates was also against the use of trepanation to treat depressed fractures. He used trepanation to treat linear injuries of the skull bones. This is confirmed by another recommendation of Hippocrates. Claiming that the thinnest and weakest bone is the crown, and another weak area is the temple [1, p. 582], he was strongly against incisions in the temple because of the risk for injury of the "vein" located there and the development of convulsions in the operated person [1, p. 591]. Today, we know that more than 70% of epidural hematomas that need trepanning are located precisely in the temporal region. As judged by the character of the successful trepanation performed by the Pazyryk surgeon, his purpose was the intracranial contents. The opening is of sufficient size and centered on the fracture line, all layers of the parietal bone are removed. The trepanation window is very suitable for evacuation of an intracranial hematoma!

According to the literature, prehistoric trepanations had a high survival rate for trepanned individuals without signs of post-operative complications. These

***Fig. 3*. The skull of a female from the mound 2 of the Kyzyl-Dzhar-IV burial mounds.**
a — lateral projection; b — frontal projection; c — vertical projection.

figures reached 50—90% [7, 14]. Successful completion of ancient skull operations is associated with a small diameter of the most openings and making them in safe areas to avoid injuries to the sutures and the dura mater [33]. In the described case, upon making the opening, the Scythian surgeon quite carefully backed out of the suture by more than one centimeter, at a distance where the sagittal sinus edge ends, massive bleeding from which requires, even today, special technologies and materials to stop it. However, this is not to say that the Pazyryk healer made a small trepanation window. A modern neurosurgeon in a similar situation would make an opening of a similar diameter.

The second skull from Kyzyl-Dzhar (Kyzyl-Dzhar-IV burial mounds, mound 2, #KA TSU — 2009) belonged to a young female aged about 30 years. Its examination and MSCT data indicate that the female suffered a severe injury in the form of a fracture of the right temporal bone and the middle cranial fossa base. By the nature of the injury, it may be assumed that the injury resulted from falling from a height. A circular opening with the outer size of 39×36 mm and the inner size of 23×16 mm was made in the posterior portions of the crown strictly along the midline over the sagittal suture. The opening is perforated with removal of the outer bone layer, cancellous bone, and inner (vitreous) table **(Fig. 3)**. Signs of

