






RESEARCH ARTICLE

A previously undescribed cranial surgery technique in the Carpathian Basin 10th century CE

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Abstract

In this paper, the authors give a new insight to the indication and preparation of trepanations through the analysis of a newly discovered case of 10th-century-CE surgical trepanation found in the material of Sárrétudvari-Poroshalom. We also intend to outline the implications of this particular case to the general methodology of trepanation research. We estimated basic anthropological data (sex and age-at-death) and performed analyses of paleopathological and activity-related lesions. Computed tomography, radiocarbon, and genetic analyses were also conducted. Beside other prior traumas, two codependent lesions were detected on the right parietal bone with no sign of healing. In this lesion complex, an original sharp force trauma was observable surrounded by two curved, intentionally created furrows, which can be interpreted as attempted surgical trepanation presumably performed with a U-shaped gouge. The results of the analysis of activity-related changes and archeological examination corroborate the assumption that the injuries described on the skull may have been, indeed, acquired during activities connected to military lifestyle, and the individual may have been a high-ranking military leader in his community. This unique case has paramount importance providing more detailed knowledge of past medical practices. The application of U-shaped gouge has not been formerly documented in the literature, which opens a new perspective both in the osteological investigation of these interventions and the archeological research concerning ancient medical technology. Our results may suggest a possible mode of tool use, and aid future reconstruction attempts concerning the hypothesized 10th-century-CE trepan from Tiszaeszlár-Bashalom.

KEYWORDS

Hungarian Conquest period, trepanation, surgical intervention, head injury, activity-related changes

1 | INTRODUCTION

Since Paul Broca's publication in 1867 (Broca, 1867), researchers have been fascinated with trepanation, but there are still a lot of unanswered questions concerning this topic. The Eastern European scientific tradition differentiates between two forms of *intra vitam* trepanation: surgical (or complete) and symbolic (or incomplete, or skullmark) interventions (Anda, 1951; Jordanov et al., 1988; Mednikova, 2003; Nemeskéri et al., 1965; Nemeskéri, Harsányi, & Acsádi, 1960; Simalcsik, 2018). Both surgical and symbolic trepanations may have had a couple of possible reasons of intervention in their background. Therapeutic interventions may have had pure medical purposes, magico-therapeutic interventions were aimed at solving health issues with ritual methods, and magico-ritual trepanations were intended for other purposes than health problems (Aufderheide & Rodríguez-Martín, 1998; Lisowski, 1967). In case of symbolic trepanations, bone material of the outer table and sometimes from the diploe is removed, without penetrating the internal table of the cranial vault (Bartucz, 1950; Jordanov et al., 1988; Mednikova, 2003; Nemeskéri, Harsányi, & Acsádi, 1960; Simalcsik, 2018). These usually round, or sometimes almond-shaped or elongated, lesions most often localize in the area of cranial sutures on the very top of the head (Bereczki et al., 2015; Jordanov et al., 1988; Nemeskéri, Harsányi, & Acsádi, 1960; Simalcsik, 2018). Symbolic trepanations seem to be a ritual phenomenon usually occurring among peoples of the steppe or populations with contact with them. The intervention has no proven medical benefits. In most cases, the underlying reason of the operation is undetectable on the bones, so it is difficult to determine whether there was a therapeutic aspect of the intervention or not (Bereczki et al., 2015; Gresky et al., 2016).

In case of surgical trepanation, the internal table of the cranial vault is penetrated. These surgeries with high geometric diversity are most frequently localized in the frontal or parietal bone (Józsa & Fóthi, 2007), often scattered in a pattern similar to the majority of cranial traumas (Cohen et al., 2014). Except for a few cases with probable ritual intention (e.g., Gresky et al., 2016), most of them may have had a curative purpose (Bereczki, 2013; Bereczki et al., 2015; Nemeskéri, Harsányi, & Acsádi, 1960). Beside the different diseases and symptoms affecting the head (e.g., headache and meningitis), the treatment of a head injury is assumed to be one of the main therapeutic indication (e.g., Gresky et al., 2016; Jørgensen, 1988; Nemeskéri et al., 1965; Verano, 2003). Trauma is rarely visible on the skull near the trepanation (e.g., Andrushko & Verano, 2008; Jørgensen, 1988). In most cases, the bone affected by the original injury may have been removed; therefore, no traces of trauma remained by the end of the procedure (Aufderheide & Rodríguez-Martín, 1998; Gresky et al., 2016; Verano, 2003).

All forms of *intra vitam* surgical trepanations were usually designed to remove bone material from the skull without damaging the meninges, brain, or blood vessels (Aufderheide & Rodríguez-Martín, 1998; Lisowski, 1967). There are four widely accepted techniques of surgical trepanations, namely, scraping, grooving, drilling

with cutting, and sawing (e.g., Aufderheide & Rodríguez-Martín, 1998; Gross, 2009; Lisowski, 1967). However, the technical descriptions of these methods are not uniform in the literature. This is especially true for the scraping technique. In most cases, it is defined as repetitive parallel scraping abrasion of the ectocranial surface until the skull vault is penetrated (e.g., Aufderheide & Rodríguez-Martín, 1998; Verano, 2016). However, according to another definition, the bone can also be scraped through with a sharp tool that is pointed at the surface in a certain angle, and the bone fragment is removed, when the operator reaches the desired depth at the end of the procedure (Ortner, 2003). The second interpretation is quite similar to the push-plow technique described by Parry in 1940 (Parry, 1940). Furthermore, it is often difficult to determine the exact method of intervention and to classify certain trepanations into the above categories, because the healing process obscures the traces caused by the trepanning device. In addition, the uniqueness of each case forces the operators to adapt their technique to the circumstances of the situation (Gresky et al., 2016; Tullo, 2010).

It must be noted that all forms of trepanation can be mistaken for a series of other phenomena. Traces of cauterization (Bockenheimer, 1922), blunt force trauma, abscess removal, and symptoms of infections (e.g., syphilis) can mimic symbolic trepanations (e.g., Bereczki et al., 2015; Simalcsik, 2018); enlarged parietal foramina, meningocele, weapon wounds, skull fractures, or bone cancer can sometimes resemble surgical trepanations (Verano, 2016). Healed or remodeled cases of symbolic trepanation and, for example, blunt force trauma are virtually impossible to be distinguished in certain cases (Bereczki et al., 2015). However, very good differential diagnosis guides are available for symbolic (Simalcsik, 2018) and surgical (Verano, 2016) trepanation, too that consider the latest results and research history of both interventions.

More than 130 skulls with surgical trepanations are known in the Carpathian Basin (e.g., Anda, 1951; Bartucz, 1966; Bereczki et al., 2003, 2010, 2015; Józsa & Fóthi, 2007). The earliest cases can be dated to the Neolithic period (Bartucz, 1966), but the majority of them derives from the Hungarian Conquest period (9–10th century CE) and around the time of the Hungarian Kingdom's foundation (10–11th century CE; Józsa & Fóthi, 2007). According to written sources and archeological data, equestrian and military lifestyle was characteristic to the communities from this era (e.g., Révész, 1996; Veszprémy, 2017).

In the Carpathian Basin, the vast majority of cases was created with a method (Nemeskéri et al., 1965) very similar to the technique described by Ortner (2003). The area was chiseled around with a sharp pointed tool, then the lamina externa and the diploe were cut into with carving moves. The shape was engraved in the surface. At the end, the lamina interna was cut through, and the skull fragment was removed just like in most other methods (Bereczki, 2013; Nemeskéri et al., 1965). The last step may have been the fine retouch of the surrounding surface that is often observed in *perimortem* cases from Hungary; fine parallel scraping marks can be found around the aperture, usually removing only fractions of 1 mm depth of material

from the surface. This method is suitable for opening an intact skull and also for clearing the edges of an existing cranial wound (Nemeskéri et al., 1965).

In this paper, we intend to give a new insight into the indication and preparation of trepanations through the analysis of a newly discovered case of 10th-century-CE surgical trepanation found in the material of Sárrétudvari-Poroshalom. We also wish to outline the implications of this particular case to the general methodology of trepanation research.

2 | MATERIAL

The Sárrétudvari-Poroshalom (Hajdú-Bihar county, Eastern Hungary) (Figure 1) 10th-century-CE cemetery was partially excavated with 17 graves (Nepper, 2002). The Poroshalom series is considered as one of the richest 10th-century-CE cemeteries in the region. From both archeological and anthropological aspects, grave No. 1, the subject of our investigation, stands out among the burials.

Grave No. 1 contained a partial horse burial with horse-riding equipment (bit and stirrups). Weapons, like saber and archery

equipment (antler bow plates, parts of quiver, and arrowheads), were also unearthed from this grave (Nepper, 2002). Besides, the grave also contained a lot of valuable grave goods, for example, gilded silver belt ornaments (Nepper, 2002), considered as a status symbol in the Hungarian Conquest period (Figure 2a, b, and c) (Révész, 1996).

Despite the incompleteness of the skeleton (the main part of the pelvis, the whole spine, and the sacrum were missing among other bone elements), the state of preservation of the available osteological material was rather good (Figure 2d).

3 | METHODS

Radiocarbon analysis was performed to confirm the archeological dating of the remains. The sample (rib fragment) was measured in the AMS laboratory of the Institute for Nuclear Research, Hungarian Academy of Sciences, Debrecen, Hungary (e.g., Molnár et al., 2013). The result of the conventional radiocarbon dating was calibrated with the OxCal 4.4 software (<https://c14.arch.ox.ac.uk/oxcal/OxCal.html>, date of calibration: November 30, 2020) with IntCal 20 settings.

