Neurosurgery During the Bronze Age: A Skull Trepanation in 1900 BC Greece

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Key words
- CT evaluation
- Kirra
- Trephination

Abbreviations and Acronyms
CT: Computed tomography

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OBJECTIVE: **Paleoneurosurgery represents a comparatively new developing direction of neurosurgery dealing with archaeological skull and spine finds and studying their neurosurgical aspects. Trepanation of the cranial vault was a widespread surgical procedure in antiquity and the most convincing evidence of the ancient origin of neurosurgery. The present study considers a case of trepanation from the Middle Bronze Age Greece (1900–1600 B.C.).**

METHODS: **The skull under study belongs to skeletal material unearthed from Kirra, Delphi (Central Greece). Macroscopic examination and palpation, as well as three-dimensional computed tomography, were used in this study.**

RESULTS: **There is osteological evidence that the skull belongs to a man who died at 30–35 years of age. The procedure of trepanation was performed on the right parietal bone. Both macroscopic and computed tomography evaluation demonstrate an intravital bone reaction at the edges of the aperture. Projected on the right surface of the brain, the trepanation is located on the level of the central groove. The small dimensions and the symmetrical shape of this hole give us an indication that it was made by a metal tool.**

CONCLUSION: **We conclude that this paleopathological case provides valuable information about the condition of life and the pre-Hippocratic neurosurgical practice in Bronze Age Greece.**

BACKGROUND

Paleoneurosurgery represents a comparatively new, still-developing aspect of neurosurgery that comprises the identification of archaeological skull and spine finds and the study of their neurosurgical aspects (7, 13). Skull trepanation of the cranial vault, one of the most intriguing paleoneurosurgical techniques, was widespread in antiquity. This neurosurgical operation (also called trephination or trephinement) involves the removal of one or more pieces of bone without causing any damage to the blood vessels, the three membranes that envelop the brain, or the brain itself; it is a procedure that requires both skill and care from the part of the surgeon.

The earliest unequivocal case dates from the Late Neolithic Ages, 7000 years BC at Ensisheim in the French region of Alsace (1), whereas related evidence could perhaps date as far back as 10,000 BC, or the Mesolithic era (18). However, trepanation was well known to prehistoric Europeans (10), Indians (23), and Pre-Columbian populations of South America (8) up to the Arabic and Islamic scholars of the Middle Ages (20).

In trepanation, the skull is perforated via various techniques. Surgical instruments used in the Neolithic period included hand drills of flint and obsidian stone, whereas in the Bronze Age both stone and metal instruments were used. Osteoarchaeological evidence suggests four basic techniques of trepanation (Figure 1): 1) scraping with a rough or abrasive tool until the dura was exposed; 2) using a sharp-point stone to carve a circular piece of bone from the skull; 3) drilling multiple burred holes to create a circle and then cutting the space between the holes to allow removal of a disk of bone—a more dangerous method and therefore probably a rare technique; and 4) making four cross cuts to remove a rectangular piece of bone (15).

The first trepanned skull, the Cuzco skull, located in a place that later offered tens of other trephined skulls, was discovered in the mid-1800s (2). The suggested prehistoric motives for surgery are as follows: therapeutic, that is, to relieve pain or intracranial pressure after head trauma; magical therapy, that is, to release evil spirits or collect cranial amulets; and ritual acts to appease the gods (15). In Europe most of the trepanned skulls belong to men, and the aperture exists on the left side. This seems to be associated with head wounds, particularly cranial fractures sustained in battle (11). Unlike in Europe, however, trepanation in Mexico frequently was applied to women and children, most of whom showed clear evidence of a fracture before trepanation (12).

Hippocrates, the famous doctor who lived in Hellas in the 5th-century BC, was the first to prescribe trepanation. In his essay *On Wounds in the Head*, the father of medicine describes trepanation in detail and recommends it as a therapy for head injuries, especially for head fractures (18, 25).

Trepanation may also have been used for other problems concerning the cranium, such as nontraumatic headaches, treponematoses, median otitis, and

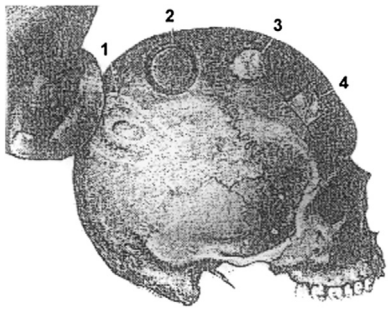

Figure 1. Ancient methods of trepanation. *1,* Scraping with a rough or abrasive tool until the dura is exposed. *2,* Using a sharp-point stone to carve a circular piece of bone from the skull. *3,* Drilling multiple burred holes to create a circle and then cutting the space between the holes to allow removal of a disk of bone. *4,* Making four cross cuts to remove a rectangular piece of bone.