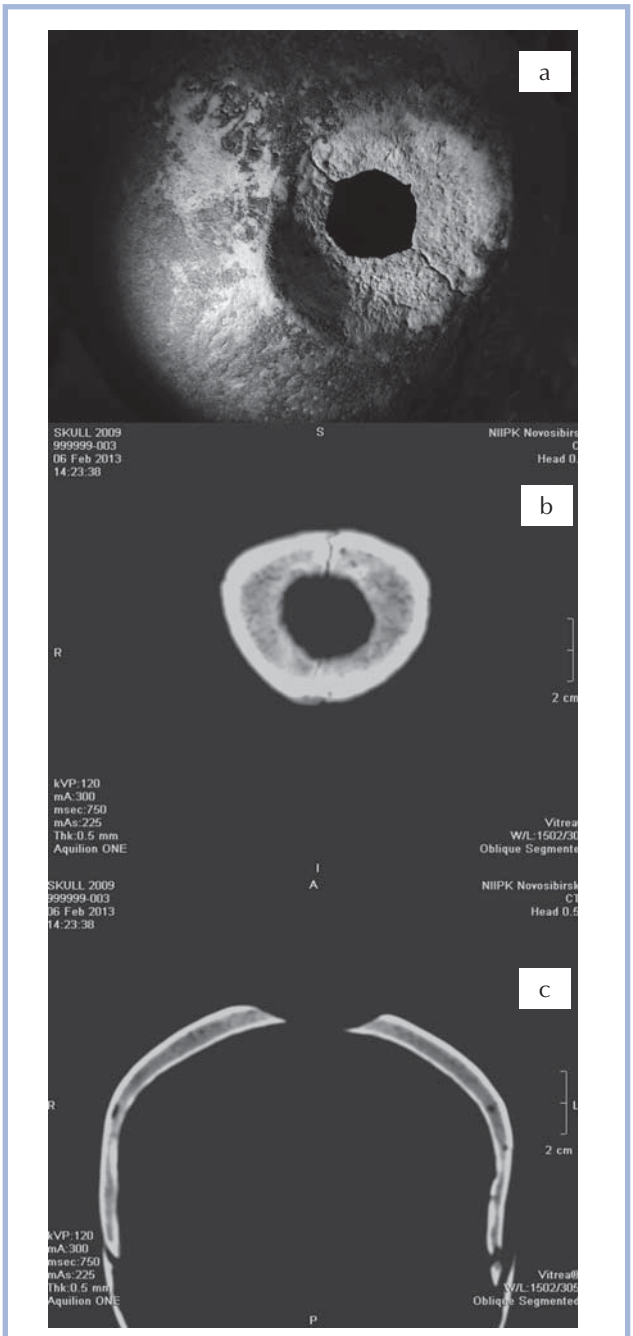

***Fig. 4*. Trepanation defect in the skull of a female from the mound 2 of the Kyzyl-Dzhar-IV burial mounds.**

a — photographic image; b — MSCT: a horizontal slice through the surface of the trepanation defect; c — MSCT: a slice through the trepanation defect in vertical projection. Signs of bone regeneration at the defect edge are missing.

bone growth are not present. This conclusion is confirmed by MSCT, which did not detect reorganization of the bone trabeculae **(Fig. 4)**. These findings suggest that the injured female died either during surgery or shortly after its completion. Another explanation for these findings is that the operation was performed postmortemly. The surgery technique, which will be discussed below, was significantly different from trepanation in the first case.

And finally, the third skull (Bike-III burial, mound 3) belonged to a male of 50—60 years. The visual examination of the skull indicates that it has a congenital deformity in the form of flattening of the right half of the occipital bone due to non-uniform closing of the occipital sutures. No injury traces on the skull were found.

15 mm behind the coronal suture and 50 mm away from the sagittal suture, there is a semi-oval hole with the outer size of 52×45 mm and the internal defect size of 22×34 mm. The bone thickness at the trepanation area is 2 mm **(Fig. 5)**. There are distinct signs of new bone growth, which was confirmed by MSCT **(Fig. 6)** and indicates long survival of the individual after the trepanation.

This successful result of two of the three presented operations is worthy of a detailed discussion of the technological details of these manipulation.

Five basic methods to perform trepanations have been described [17, 27]. One was already mentioned in the introduction — a procedure to make a rectangular opening in the bone by intersecting incisions. The first skull of this type was found in Peru. The opening was performed with a knife made of silicon or volcanic glass.

The second method is based on bone scraping. Paul Broca, with a piece of glass, performed this trepanation on the skull of an adult, which took him 50 min [28].

The third method involves cutting a circular groove followed by lifting off the bone disc. This method was widely used until recently in Kenya [13].

The fourth method to form a circular trepanation window requires the use of a crown saw. This method was described by Hippocrates, further improved by Roman physicians, and used in modern medicine until recently.

The fifth method is to drill a circle of closely spaced holes the bone and then to cut or chisel the bone between the holes. This technology was recommended by the Romans, adopted by the Arabs, and used in the Middle Ages. It was developed to the method that, in certain cases, is used to this day, despite the availability of high-speed electric and pneumatic drills equipped by craniotomes with routers from high-alloy steel. The method is based on that the bone between burr holes is cut using the Gigli saw, which was carried out under the bone over the dura mater by means of a guide.

Pazyryk surgeons might use iron, copper, and bronze to perform trepanations. High field MRI of the trepanned skulls did not reveal the presence of a ferromagnetic (iron) in the bone cutting area. Copper is rather soft metal to cut a bone. Most likely, Pazyryk healers used firm and suitable bronze tools.

Upon excavation of the Pazyryk cultural artefacts, archeologists did not find the specialized tools that could be attributed to medical ones, which might be used for craniotomy. However, in almost all the graves of Pazyryk people, regardless of their social status, bronze knives

***Fig. 5*. The skull of a male from the mound 3 of the Bike-III burial mound.**
a — frontal projection; b — projection of the rotation to the right by 3/4th; c — lateral projection; d — vertical projection.

have been found **(Fig. 7)**. This is a vital tool in everyday life of a cattleman.

A mass spectral analysis and an X-ray fluorescence analysis of bone samples taken from the place of the ancient trepanations, which we carried out under the RFBR grant, demonstrated that the most likely tool to be used by the Scythian surgeons was a bronze knife [6].

It is noted that the scraping method provided the highest survival percentage of ancient trepanations [15]. A comparison of the probability for bone healing and, consequently, the survival of patients, based on a large set of data from Anatolia, revealed that the best result was obtained for the scraping method compared to sawing and drilling [9].

The ancient Celts, whose settlements stretched from France to the Danube and to the Black Sea shores, continued to use widely the bone scraping method for trepanations [20], and the drilling method, which was already known by that time, was used only in a few places.