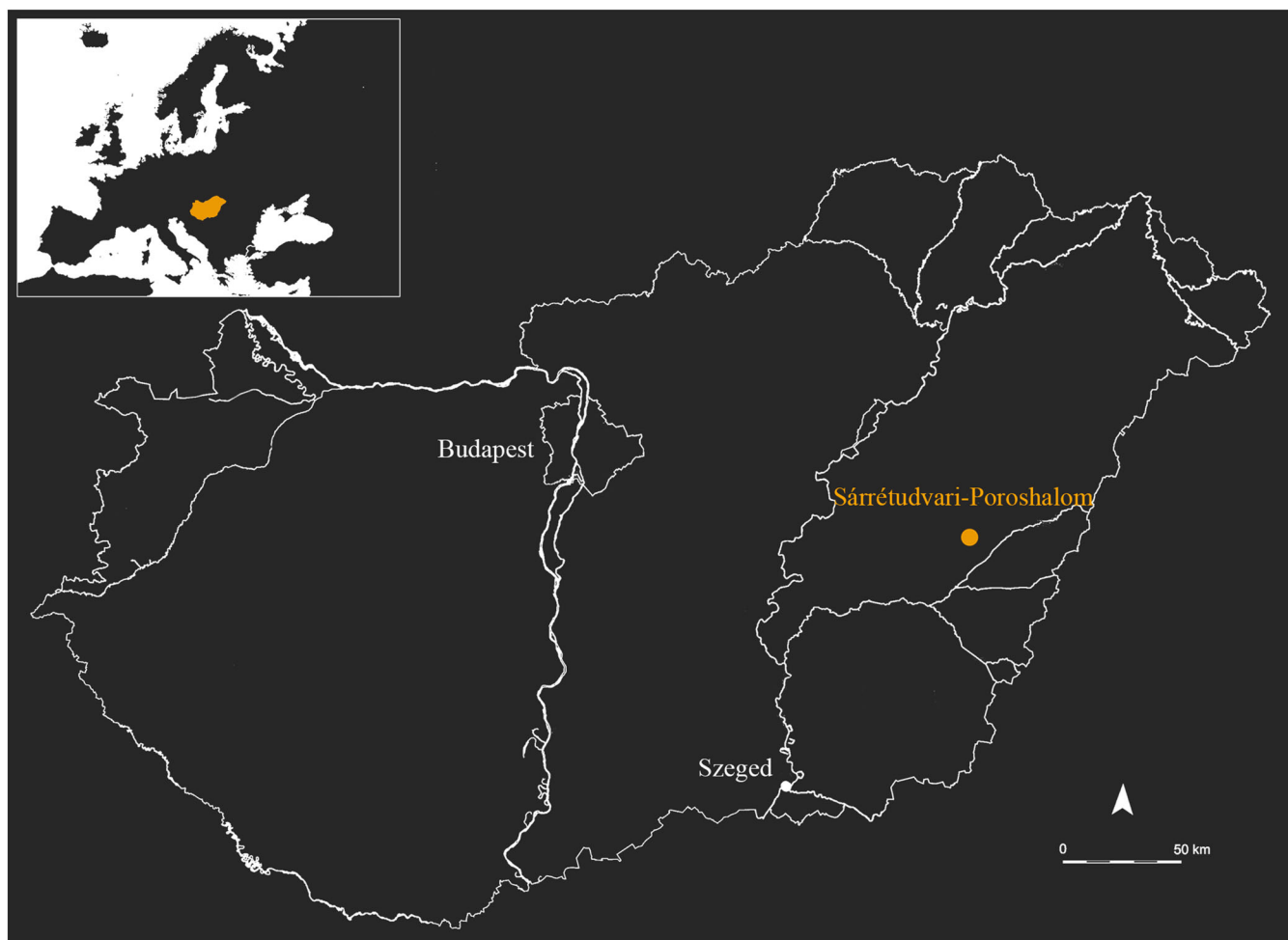


FIGURE 1 Location of the Sárrétudvari-Poroshalom 10th-century-CE cemetery in present-day Hungary [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

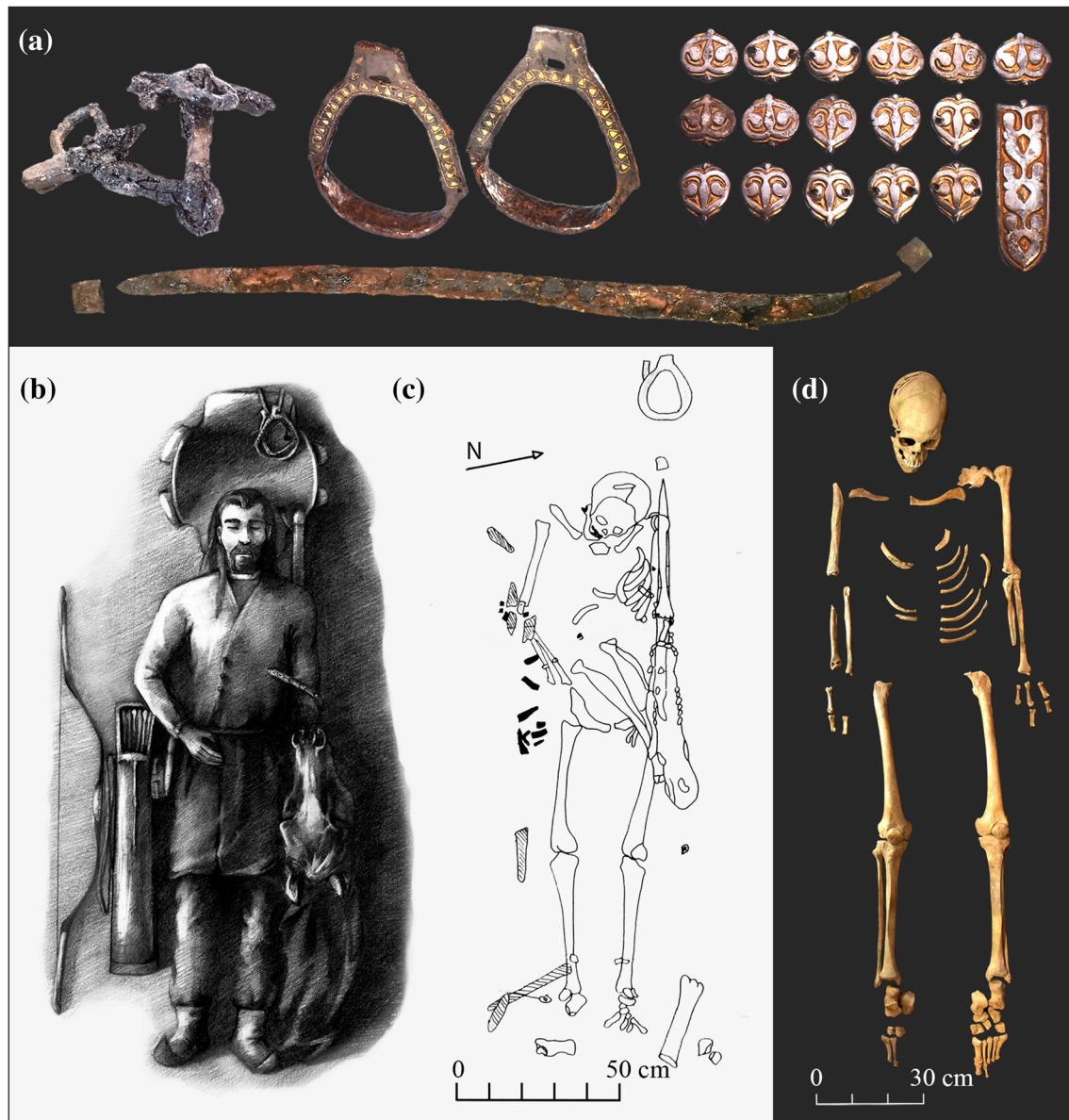


FIGURE 2 (a) Grave goods from Sárretudvari-Poroshalom grave No. 1. From left to right: iron bit with iron sidebars and jointed mouthpiece, iron stirrups with bronze inlay of metals (damascening), gilded silver belt ornaments, and iron saber (Nepper, 1996). (b) Graphical reconstruction of the burial. (c) Drawing of the burial of Sárretudvari-Poroshalom grave No. 1 (Nepper, 2002). (d) Available osteological remains of the individual buried in Sárretudvari-Poroshalom grave No. 1 [Colour figure can be viewed at wileyonlinelibrary.com]

Sex and age-at-death was estimated based on standard macromorphological methods (Éry et al., 1963; Knussman & Martin, 1988; Loth & Işcan, 1989; Nemeskéri, Éry, & Kralovánszky, 1960; Szilvássy, 1978) (Table S2).

Genetic sex was determined based on Y and X chromosome read ratios after shallow shot-gun sequencing (Skoglund et al., 2013). Details of ancient DNA extraction, Next-Generation Sequencing library preparation, sequencing, and sequence analysis methods have been published earlier (Neparáczki et al., 2018).

The paleopathological analysis was conducted using macromorphological characteristics of the skeleton. For a more in-depth examination of the skull, a CT scan was performed using a Philips Brilliance iCT 256 CTscanner (Department of Radiology, University of

Szeged, Szeged, Hungary) with 0.1-mm slice thickness. Furthermore, microscopic photos were created by using a Nikon SMZ1500 stereomicroscope with a 10× (C-W10xB/22) eyepiece, 1× objective, and magnifications between 0.75 and 4. An extra light source (Volpi Intralux® 5100, 230 V, 50 Hz) was also used.