mastoid inflammation and possibly metastatic carcinoma. Both healed and unhealed trepanations may be confused with other findings. For example, a circular lesion may represent a roundel of bone sliced away by a sword, whereas a straight-sided lesion may be attributed to the removal of a fragment from a comminuted fracture (15). Openings in the skull may be the result of infectious factors (14), such as tuberculosis, syphilis, osteomyelitis, or the result of tumors or traumatic conditions at birth. Furthermore, enlarged parietal foramina, "Fenestrae parietalis symmetricae," and bilateral osteoporosis of the parietal bone are the three conditions that may be diagnosed as trepanation in the parietal bones (15). Trepanation-like lesions also may have been produced through rock abrasion or the active acid in the grave or even by the activities of organisms such as beetles, rodents, and porcupines (8, 11).

Trepanation is practiced today in several places of the world, albeit rarely. This ancient operation is still regularly practiced among the Gusii of Kenya, a Bantu people, and theirs is perhaps the last surviving traditional practice of its kind. For the traditional craniotomists of Gusii, the motives for surgery are purely therapeutic or diagnostic and therapeutic. Absolute indications for craniotomy appear to be acute head trauma, where the surgical goal is to remove skull fractures that may be impinging on the brain or to relieve intracranial pressure caused by subdural haematoma. Furthermore, the most common elective procedures are indicated for posttraumatic chronic headaches. The mortality rate has been reported to be <1% (17, 22).

OBJECTIVES

The aim of the present paper is to present one of the most ancient cases of trepanation on a skull excavated in Greece. The approach to this trepanation case (FOP 1/S 9; 1900 BC) has been by macroscopic observation (16), whereas this paper attempts documentation via computed tomography (CT) methods.

As for the archaeological context, Kirra is located approximately 10 km northwest Delphi. According to the archaeological evidence, this ancient city developed significant cultural activity during the Middle Bronze Age (1900–1600 B.C.), 1000 years before the golden period of Delphi Oracle, which followed the First Sacred War (600–590 BC). The skull (FOP 1/S 9) belongs to the archaeological and skeletal material unearthed from Kirra (Central Hellas) in 1984 (24).

MATERIALS AND METHODS

The skull (FOP 1/S 9) was unfortunately the only part of the skeleton that remained intact during the archaeological excavation. Both macroscopic examination and three-dimensional CT were used in this study.

CT Technique

The skull was placed and stabilized in anatomical position with the orbitomeatal line parallel to the section level. The whole cranium was grooved with 1-mm thick fine sections. Next, the cranium was grooved anew with 5-mm thick sections and recomposed with 3.5-mm-thick sections. The power parameters, as well as the technical parameters, are represented in Table 1.

At a later stage there was a three-dimensional reconsruction of the pictures. Therefore, we are able to produce pictures of cross sections with bone algorithm (primary pictures) as well as three-dimensional pictures of the cranium under study.

RESULTS

Macroscopic Evaluation

The relatively large size of this skull and also the excessive mastoid process and supraorbital arches seem identify it as belonging to a man. The cranial sutures give us an indication that the man from Kirra died at 30–35 years of age. Trepanation was performed on the right parietal bone (Figure 2). The healed aperture of this ancient operation has relatively small dimensions (14 × 10 mm). The actual hole has shorter dimensions (8 × 7.5 mm). The shape of the actual hole is oval or ellipsoid. The skull shows normal bone healing after surgery at the margins of trepanation openings and is marked grossly by a closed diploe. There is good osteological evidence that the young man survived the operation and lived for a long time (months to years) after it.

A close assessment for pathologies and underlying diseases, the study of the morphology of the defect within the

Table 1. Computed Tomography: Technical Parameters

	Spiral Scanning	Sequence Sections
Thickness of reconstructions, mm	5	1
Thickness of sections, mm	3.5	–
Number of sections	46	147
Field of view	239	224
Matrix	512	512
Exposure time, seconds	1.5	1.5
KV	140	
Milliseconds	43	

KV, kilovolt.

Figure 2. Photograph of the trephined skull from Kirra (FOP 1/S 9).