Hippocrates described four tools for trepanation: three devices for bone perforation (a trepan, a serrated trepan, and a probe to determine the depth of cutting the bone and the mobility of the bone fragments) and a rasp for scraping the bone tissue and isolation it from the soft tissues of the head [1, p. 579—600]. A Scythian surgeon was enough to use a universal bronze knife.

We used a trasological analysis of the operation traces [6] to simulate the process of removing the bone fragments upon constructing the trepanation skull defect. The operation was obviously carried out in two stages. First, the most firm cortical layer of the bone was cut off using rotational motions without perforating the skull. The bone cutting plane is tangential to the spherical surface of the skull. Only then, at the second stage of operation, directing probably the same tool under a steeper angle, the spongy part of the bone was removed, and then the vitreous table adjacent to the dura mater was carefully lifted off and removed. If instrument motions at the first stage have a relatively long “working stroke”, then at the second stage they are traces of relatively more frequent, short movements of the surgeon hand. A comparison of the operation techniques for the three presented skulls reveals that trepanation in the female with the opening in the sagittal suture area was performed with more rough, sticking movements [6].

Since the Pazyryk Culture has left no written evidence of medical activity, the problem of reconstruction of motivation for Scythian surgeons to conduct cranioto-

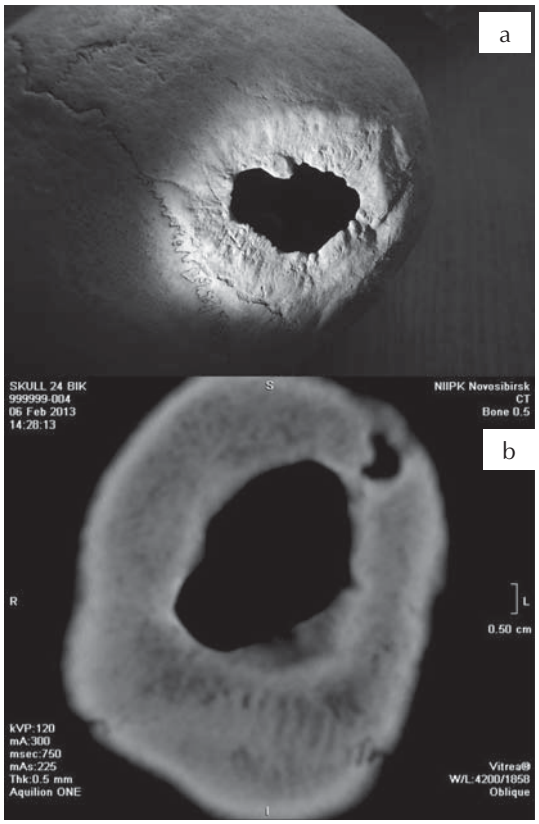

***Fig. 6*. Trepanation defect in the skull of a male from the mound 3 of the Bike-III burial mound.**

a — photographic image; b — MSCT: a sdjscy through the trepanation defect in the horizontal projection. Clear signs of bone regeneration at the defect edge are present.

***Fig. 7*. A bronze knife from Pazyryk graves.**

my is a challenge. However, it should be noted that if in the case of Neolithic trepanations, it is at all difficult to understand why and who did it [16, 18], with a few exceptions [34], the manipulations on the head in the Pazyryk Culture were obviously of medical nature and performed by specialists with certain knowledge about the organization of the human body and its diseases.

In the first presented case of skull trepanation, operation was aimed at treatment of the patient with severe traumatic brain injury. According to the opening location in the center of the fracture indented from the sagittal suture, the formed defect size as well as precision of manipulations on the bone, the Scythian healer was a perfect diagnostician and trained surgeon with good knowledge of anatomy. The operation clearly was of medical nature and was very likely aimed at removing an intracranial hematoma.

In the second case, this also was an attempt to treat head injury. The adverse outcome of the operation might be associated with many circumstances, of which severity of primary injury should be put first. Eventually, even today, having the state-of-the-art neurosurgical and intensive care technologies, we lose patients after trepanation due to severe primary injury to the brain or other organs in concomitant injury. It is possible that a certain role was played by an unfortunate and inexplicable choice of the place for trepanning on the skull just over the largest venous collector of the brain with a risk for fatal bleeding. It can not be ruled out that a more rough operation technique determined the adverse outcome of treatment. Probably, a human factor, the choice of a doctor, was of crucial importance in those ancient times.