During the examination, we also paid attention to activity-related skeletal changes including enthesal changes, joint changes, and traumatic lesions, especially the possible skeletal traces of horse-riding and use of weapons (e.g., Berthon, 2019; Berthon et al., 2019; Tihanyi, 2020; Tihanyi et al., 2020). Metric indices of shape and robusticity of the postcranial skeleton were also recorded. After studying several activity analysis methods (e.g., Henderson et al., 2016; Mariotti et al., 2007; Villotte

et al., 2010) and their advantages and disadvantages (e.g., Michopoulou et al., 2015; Nikita et al., 2019), we decided to use binary (presence/absence) scores following the criteria of Villotte et al. (2010) for the enthesal changes, and symptoms described by Waldron (2009) for the joint changes. Additionally, if an enthesis was postmortem damaged or missing, we signed it as nonobservable.

4 | RESULTS

4.1 | Radiocarbon dating, and age-at-death, and sex estimation

The radiocarbon analysis (conventional radiocarbon age is 1108 ± 25) confirmed the archeological dating (888–994 CE calibrated radiocarbon age with 95.4% probability). However, more precise dating—compared with archeological data—was not achievable (Figure S1). Based on skeletal morphology, the individual from grave No. 1 was most likely a 25- to 30-year-old male (Table S2). Because in the absence of pelvic remains, the morphological sex estimation was uncertain, we also considered genetic sex determination to confirm our data.

The Y/X chromosomal ratio was 0.238636364 ($R_y = 0.0673$), which indicated that the individual was male.

4.2 | Paleopathology

4.2.1 | Traumatic lesions

Four traumatic lesions were observed on the skull in different localizations (Figures 3 and S2):

Lesion #1: A well-healed, kidney-shaped, depressed lesion is located on the left side of the frontal bone, 20 mm from the *planum medianum* and 10 mm from the *margo supraorbitalis*. The affected area is 20 mm in the biggest and 10 mm in the smallest diameter, and approximately 1.5 mm deep (Figure 4).

Lesion #2: An elongated lesion expands along the entire length of the left parietal bone and 20 mm long on the occipital bone. The course of the injury follows the shape of the *sutura squamosa* to the sagittal direction. The trauma begins at the *sutura coronalis*, 45 mm laterally from the bregma, and extends to the left lateral end of the *linea nuchae inferior*. The total length of the injury is 155 mm. The surface of the bone had strongly remodeled during healing; therefore, the extent of the original trauma cannot be measured precisely. The biggest diameter of the affected area is 35 mm. Despite the apparent signs of bone remodeling, there is still considerable bone deficiency in the middle section of the lesion in 30 mm length and 1 mm width. The skull shape is slightly deformed along the healed trauma, and the affected sections of the coronal and lambdoid sutures had also obliterated (Figure 5).

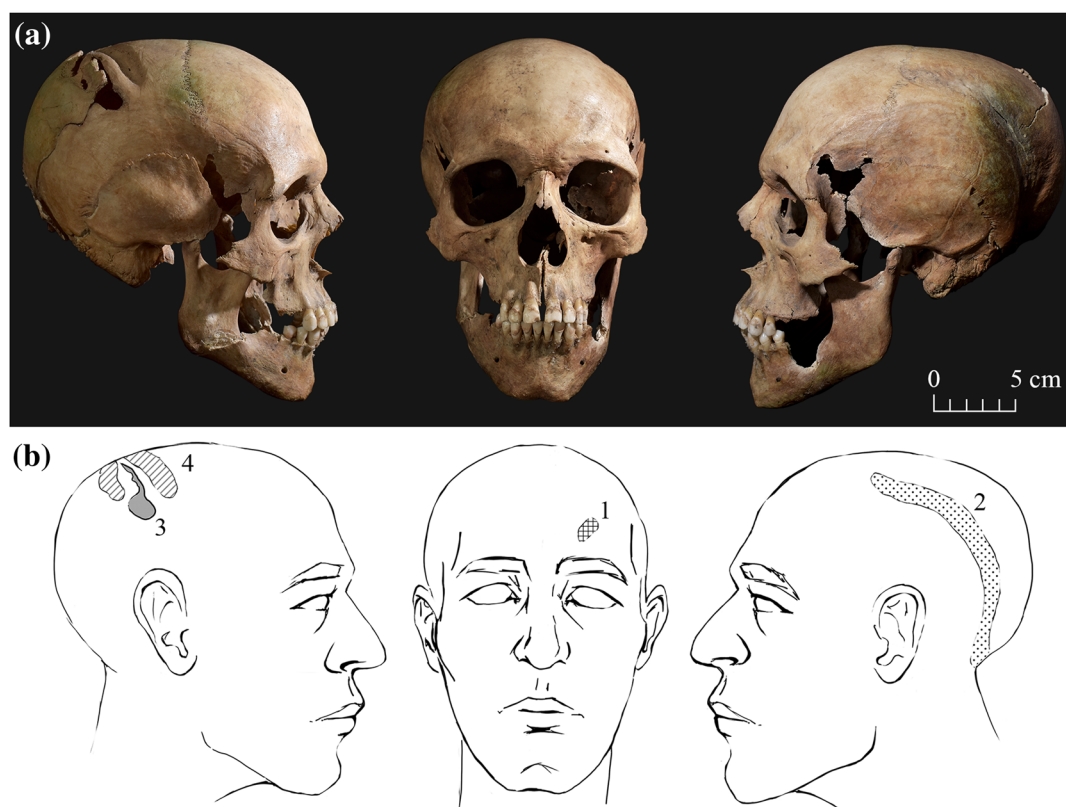


FIGURE 3 Localization of the lesions on the cranium. (a) Right lateral, anterior, and left lateral view of the cranium. (b) Square grid area—Lesion #1, dotted area—Lesion #2, gray filled area—Lesion #3, and striped area—Lesion #4 [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

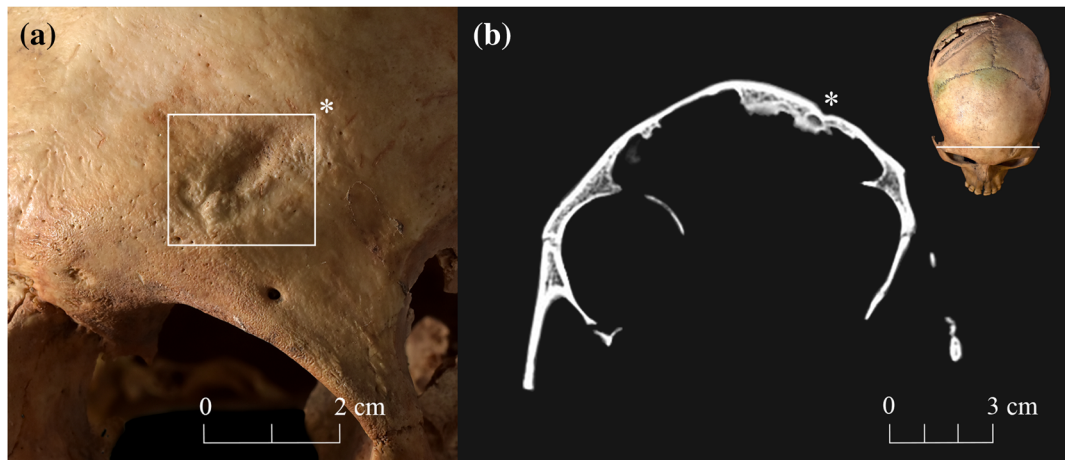


FIGURE 4 Lesion #1. (a) Antero-lateral view of the cranium with the depressed lesion in square. (b) Computed tomography in the coronal plane (upper right corner) showing the approximately 1.5 mm depth of the lesion [Colour figure can be viewed at wileyonlinelibrary.com]

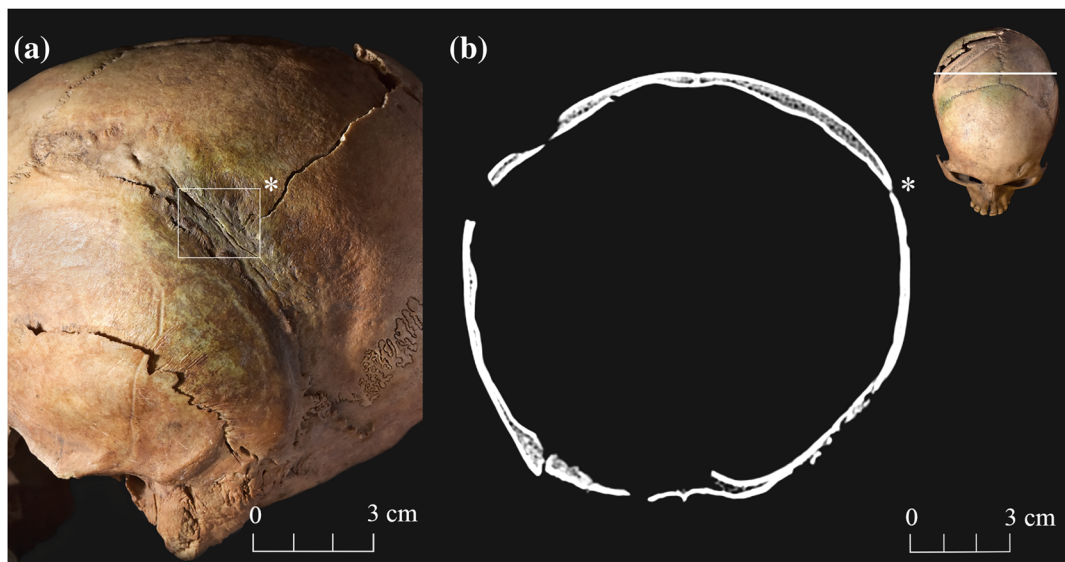


FIGURE 5 Lesion #2. (a) Postero-lateral view of the cranium. Elongated lesion of the left parietal bone and on the occipital bone with a deficient area in square. (b) Computed tomography in the coronal plane (upper right corner) from the deficient area [Colour figure can be viewed at wileyonlinelibrary.com]