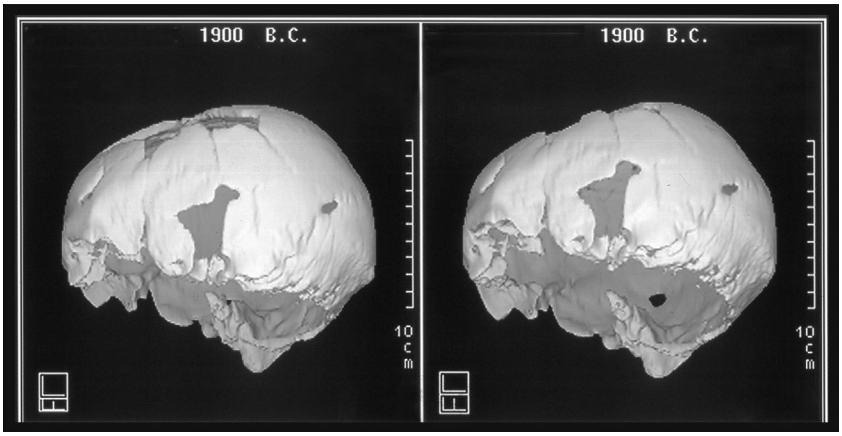

Figure 4. Three-dimensional reconstruction, left lateral oblique posterior view as seen from below, through some bone-deficiency of the cranial base: Trepanation from the inside showing sharp margins. On the first plane, deficiency of the left parietal bone is discerned, as well as of a big part of the cranial base.

context of known trepanation techniques, the fracture lines, and the exact position (in comparison with existing research studying differential diagnoses, including artifact or trauma cases) (6) suggests a strong hypothesis of a healed trepanation compared with the aforementioned mentioned alternative explanations. This "teardrop"-shaped trepanation is medium-sized and was made via the scraping technique.

CT Evaluation

The primary pictures, after they were processed with the specialized three-dimensional program, emerged as three-dimensional pictures, which were exact reproductions. Trepanation can clearly be distinguished, as well as the holes at the cranial base. The three-dimensional depiction enables the study of the cranium from every possible visual angle (front, back, lateral, or from the inside). Moreover, there is the possibility of a virtual excision of section of the cranium (cut) on any level, for better study and exposure of internal structures and ventricles. A drawback of the three-dimensional depiction and also a restriction is the presence of "holes" caused by bone deficiency, in places with accentuated thinning of the bone.

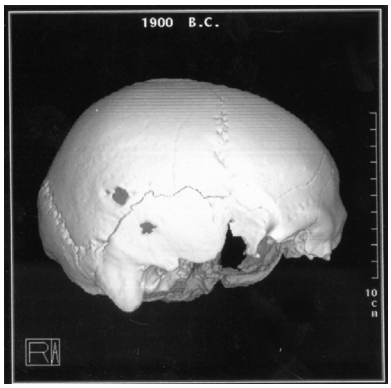

Figure 3. Three-dimensional reconstruction, right lateral oblique view: Skull trepanation exhibiting slanting borders and slightly smaller inner diameter. Tiny bone deficiency is discerned underneath the squamous suture.

The trepanation is located on the right parietal bone, posteriorly, 5 mm above the squamous suture. It exhibits regular oblique edges, which make the opening on the outer slate few millimeters bigger than that on the inner slate. The back edge of the trepanation is more slanted than the front one. CT scan demonstrates an irregular and more radiolucent bone reconstruction at the margins of the aperture. This new bone formation is an intravital reaction complicated by a mild infection. The bone deficiency on the left section of the cranium is clearly depicted, as well as the re-establishment of the fragments torn off the left cranial vault, up to the left temporal bone. Only a small part of the facial cranium is depicted, the part of the orbits and the nasion (Figures 3–5).

OBSERVATIONS AND DISCUSSION

Hippocrates was the first author who medically described trepanation, although he was cautious in practicing it. He provided the first detailed description of human skull anatomy and influenced the gradual development towards modern neurosurgery (18). However, according to the archaeological data, the technique of trepanation had been known in the Greek area since the Early Bronze Age (18). This current study presents a case of trepanation dating to a prehistoric period, approximately 2 millennia BC. Although in south Greece, the Minoan Crete developed a significant civilization at that time, there is only little archaeological data available about central Greece. The careful opening of the cranium, the anatomical region that the ancient surgeons selected, and the success of the operation give us an indication of the knowledge and operative abilities of the Middle Bronze Age people. It is a paleopathological case that provides valuable information about the pre-Hippocratic medicine in Greece.

Placing the herein analyzed case (16) among the existing ones creates a historical context for prehistoric brain neurosurgical practice, as it adds to at least eight other documented cases around the same era (Table 2). Skull trepanation during the Bronze Age in Greece has also been reported in Argos (9), Asine (5), Ilia (19), Lerna (3), and Mycenae (4).