In the third case, where there are no signs of skull injury, the trepanation was performed over the motor cortex and the trepanned person died at the extreme, at that time, age, survived for a long time after the surgery. The causes for the operation remain unclear. It is quite possible that this is the case of treatment of head injury that did not leave marks on the skull. However, other causes can not be excluded, e.g. meningiomas [29] or a parasitic brain lesion. In the modern Siberia and Altai, cases of brain cysticercosis and echinococcosis requiring surgical treatment are rather common. Animals, which were bred by the Altai cattlemen 2,500 years ago, are the main or intermediate hosts in the life cycle of helminthes and could be a source of infection. A high level of diagnosis and successful implementation of intracranial interventions by ancient surgeons do not exclude the possibility of removing helminthes from the brain of the individual from Bike-III.

Conclusion

According to the obtained data, the level of diagnosis and implementation of surgical manipulations on the head was high enough in the Pazyryk culture surgeons. They had serious knowledge of the anatomy of the skull and intracranial venous collectors.

One of the operations was carried out as if the Pazyryk surgeon was guided by the recommendations of the great Greek physician Hippocrates. It makes sense to assume either the convergent development of the

linear fracture treatment technology or a connection between the early nomads of Siberia and medical centers of the ancient world.

It is unlikely that the trepanations were performed for ritual reasons, since the cause for two cases was a brain injury. Written sources of the beginning of our era indicate that doctors who performed trepanations realized that it is rather risky surgery. Aretaeus of Cappadocia branded trepanation, calling it "bold remedy" [31]. Galen, describing the risks of brain injury during trepanation, stressed the need in repeated practice in this operation to become a master [25, p. 75, 76, 183]. The analysis of 40 cases of trepanation in Anatolia from the Neolithic to the late Ottoman period revealed that the causes for these operations were mainly skull injuries and, in some cases, tumors and training of doctors [9]. Other authors, analyzing the skull of ancient times from Italy, also conclude on training in performing trepanations [10].

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Commentary

The study of Prof. A.L. Krivoshapkin and authors is, unfortunately, the first in the last 122 years of the Russian history. The previous and only description of the skull with traces of trepanation found on the territory of Russia (now not Russia already) was published in 1892 [2]. Since the primary source is difficult of access, it is worth reminding its content.

During the excavation of the ancient city on the Knyazh'ya mountain (Kiev province), a skull with traces of trepanation dated by the 13th century A.D. was found. According to the decision of archeologists and doctors [1, 2], the skull belonged to a young male who defended a besieged fortification and suffered an open, penetrating traumatic brain injury (probably arrow wound). He was immediately provided with specialized care. The wound was incised, resective trepanation was performed by expanding the edges of the bone defect to 2.75×2.5 cm. The injured male died soon after the operation and was buried in the city. Analyzing this observation, it is difficult to suggest that unique surgical interventions were performed in a small fortified settlement ("city"). It is obvious that craniotomy in Russia, like in other countries, was rather routine operation.

However, the fate of this skull is unknown. I am almost convinced that domestic archeological museums and repositories have other similar skulls, examination of which with the use of modern facilities could provide us with a lot of new information. But as far as I know, the only Russian team carrying out this research is the authors of this article. Much wider studies in this field are conducted in other countries.

There are known the results of excavation of the Peruvian necropolis, where approximately 10% of skulls have trepanation traces, with the nature of bone changes indicating that about 60% of patients underwent the operation and survived after it for at least several months [4].

About 1/3rd trepanations were performed for traumatic brain injury, with their outcome being primarily determined by the severity and localization of injury. In the overwhelming majority of cases of injury to the parasagittal region, the outcome was adverse (as revealed by the lack of reactive changes in the trepanation defect edges).

Indications for craniotomy in the remaining 2/3rd cases remain unclear. Presumably, these might be osteomyelitis of the skull bones, headache, epilepsy, and mental disorders; it is very likely that skull trepanation was performed for ritual purposes. Interestingly that the ancient Incas did not resect the bone over the superior sagittal sinus when performed bilateral trepanation.

In addition to trepanation, the Incas performed also plastics of bone defects with gold or silver plates. Infectious complications (osteomyelitis) were observed only in 15% of cases [3].

In Europe, the remains were not preserved so good, and the earliest ones with traces of trepanation belong to the Middle Ages. For example, in graves found in the territory of Germany and dated by the 6th—8th century A.D., traces of trepanation are present only on 8 of 384 skulls (about 2%). Interestingly that death from osteomyelitis on the 4th week after the operation occurred only in one case, consequently, the mortality rate, which is equal to the infectious complication rate, was 12.5% [4]. It is also interesting that one of the patients of this "series" who had successfully undergone trepanation in the frontal region performed with pliers died much later from a penetrating wound in the parietal-parasagittal region, caused by a blow of the sword.

It is encouraging that interest in the history of Russian medicine has arisen again after a long period. I would like to thank the authors for the pleasure of reading the article and to wish them continued success.

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