Lesion #3: A linear injury can be seen in the middle part of the right parietal bone, with a 45° deviation from the frontal plane (Figure 6a). The injury is a 65 mm long and maximum of 5-mm-wide elongated aperture (Figure 6b). The lateral 20 mm of this opening widens to an irregular teardrop-shaped artificial hiatus of 13 mm width. The lateral rims of this wound are mostly flat and inclined; the medial 45-mm-long part consists of almost perpendicular rims. All three layers of the bone are visible in the rims with no signs of healing, and all exposed surfaces are cracked. A 11-mm-long and 2- to 3-mm-wide bone fragment is attached to the dorsal rim of the medial section, leaning inwards to the middle of the lesion (Figure 6c). From the teardrop-shaped artificial hiatus in the lateral end, a clear, 75-mm-long, slightly undulating fracture line expands towards the right side of the *sutura lambdoidea*. Another 30-mm-long cracked fracture line runs medially from the medial end of the

artificial hiatus towards the *sutura sagittalis*. Because the skull post-mortem deformed in the soil, a large piece of the right parietal bone does not fit perfectly to the other parts of the cranium along the *sutura lambdoidea*, the *sutura sagittalis*, and the fracture lines. Therefore, the dorsal rim of the elongated artificial hiatus does not follow the original structure of the wound. The dorsal part of the *sutura sagittalis* and the right side of the *sutura lambdoidea* show several postmortem hiatuses.

Lesion #4: The elongated aperture (#3) is surrounded by two slightly curved furrows of 4 mm depth with a U-shaped cross section (Figure 7a,b). The structure of the diploe in the furrows is clearly detectable and shows no sign of healing (Figure 7c). The anterior furrow is 75 mm long and 12 mm at its widest diameter, whereas the posterior furrow is 70 mm long and 15 mm at its widest diameter. The surface of these furrows is covered with very fine, approximately

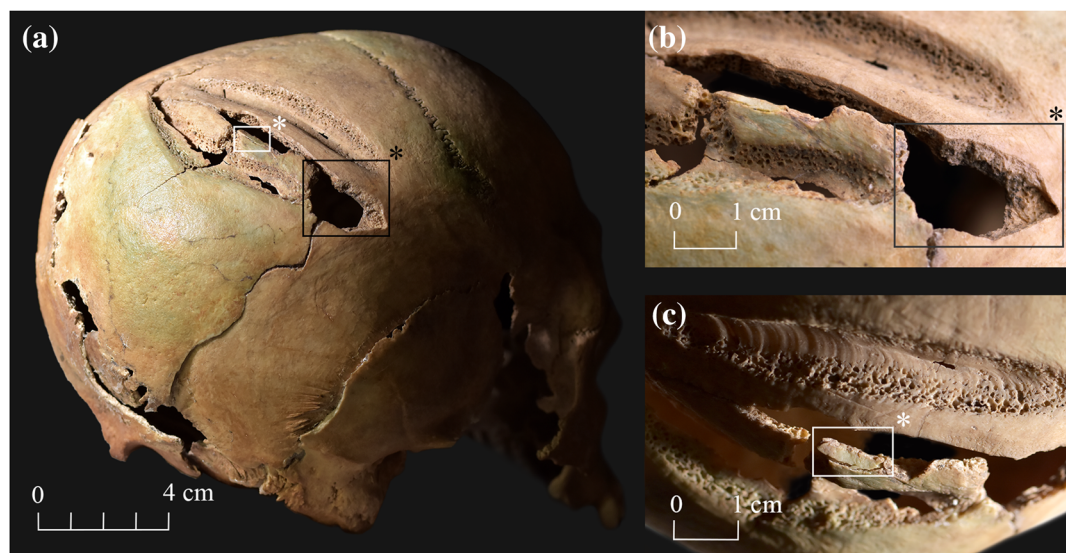
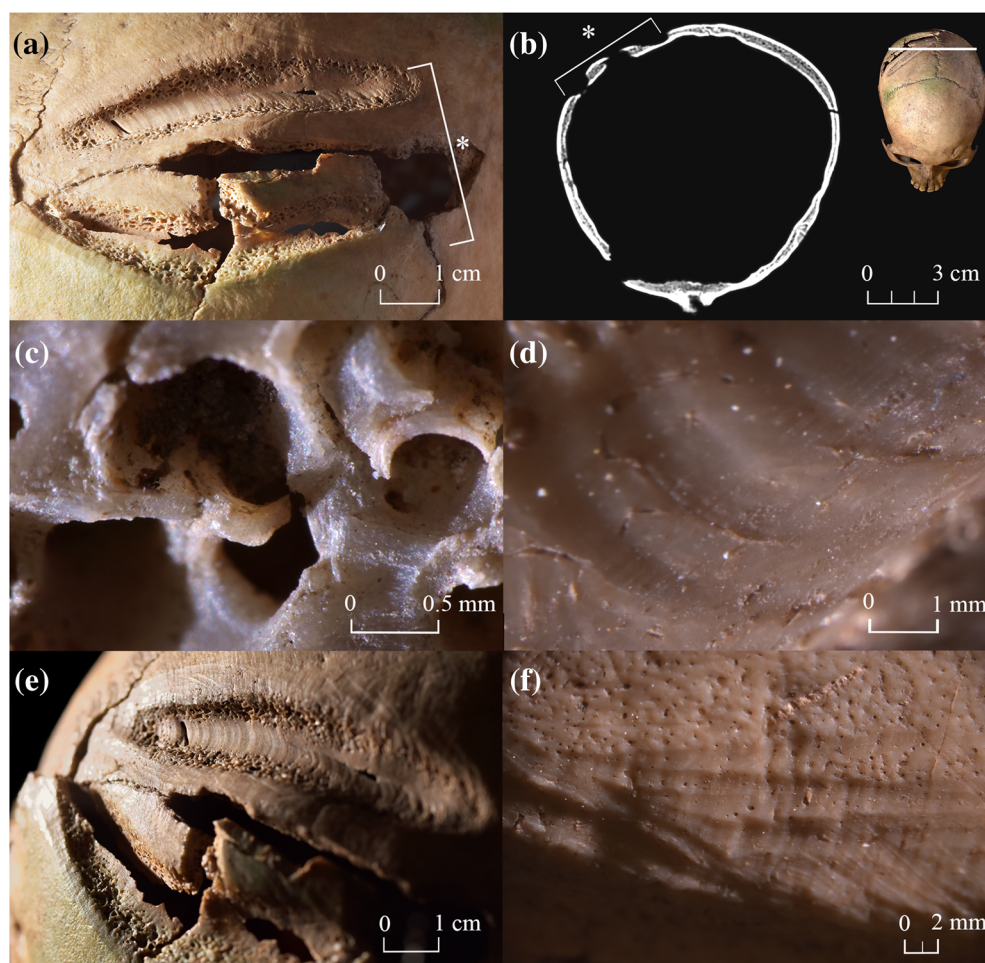


FIGURE 6 Lesion #3. (a) Posterio-lateral view of the cranium. Linear injury in the middle part of the right parietal bone with a teardrop-shaped artificial hiatus and slightly undulating fracture lines expanded from the wound. (b) Posterio-lateral view of the cranium. Teardrop-shaped artificial hiatus at the lateral section of the lesion in square. (c) Antero-superior view of the cranium. In square: bone fragment on the dorsal rim of the medial section implying perimortem trauma [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 7 Lesion #4.

(a) Posterio-lateral view of the cranium. Slightly curved furrows around Lesion #3. (b) Computed tomography in coronal plane from the signed area, showing the U-shaped cross-section of the furrows with the artificial hiatus of Lesion #3 between them. (c) Stereomicroscope image from superior view. The absence of the healing process on the surface of the cells of the diploe. (d) Stereomicroscope image from superior view. The U-shaped grooves inside the furrow and the fine longitudinal lines, which stand at the right angle to the grooves. (e) Lateral view of the cranium. Fine semicircular grooves on the surface of these furrows and fine linear scratch marks in the proximity of the furrows. (f) Stereomicroscope image from superior view. Deeper, U-sectioned and shallower, parallel fine linear scratch marks next to the furrow on the anterior side [Colour figure can be viewed at wileyonlinelibrary.com]



0.5-mm-wide semicircular parallel grooves approximately 70° to the longitudinal axis of the lesions. The grooves are not perfectly parallel with each other, though it is very difficult to see with the naked eye (Figure 7d,e). On the stereomicroscopic images, fine longitudinal lines are also visible on the bottom of the furrow. These lines are mostly parallel with the furrow and stand at the right angle to the grooves (Figure 7d). The furrows reach the internal table of the cranial vault, which is thinned and penetrated in a 4-mm-long and 1-mm-wide section of the anterior lesion, and exhibit possible postmortem damages in the posterior one. A 5-mm-long and 1-mm-wide blood vessel impression is also observable in the anterior curve, 20 mm from the *sutura sagittalis*. Besides, approximately 1-mm-wide fine linear scratch marks are detected on the outer table in the proximity of both furrows in a maximum of 10-mm-wide area. On the stereomicroscopic image, it is detectable that some of the linear scratch marks are a little

deeper and have a U-section, whereas the others are shallower and parallel to each other (Figure 7f).