Interestingly enough, this is the only case of Bronze Age trepanation outside of the greater area of Peloponnese. Perhaps in some areas, especially Argolis, where seven

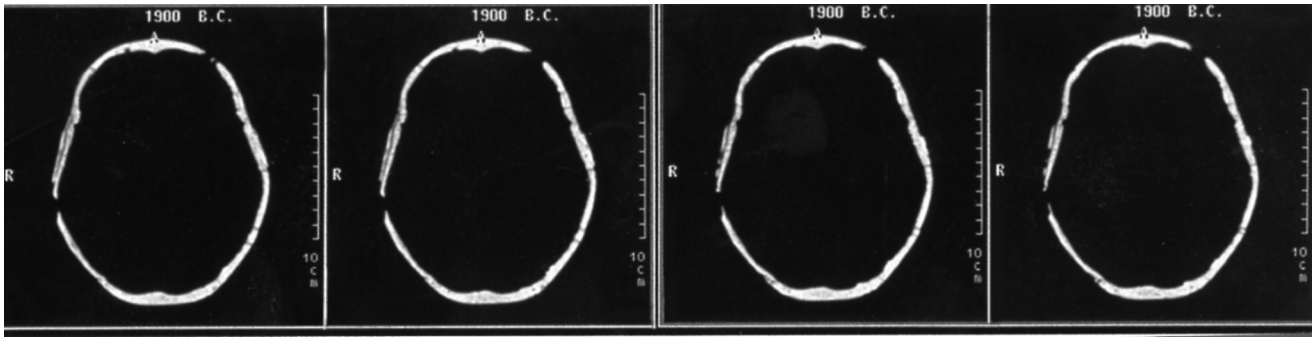

Figure 5. Successive cross sections, 1-mm thick on the trepanation plane: The slanted border of the trepanation is discerned on the right, mainly of the rear part. It can be compared with the border of bone deficiency on the left frontal bone, which has by chance been depicted by the same sections.

of the nine known cases have been found, a primitive school, following an oral tradition, had been created. Even more intriguing is the fact that this is the only case in which the trepanation is localized on the right part. Contrary to the generally greater frequency of operations encountered on the left side, this case performed on the nondominant hemisphere could suggest, although not strongly considering the knowledge limitations of the era, an ancient appreciation from the paleoneurosurgeon of a safer procedure (which would imply replication of the treatment to establish efficacy and safety) (6) or could be completely circumstantial.

Kirra during the Bronze Age, especially the Middle stage, was a flourishing city. Built at the crossroads of three major trading routes, the site has provided archaeological evidence of a prosperous civilization. Indeed, findings from around the time of 1900 BC, the era to which the herein presented trephined skull belongs, have revealed a large and dense city. However, underground currents have impeded the excavation of the Bronze Age layers. Nevertheless, it is reasonable to speculate on the ancient medical progress of an overall progressive place through which knowledgeable travelers may have passed (16).

It is hard to conclude with certainty on the reason for trepanation in the Kirra skull or the other Bronze Age cases. Prehistoric findings and a lack of artifactual evidence, in the form of surgical instruments, associated with Bronze Age trepanation cases from the relevant sites (19) leave much to the imagination. However, the small dimensions and the symmetrical shape of this hole give us an indication that it was made by a metal object, whereas historically physicians of Greece most frequently opened the skull after closed-head injuries (6). Nonetheless, lack of fractures or other signs of trauma around the aperture, located on the level of the central groove, impedes our establishment of a clear cause.

Most of the aforementioned aspects have been analyzed after a thorough CT examination, which depicts intravital reaction of archaeological bones better than macroscopic or radiographic methods (11, 21). The fine section on the level of trepanation gives us a clear picture of new bone formation while avoiding the superimposed images of radiography, and the CT scan of healed lesion shows a clear picture of bone regeneration.

Table 2. Trepanation Cases in Bronze Age Greece

City, Area	Trepanation Cases	Bronze Age Stage	Reported
Argos, Argolis	2	Late	1958
Lerna, Argolis	2	Middle	1971
Mycenae, Argolis	1	Middle	1973
Asine, Argolis	2	Middle	1982
Kirrha, Delphi	1	Middle	1994
Agia Triada, Ilia	1	Late	2011

CONCLUSION

We describe a skull trepanation from the Bronze Age Greece. Although there is not enough data about the cause and the goals of this operation, no one should dispute the knowledge and the abilities of the ancient neurosurgeon who managed to design rightly and operate successfully lengthening the life of the young inhabitant of Kirra. Given the exceptional fact that, through a misty path, trepanation has survived from the Bronze Age through to modern practice, we can reasonably bear that, indeed, neurosurgeon's profession must be one of the world's oldest (10).

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