4.3 | Activity-related changes

Entheseal changes were observed on the attachment sites of the *musculus (m.) triceps brachii caput longum* on the left scapula, the *ligamentum costoclaviculare*, and the *m. deltoideus* on the left clavicle, *m. pectoralis major* on the left humerus, *m. brachialis* and *m. supinator* on the left ulna, as well as *m. flexor digitorum brevis* on the left calcaneus (Figure 8). List and description of entheseal lesions observed are included in Table 1. The bones of the right side cannot be examined in most cases because of taphonomic damage. No joint changes were observed on the available bones, and no further trauma was detected

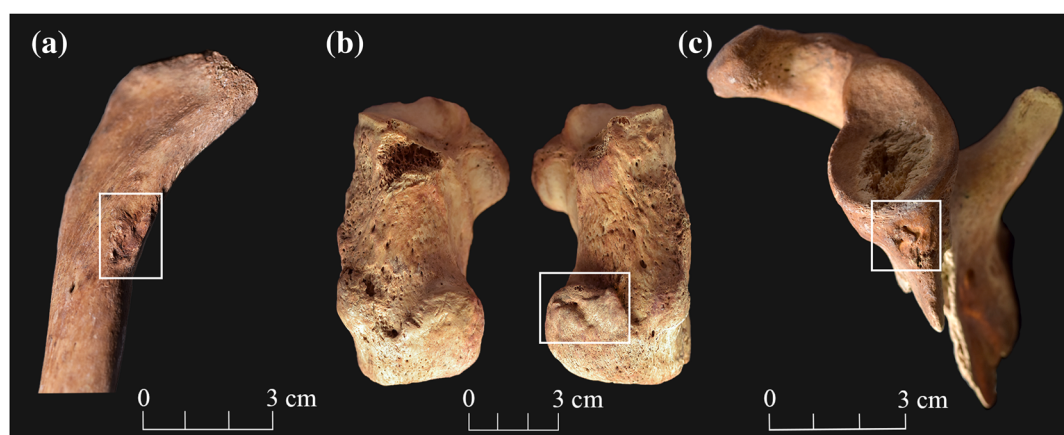


FIGURE 8 Enthesal changes on the postcranial bones of Sárretudvari-Poroshalom grave No. 1. (a) Antero-superior view of the clavicle. Enthesal changes in the form of rugosity and osteophytes on the attachment site of *m. deltoideus*. (b) Inferior view of the calcaneus. Enthesal changes in the form of bone ridges and osteophytes on the attachment site of *m. flexor digitorum brevis*. (c) Inferio-lateral view of the scapula. Enthesal changes in the form of osteophytes and surface rugosity on the attachment site of *m. triceps brachii caput longum* [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 List and description of the entheses and the muscular function observed in the study (only the ones that showed changes are included)

Bone	Site of the observed changes	Muscles attached to the site	Function
Scapula	<i>tuberculum infraglenoidale</i>	<i>m. triceps brachii caput longum</i>	Adduction of the arm in the glenohumeral joint, and extension of the forearm in the elbow joint.
Clavicle	<i>impressio ligamenti costoclavicularis</i>	<i>ligamentum costoclaviculare</i>	Inhibit joint movements. Shows the extent of movements initiated by the muscles adhering to the upper limb and the scapula.
	<i>extremitas acromialis claviculae, anterior</i>	<i>m. deltoideus</i> ^a	Adduction, medial rotation and flexion of the arm in the glenohumeral joint.
Humerus	<i>crista tuberculum majoris</i>	<i>m. pectoralis major</i> ^a	Adduction, medial rotation, and flexion of the elevated arm.
Ulna	<i>tuberositas ulnae</i>	<i>m. brachialis</i> ^a	Flexion of the upper limb in the elbow joint.
	<i>crista supinatoris</i>	<i>m. supinator</i> ^a	Supination of the hand in radio-ulnar joints.
Calcaneus	<i>tuberculum calcanei medial process</i>	<i>m. flexor digitorum brevis</i>	Flexion of the toes in the metatarsophalangeal joint and interphalangeal joint.

Note: *m.*: *musculus*.

^aIndicates entheses showing changes in a significantly higher frequency in the case of individuals buried with weapons in the 10th-century cemetery of Sárretudvari-Hízóföld, compared with nonwarrior individuals (Tihanyi, 2020).

on the postcranial skeleton. Robusticity indices of the bones are presented in Table 2. Additional data are given in Table S1.

5 | DISCUSSION

5.1 | Diagnosis of the traumatic lesions and activity-related changes

Traces of healing are clearly visible in two injuries (#1 and #2); therefore, they must have occurred *ante mortem*, but their relative temporal relationships could not be defined. The observed three traumatic lesions occurred during at least two independent events.

Lesion #1: There is no abnormal blood vessel impression and new bone formation in the area of the lesion; therefore, there is no sign of inflammation (Ortner, 2003). The flat and irregular shape of the rim, the location of the lesion, and the lack of cranium penetration reduce the probability of abscess or meningocele (Ortner, 2003; Verano, 2016). The lesion did not show any of the characteristics of symbolic trepanation, as well (Bereczki et al., 2015; Mednikova, 2003; Nemeskéri, Harsányi, & Acsádi, 1960; Simalcsik, 2018; Vlček, 1995). Moreover, the CT analysis showed that the external cortical layer was not thinned but sunk into the frontal cavity, which also excludes the osteolytic or symbolic trepanation origin. Therefore, this lesion should be considered as blunt force trauma based on the depressed and kidney-

TABLE 2 List and description of indices of robusticity and shape of the long bones preserved (only the ones that were measurable are included)

Bone	Index name	Formula and definition	Values		Comparative data (Berthon, 2019 Tihanyi, 2020)			
			Left	Right	ARM/RD		LIS	
					Left	Right	Left	Left
Scapula	<i>cavitas glenoidalis</i> length-width index	100× (transverse diameter of the glenoid fossa (M13)/vertical diameter of the glenoid fossa (M12))	75	—	72.62	71.13	75.06	74.8
Clavicula	Robusticity index	100× (circumference of midshaft (M6)/maximal length (M1))	29	—	24.11	24.75	23.88	24.37
Humerus	Head cross-sectional index	100× (transverse diameter of the head (M9a)/longitudinal diameter of the head (M10a))	93.75	—	89.9	90.89	93.66	93.20
Ulna	Diaphysis diameter index	100× (dorso-ventral shaft diameter (M11)/transverse shaft diameter (M12))	80.55	83.33	77.49	79.09	74.91	75.36
Radius	Robusticity index	100× (minimal circumference (M3)/physiological length (M2))	19.17	—	18.13	18.73	17.71	17.93
	Diaphysis diameter index	100× (minimum sagittal shaft diameter (M5)/a maximum transverse shaft diameter (M4))	69.44	—	66.09	64.83	69.98	67.95
	Distalis epiphyseal breadth index	100× (distal maximum breadth (M5 (6))/physiological length (M2))	13.14	—	15.09	15.15	13.76	13.72
Femur	Epicondylar width-transverse shaft diameter index	100× (mediolateral diameter of midshaft (M7)/epicondylar width (M21))	39.53	39.53	35.95	35.61	34.23	33.72
Tibia	Robusticity index	100× (minimum circumference of shaft (M10b)/physiological length (M2))	22.16	22.68	21.62	21.85	21.43	21.64
	Platycnemic index	100× (mediolateral diameter at nutrient foramen (M9a)/anteroposterior diameter at nutrient foramen (M8a))	71.05	76.32	66.73	65.71	68.56	67.35
Fibula	Robusticity index	100× (minimum circumference of midshaft (M4a)/maximum length (M1))	10.87	10.99	10.37	10.80	9.90	10.26
Talus	Length-width index	100× (talar width (M2)/talar length (M1))	80.36	80.36	79.73	79.61	74.41	74.98
	Length-height index	100× (talar height (M3)/talar length (M1))	60.71	60.71	60.86	60.48	57.65	57.51
Calcaneus	Length-height index	100× (height of body (M4)/total length (M1a))	61.74	61.84	52.97	52.70	48.76	48.77

Note: Measurement codes from Martin (re-edited by Bräuer, 1988). ARM/RD: average values of individuals who were buried with weapon- (ARM; Tihanyi, 2020) and/or horse-riding- (RD; Berthon, 2019) related grave goods in Sárrétudvari-Hízófold; LIS: average values of nonrider and nonwarrior individuals used for comparison by Berthon et al. (2019) and Tihanyi et al. (2020). The indices with background have a closer similarity with the ARM/RD groups

shaped “small contact area” (e.g., Aufderheide & Rodríguez-Martín, 1998; Cohen et al., 2014; Ortner, 2003).

Lesion #2: It could be the trace of a possible sharp force trauma (e.g., Aufderheide & Rodríguez-Martín, 1998; Cohen et al., 2014; Ortner, 2003), which cracked the left parietal in a fronto-occipital direction. Because of the inflammation during the healing process, the strongly remodeled bone surface obscures the original size and extent of the trauma and traces of possible curative interventions. Therefore, no conclusions can be drawn about the weapon used. However, the deformation of the skull shape may refer to the injury having happened in adolescence, before the skull growth was completely finished.

Lesion #3: Unlike the previous ones, lesions #3 and #4 show no sign of healing; therefore, they could be a consequence of perimortem events. Based on the dimensions and the mainly flat and inclined edge of lesion #3, sharp force trauma is assumed. The course of the medial 30-mm-long crack and the lateral 75-mm-long fracture line, as well as the bone fragment leaning inwards to the middle of the lesion prove that the subject sustained the injury shortly before his death. The teardrop-shaped artificial hiatus located on the lateral part of the wound presumably occurred when the weapon was pulled out. Considering the military traditions of the era, the described characteristics refer to some kind of short-edged weapon, which may have been a type of ax (e.g., Anda, 1951; Kalmár, 1971).

The assumption that during his lifetime, the individual engaged in weapon-related activities is confirmed by the archeological data. The grave goods perfectly fit the descriptions of 10th-century-CE Hungarian mounted archers (e.g., Veszprémy, 2017) and the characteristics of the graves with weapon-related grave goods in the 10th-century-CE Carpathian Basin (e.g., Révész, 1996). Besides, the status symbols, such as the belt with gilded silver ornaments (Révész, 1996) found in the grave, suggest that the individual may have been a high-ranking military leader in his community.

However, the representative value of the grave goods (e.g., Härke, 1992, 1997), such as the weapons, is still a controversial issue; thus, the grave goods alone are not enough to evaluate the past lifestyle. In the recent decades, the investigation of the so-called activity-related skeletal changes opened new perspectives concerning the reconstruction of possible lifestyle, and especially the horse-riding- and weapon-related activities (e.g., Berthon et al., 2019; Pálfi & Dutour, 1996; Rhodes & Knüsel, 2005; Thomas, 2014; Tihanyi et al., 2020).

Activity-related changes are influenced by many factors, such as sex, age, pathology, and population differences (e.g., Michopoulou et al., 2015; Nikita et al., 2019; Thomas, 2014; Waldron, 2009), but in our case, the most limiting effect of the investigation was bone preservation. The young age-at-death of the studied individual provides an opportunity to evaluate entheses and joint changes. However, age may also have contributed to the fact that joint changes could not be registered on the available bones. On the other hand, the entheses showing lesions and the indices of shape and robusticity (Tables 1 and 2) suggest the repetitive load of the shoulder (e.g., *m. deltoideus*), trunk (e.g., *m. pectoralis major*), arm (e.g., *m. triceps brachii*), and forearm/hand muscles (e.g., *m. brachialis* and *m. supinator*), as well as the legs

and feet (e.g., *m. flexor digitorum brevis*) of the lower limb. This general load suggests a complex form of movement and muscle work, which requires the elevation and rotation of the arms, flexion, and supination of the forearms. Certainly, these are not specific to one activity, but compatible with the anatomical conditions described on contemporary archers (e.g., Axford, 1995). Based on literature data, the observed phenomena show analogies with the localization of lesions and average ratios of metric values described in other skeletal series (i.e., other 10th-century-CE series from the Carpathian Basin) with weapon-related and/or horse-riding-related equipment (Dutour, 1986; Pálfi & Dutour, 1996; Rhodes & Knüsel, 2005; Thomas, 2014), and especially the 10th-century-CE series of Sárretudvari-Hízófold (e.g., Berthon, 2019; Tihanyi, 2020) (Tables 1 & 2). Although, there is no known unique pattern, the registered changes can correspond to activities including horse riding and archery.

The results of the analysis of activity-related changes and archeological examinations suggest that the injuries described on the skull may have been, indeed, acquired during activities connected to the well-known military lifestyle of these populations (Tóth, 2015).

Lesion #4: Based on the shape, dimensions, and fine grooves on the surface of the two curved furrows, they cannot be considered as a weapon-induced injury, and it should be interpreted as a deliberate intervention, a trepanation.

If the surgeon did not intend to penetrate the lamina interna, the two furrows could be interpreted as a symbolic trepanation. However, the shape of the lesion cannot be paralleled with most of the known symbolic trepanations (Bereczki et al., 2015; Mednikova, 2003; Nemeskéri, Harsányi, & Acsádi, 1960; Simalcik, 2018; Vlček, 1995); furthermore, the localization is not typical for those either. A symbolic trepanation would not have had any apparent medical benefits to the healing process of the original injury. Therefore, we think that furrows should not be interpreted as the signs of a symbolic trepanation.

If the surgeon did intend to penetrate the lamina interna, the two furrows should be interpreted as an incomplete surgical trepanation. On this particular skull, the two curved furrows surround a probable weapon-induced injury, so the most likely reason for the intervention is the treatment of this wound. Based on the above, the surgical trepanation was aimed to remove the damaged area but remained unfinished/incomplete.

5.2 | Reconstruction of the method of trepanation

One of the main reasons for making surgical trepanation can be to treat head wounds (e.g., Gresky et al., 2016; Jørgensen, 1988; Nemeskéri et al., 1965; Verano, 2003). One of the first descriptions about the trepanation process was recorded by Hippocrates in the Hippocratic Corpus, stating that in case of certain head injuries with cracked, splintered edges, surgery should be performed to avoid inflammation of the meninges, and the wound should be cleansed of the splintered area (Craik, 1998; Hanson, 1999; Tullo, 2010). In this case, performing the surgery may have already contributed to a faster recovery (e.g., Kushner et al., 2018; Sperati, 2007).

One of the most effective ways to remove part of the skull vault is to take out a disk of bone in one piece, which is a characteristic feature of most of the described trepanation methods (e.g., Aufderheide & Rodríguez-Martín, 1998; Parry, 1940). With the case of the Sárrétudvari-Poroshalom grave No. 1, we can gain a rare insight into the process.

As a first step, after the removal of the external soft tissue, the intact, undamaged bone surface was carefully deepened in two curved furrows, 5 mm from the wound. Based on the visible fine scraping marks on the surface of the bone, the furrows were deepened with parallel chiseling movements, using either a sharp bladed instrument held to the surface at a certain angle, or a fine chisel or gouge with a U-shaped cross section, or some kind of a rotating device (e.g., drill) held parallel with the surface. In the latter case, our findings would probably indicate a formerly unknown method of drilling.

According to our current understanding, the gouge method seems to be most likely of the abovementioned possibilities. The stereomicroscopic images reinforce the hypothesis of the use of U-shaped gouge. The fine longitudinal lines on the bottom of the furrow are probably caused by the fine unevenness of the U-shaped blade in question and cannot be created with a rotating device. Similar bone gouges are still used in modern medicine, and the 10th-century-CE population also had the technical development to produce such tools (Fodor, 1996). Remains of a hypothetical trepan have been known from the 10th-century-CE Tiszaeszlár-Bashalom site, the geometry of which approximately matches our lesions. The trepan has been reconstructed in two different ways before (Dienes, 1956; Fodor, 1996), but the actual structure of the corroded tool is still unknown. Therefore, our results may suggest a possible mode of tool use, and may help future reconstruction attempts concerning the Tiszaeszlár-Bashalom trepan. On the other hand, the application of U-shaped gouge formerly has not been documented in the literature, which opens a new perspective both in the osteological investigation of these interventions and the archeological research concerning ancient medical technology.

Our findings also show that the final superficial retouch (Nemeskéri et al., 1965) was probably performed parallel with the main intervention (as seen on the outer edges of the arched furrows) instead of being delayed until the very end of the operation. The fine linear scratch marks detected in the proximity of both furrows are either part of the clean-up process, or they show the initial removal of the periosteum before the beginning of the bone removal. It is presumable that the deeper U-sectioned linear scratch marks may have been made with the same tool, which was used to form the furrows. The shallower parallel scratch marks were probably created with scraping moves, with another knife-like tool, held at an acute angle to the surface.

This process of deepening the furrows would have been continued until the two arches merged. After that the lamina interna would have been finally pierced through, so that the damaged area became removable mostly in one piece. The morphology of several published surgical trepanations shows that the irregularities of the bony edge of

the trepanation opening were often adjusted as a last step (Aufderheide & Rodríguez-Martín, 1998; Bereczki, 2013; Nemeskéri et al., 1965; Ortner, 2003).

5.3 | A new perspective for classifying trepanations

Our new case seems to show similarities with several methods described earlier, including the grooving method (e.g., Aufderheide & Rodríguez-Martín, 1998; Gross, 2009; Lisowski, 1967), the push-plow method (Parry, 1940), a variation of the scraping method (Ortner, 2003), and the trepanation method described in other Hungarian materials (Nemeskéri et al., 1965). However, our reconstructed method of intervention also differs to a certain extent from each of these methods. The application of a U-shaped gouge, in particular, has never been documented in any material from the Carpathian Basin, and we have no knowledge of any international findings either. However, this method may have been used in other previously described cases of surgery, but the complete nature of the trepanation or advanced healing in those cases had not allowed the reconstruction of the precise method. Consequently, a revision of previously described cases in this respect is necessary.

It seems very likely that we should not think of trepanation as an intervention that is permanent and canonical in certain cultures and historic periods concerning its tool use and methodology. Even though trepanations may have a preferred or common way of intervention in certain moments in human history, no two lesions are identical. We must keep in mind that although trepanations may have a traditional aspect, each instance of intervention is applied to the unique circumstances at hand (Gresky et al., 2016; Tullo, 2010). Categorization based on intervention method is also hindered by different stages of healing and remodeling.

If our assumption is correct and there are traces of an unfinished/incomplete surgical trepanation on the skull, the question arises as to what might have been the reason for the precocious termination of the surgery. The most likely reason is that the individual died during the intervention. This can be the result of the original soft tissue trauma or even major blood loss during surgery. The time between the injury and death cannot be accurately estimated only from the macromorphological characteristics of the bone, as it is influenced by a number of factors, and first visible signs of healing may take weeks to appear on the bone surface (e.g., Boyd, 2018; Cappella et al., 2019; Malone et al., 2011). Considering this, within the present methodological opportunities, we cannot be certain in the exact chronology and reason for the discontinuation of surgery and the death of the individual.

The case discussed in this paper has paramount importance not only for providing more detailed knowledge of past medical practices and a unique U-shaped tool but also for the methodology of the research field. The inherent problems in the designation of surgical (or complete) and symbolic (or incomplete, or skullmark) trepanation have already been discussed in previous research (Bartucz, 1950;

Bereczki et al., 2015; Nemeskéri, Harsányi, & Acsádi, 1960), but both pairs of terms remain in use to this day.

This is a controversial theoretical issue, but it can also pose practical questions and hinder the diagnosis and interpretation of other presumably unfinished trepanations like the present Sárrétudvari-Poroshalom case. Moreover, the same issue also applies to long healed interventions, where most marks and traces of the intervention are masked by remodeling (Bereczki, 2013; Bereczki et al., 2015; Verano, 2016).

The main problem is that we must assume the intention of the surgeon concerning the completed procedure, when categorizing trepanations. We must also consider how unfinished interventions at different stages of preparation may look like in their fresh perimortem state, and after varying periods of survival and healing. Based on this idea, most aspects of categorization are questionable.

On the other hand, the term “incomplete” implies interruption of a process, so in this sense, both surgical and symbolic trepanation can be incomplete. Based on this, the term “incomplete” trepanation should not be used as synonymous with “symbolic trepanation” or “skullmark.” With ongoing research in the trepanned material of Hungary, we hope to clarify some related issues in the near future.

6 | CONCLUSION

The material of our study is a newly discovered case of 10th-century-CE surgical trepanation found in the material of Sárrétudvari-Poroshalom, Hungary. The significance of the case is given by the incompleteness of the surgery and the method of intervention that it allows us to investigate. We have acquired completely new information regarding the use of a U-shaped gouge in ancient cranial surgery, which opens a new perspective both for the osteological investigation of these interventions and the archeological research concerning ancient medical technology. Our results may suggest a possible mode of tool use and aid future reconstruction attempts concerning the hypothesized 10th-century-CE trepan from Tiszaeszlár-Bashalom. In addition, it supports the long-held hypothesis that one of the possible intentions of surgical trepanation is the cure of a primary trauma.

The incomplete nature of the trepanation emphasizes some methodological problems of the research field, as well. Because both surgical and symbolic trepanation can be incomplete, we concluded that the term “incomplete” should not be used as synonymous with “symbolic” or “skullmark.”

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CONFLICT OF INTEREST

None declared.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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REFERENCES

- Anda, T. (1951). Recherches archéologiques sur la pratique médicale des hongrois à l'époque de la Conquête de pays. *Acta Archaeologica Hungarica*, 1, 251–316.
- Andrushko, V. A., & Verano, J. W. (2008). Prehistoric trepanation in the Cuzco region of Peru: A view into an ancient Andean practice. *American Journal of Physical Anthropology*, 137, 4–13.
- Aufderheide, A. C., & Rodríguez-Martín, C. (1998). *The Cambridge Encyclopedia of Human Paleopathology*. Cambridge University Press.
- Axford, R. (1995). *Archery anatomy: An introduction to techniques for improved performance*. Souvenir Press.
- Bartucz, L. (1950). Adatok a koponyalékelés (trepanáció) és a bregmasebek kapcsolatának problémájához magyarországi népvándorláskori koponyák alapján. *A Szegedi Tudományegyetem Biológiai Intézetének Évkönyve*, 1, 389–435.
- Bartucz, L. (1966). *A praehistorikus trepanáció és orvostörténeti vonatkozású sírleletek. Palaeopathologia III. Országos Orvostörténeti Könyvtár*.
- Bereczki, Zs. (2013). *Az avarok trepanációs szokásai a Dél-Alföld bioarcheológiai leletanyagának tükrében*. Dissertation. University of Szeged.
- Bereczki, Zs., Marcsik, A., & Paja, L. (2003). New cases of trephination from a 10–11th century Hungarian site. *Papers on Anthropology*, 12, 21–31.
- Bereczki, Zs., Molnár, E., Marcsik, A., & Pálfi, Gy. (2010). Evidence of surgical trephinations in infants from the 7th–9th centuries AD burial site of Kiskundorozsma-Kettőshatár. *Acta Biologica Szegediensis*, 54(2), 93–98.
- Bereczki, Zs., Molnár, E., Marcsik, A., & Pálfi, Gy. (2015). Rare types of trephination from Hungary shed new light on possible cross-cultural connections in the Carpathian Basin. *International Journal of Osteoarchaeology*, 25(3), 322–333. <https://doi.org/10.1002/oa.2304>
- Berthon, W. (2019). *Bioarchaeological analysis of the mounted archers from the Hungarian Conquest period (10th century): Horse riding and activity-related skeletal changes*. Dissertation. University of Szeged.

- Berthon, W., Tihanyi, B., Kis, L., Révész, L., Coqueugniot, H., Dutour, O., & Pálfi, Gy. (2019). Horse riding and the shape of the acetabulum: Insights from the bioarchaeological analysis of early Hungarian mounted archers (10th century). *International Journal of Osteoarchaeology*, 29, 117–126. <https://doi.org/10.1002/oa.2723>
- Bockenheimer, Ph. (1922). Über bregmanarben und ihre mutmassliche entstehung nach untersuchungen an guanchenschädeln und nach tierexperimenten. *Zeitschrift für Ethnologie*, 54, 130.
- Boyd, D. C. (2018). The anatomical basis for fracture repair: Recognition of the healing continuum and its forensic applications to investigations of pediatric and elderly abuse. In C. C. Boyd & D. C. Boyd (Eds.), *Forensic anthropology: Theoretical framework and scientific basis* (pp. 151–200). Wiley.
- Bräuer, G. (1988). Osteometrie. In R. Knussman (Ed.), *Anthropologie, Handbuch der vergleichenden Biologie des Menschen. Zugleich 4. Auflage des Lehrbuchs der Anthropologie begründet von R. Martin. Band I/1. Wesen und Methoden der Anthropologie* (pp. 160–232). Gustav Fischer Verlag.
- Broca, P. (1867). Cas singulier de trépanation chez les Incas. *Bulletins de la Société d'Anthropologie de Paris*, 2(2), 403–408.
- Cappella, A., de Boer, H. H., Cammilli, P., De Angelis, D., Messina, C., Sconfienza, L. M., Sardanelli, F., Sforza, C., & Cattaneo, C. (2019). Histologic and radiological analysis on bone fractures: Estimation of post-traumatic survival time in skeletal trauma. *Forensic Science International*, 302, 109909. <https://doi.org/10.1016/j.forsciint.2019.109909>
- Cohen, H., Sarie, I., Medlej, B., Bocquentin, F., Toledano, T., Hershkovitz, I., & Slona, V. (2014). Trauma to the skull: A historical perspective from the Southern Levant (4300BCE–1917CE). *International Journal of Osteoarchaeology*, 24(6), 722–736. <https://doi.org/10.1002/oa.2258>
- Craik, E. M. (Ed.) (1998). *Hippocrates, places in man*. Clarendon Press.
- Dienes, I. (1956). Un Cimetière de Hongrois conquérants à Bashalom. *Acta Archaeologica. Academiae Scientiarum Hungaricae*, 7, 245–273.
- Dutour, O. (1986). Enthesopathies (lesions of muscular insertions) as indicators of the activities of Neolithic Saharan populations. *American Journal of Physical Anthropology*, 71, 221–224. <https://doi.org/10.1002/ajpa.1330710209>
- Éry, K., Kralovánszky, A., & Nemeskéri, J. (1963). Történeti népszerűségek rekonstrukciójának reprezentációja. *Anthropologiai Közlemények*, 7, 41–90.
- Fodor, I. (1996). Tiszaeszlár–Bashalom. In I. Fodor, L. Révész, M. Wolf, & I. M. Nepper (Eds.), *The ancient Hungarians. Exhibition catalogue* (pp. 185–189). Hungarian National Museum.
- Gresky, J., Batieva, E., Kitova, A., Kalmykov, A., Belinskiy, A., Reinhold, S., & Berezina, N. (2016). New cases of trepanations from the 5th to 3rd millennia BC in Southern Russia in the context of previous research: Possible evidence for a ritually motivated tradition of cranial surgery? *American Journal of Physical Anthropology*, 160(4), 665–682. <https://doi.org/10.1002/ajpa.22996>
- Gross, C. G. (2009). *A hole in the head: More tales in the history of neuroscience*. MIT Press.
- Hanson, M. (Ed.) (1999). *Hippocrates, on head wounds*. Akademie Verlag.
- Härke, H. (1992). Angelsächsische Waffengräber des 5. bis 7. In *Jahrhunderts (Zeitschrift für Archäologie des Mittelalters 6.)*. Rheinland-Verlag and Habelt.
- Härke, H. (1997). The nature of burial data. In C. K. Jensen & K. H. Nielsen (Eds.), *Burial and society: The chronological and social analysis of archaeological burial data* (pp. 19–27). Aarhus University Press.
- Henderson, C. Y., Mariotti, V., Pany-Kucera, D., Villotte, S., & Wilczak, C. A. (2016). The new ‘Coimbra method’: A biologically appropriate method for recording specific features of fibrocartilaginous enthesal changes. *International Journal of Osteoarchaeology*, 26, 925–932. <https://doi.org/10.1002/oa.2477>
- Jordanov, J., Dimitrova, Br., & Nikolov, Sp. (1988). Symbolic trepanations of skulls from the middle ages (IXth–Xth century) in Bulgaria. *Acta Neurochirurgica*, 92, 15–18.
- Jørgensen, J. B. (1988). Trepanation as a therapeutic measure in ancient (pre-Inka) Peru. *Acta Neurochirurgica*, 93, 3–5. <https://doi.org/10.1007/BF01409893>
- Józsa, L., & Fóthi, E. (2007). Trepanált koponyák a Kárpát-medencében. *Folia Anthropologica*, 6, 5–18.
- Kalmár, J. (1971). *Régi magyar fegyverek*. Natura.
- Knussman, R., & Martin, R. (1988). *Anthropologie I*. Gustav Fischer Verlag.
- Kushner, D. S., Verano, J. W., & Titelbaum, A. R. (2018). Trepanation procedures/outcomes: Comparison of prehistoric Peru with other ancient, medieval, and American civil war cranial surgery. *World Neurosurgery*, 114, 245–251. <https://doi.org/10.1016/j.wneu.2018.03.143>
- Lisowski, F. P. (1967). Prehistoric and early historic trepanation. In D. Brothwell & A. T. Sandison (Eds.), *Diseases in antiquity* (pp. 651–672). Charles C. Thomas.
- Loth, S. R., & Işcan, M. Y. (1989). Morphological assessment of age in the adult: The thoracic region. In M. Y. Işcan (Ed.), *Age markers in the human skeleton* (pp. 105–135). Charles C. Thomas.
- Malone, C. A., Sauer, N. J., & Fenton, T. W. (2011). A radiographic assessment of pediatric fracture healing and time since injury. *Journal of Forensic Sciences*, 56(5), 1123–1230. <https://doi.org/10.1111/j.1556-4029.2011.01820.x>
- Mariotti, V., Facchini, F., & Belcastro, M. G. (2007). The study of entheses: Proposal of a standardised scoring method for twenty-three entheses of the postcranial skeleton. *Collegium Antropologicum*, 31, 291–313.
- Mednikova, M. B. (2003). Ritual initiation in prehistoric Eurasians based on cranial data: Symbolic trephinations. *Archaeology, Ethnology and Anthropology of Eurasia*, 1, 147–156.
- Michopoulou, E., Nikita, E., & Valakos, E. (2015). Evaluating the efficiency of different recording protocols for enthesal changes in regards to expressing activity patterns using archival data and cross-sectional geometric properties. *American Journal of Physical Anthropology*, 158, 557–568. <https://doi.org/10.1002/ajpa.22822>
- Molnár, M., Janovics, R., Major, I., Orsovski, J., Gönczi, R., Veres, M., Leonard, A. G., Castle, S. M., Lange, T. E., Wacker, L., Hajdas, I., & Jull, A. J. T. (2013). Status report of the new AMS C-14 preparation lab of the Hertelendi Laboratory of Environmental Studies (Debrecen, Hungary). *Radiocarbon*, 55(2–3), 665–676. <https://doi.org/10.1017/S0038222200057829>
- Nemeskéri, J., Éry, K., & Kralovánszky, A. (1960). Methoden zur Diagnose des Lebensalters von Skelettfunden. *Anthropologischer Anzeiger*, 24, 71–88.
- Nemeskéri, J., Harsányi, L., & Acsádi, Gy. (1960). A magyarországi jelképes trepanáció. *Anthropologiai Közlemények*, 4, 3–30.
- Nemeskéri, J., Kralovánszky, A., & Harsányi, L. (1965). Trephined skulls from the tenth century. *Acta Archaeologica Hungarica*, 17, 343–367.
- Neparáczki, E., Maróti, Z., Kalmár, T., Kocsy, K., Maár, K., Bihari, P., Nagy, I., Fóthi, E., Pap, I., Kustár, Á., Pálfi, G. Y., Raskó, I., Zink, A., & Török, T. (2018). Mitogenomic data indicate admixture components of Central-Inner Asian and Srubnaya origin in the conquering Hungarians. *PLoS ONE*, 13, e0205920. <https://doi.org/10.1371/journal.pone.0205920>
- Nepper, I. M. (1996). Sárrétudvari-Poroshalom. In I. Fodor, L. Révész, M. Wolf, & I. M. Nepper (Eds.), *The ancient Hungarians. Exhibition catalogue* (pp. 277–281). Hungarian National Museum.
- Nepper, I. M. (2002). *Hajdú-Bihar megye 10–11. századi sírleletei I–II (Magyarország honfoglalás kori és kora Árpád-kori sírleletei 3.)*. Déri Múzeum, Magyar Nemzeti Múzeum, Magyar Tudományos Akadémia Régészeti Intézete.
- Nikita, E., Xanthopoulou, P., Bertsatos, A., Chovalopoulou, M. E., & Hafez, I. (2019). A three-dimensional digital microscopic investigation of enthesal changes as skeletal activity markers. *American Journal of Physical Anthropology*, 169, 704–713. <https://doi.org/10.1002/ajpa.23850>
- Ortner, D. J. (2003). *Identification of pathological conditions in human skeletal remains*. Academic Press.

- Pálfi, Gy., & Dutour, O. (1996). Activity-induced skeletal markers in historical anthropological material. *International Journal of Anthropology*, 11, 41–55. <https://doi.org/10.1007/BF02442202>
- Parry, T. W. (1940). A comparison between two roundels removed by surgical holing from two prehistoric skulls, lately excavated in the county of Dorset; together with a full description of the push-plough method of operation that was probably employed. *Man*, 40, 33–35. <https://doi.org/10.2307/2792279>
- Révész, L. (1996). A karosi honfoglalás kori temetők. Régészeti adatok a Felső-Tisza-vidék X. századi történetéhez (Magyarország honfoglalás kori és kora Árpád-kori sírleletei 1.). Herman Ottó Múzeum, Magyar Nemzeti Múzeum.
- Rhodes, J. A., & Knüsel, C. J. (2005). Activity-related skeletal change in medieval humeri: Cross-sectional and architectural alterations. *American Journal of Physical Anthropology*, 128, 536–546. <https://doi.org/10.1002/ajpa.20147>
- Simalcsik, A. (2018). New cases of symbolic trepanation from the medieval period discovered in the space between Pruth and Dniester. *Anastasis. Research in Medieval Culture and Art*, 5(1), 146–172.
- Skoglund, P., Storå, J., Götherström, A., & Jakobsson, M. (2013). Accurate sex identification of ancient human remains using DNA shotgun sequencing. *Journal of Archaeological Science*, 40, 4477–4482.
- Sperati, G. (2007). Craniotomy through the ages. *Acta Otorhinolaryngologica Italica*, 27, 151–156.
- Szilvássy, J. (1978). Ein Method zur Altersbestimmung mit Hilfe der sterilen Gelenkflächen der Schlüsselbeine. *Mitteilungen der Anthropologischen Gesellschaft in Wien*, 61, 1–28.
- Thomas, A. (2014). Bioarchaeology of the middle Neolithic: Evidence for archery among early European farmers. *American Journal of Physical Anthropology*, 154, 279–290. <https://doi.org/10.1002/ajpa.22504>
- Tihanyi, B. (2020). századi fegyveresek aktivitás okozta szkeletális elváltozásainak összehasonlító vizsgálata. A fegyvermelléklet adás szokásának bioarchaeológiai megközelítése. Dissertation. University of Szeged.
- Tihanyi, B., Berthon, W., Kis, L., Váradi, O. A., Dutour, O., Révész, L., & Pálfi, Gy. (2020). “Brothers in arms”: Activity-related skeletal changes observed on the humerus of individuals buried with and without weapons from the 10th-century CE Carpathian Basin. *International Journal of Osteoarchaeology*, 30(6), 798–810. <https://doi.org/10.1002/oa.2910>
- Tóth, S. L. (2015). A magyar törzsszövetség politikai életrajza. A magyarság a 9–10. században. Belvedere Meridionale.
- Tullo, E. (2010). Trepanation and Roman medicine: A comparison of osteoarchaeological remains, material culture and written texts. *Royal College of Physicians of Edinburgh*, 40, 165–171. <https://doi.org/10.4997/jrcpe.2010.215>
- Verano, J. (2003). Trepanation in prehistoric South America: Geographic and temporal trends over 2000 years. In R. Arnott, S. Finger, & C. Smith (Eds.), *Trepanation: History, discovery, theory* (pp. 223–236). Swets and Zeitlinger.
- Verano, J. W. (2016). Differential diagnosis: Trepanation. *International Journal of Paleopathology*, 14, 1–9. <https://doi.org/10.1016/j.ijpp.2016.04.001>
- Veszprémy, L. (2017). A honfoglalás és kalandozás kora. In R. Hermann (Ed.), *Magyarország hadtörténete I.: A kezdetektől 1526-ig* (pp. 65–86). Zrínyi Kiadó.
- Villotte, S., Castex, D., Couallier, V., Dutour, O., Knüsel, C. J., & Henry-Gambier, D. (2010). Enthesopathies as occupational stress markers: Evidence from the upper limb. *American Journal of Physical Anthropology*, 142, 224–234. <https://doi.org/10.1002/ajpa.21217>
- Vlček, E. (1995). Genetische und paläoethnographische Aspekte der Mammutjägerpopulation von Dolni Vestonice. In H. Ullrich (Ed.), *Man and environment in the Palaeolithic: Proceedings of symposium Neuwied (Germany)* (pp. 209–211). Univ. de Liège.
- Waldron, T. (2009). *Palaeopathology*. Cambridge University Press.

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