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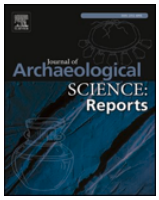

Autopsy or anatomical dissection? Comparative analysis of an osteoarchaeological sample from an 18-19th century hypogeal cemetery (northern Italy)

Arianna Vanni, Roberta Fusco *, Chiara Tesi, Marta Licata

Department of Biotechnology and Life Science, University of Insubria, Varese, Italy

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ABSTRACT

Skeletal evidence of post-mortem procedures is not uncommon in paleopathological studies. This aspect is often overshadowed by the description of the pathology found due to the difficulty in differentiating the stigmata left on the bones from technically similar practices such as autopsy and dissection. The discovery of five crania of adult individuals exhibiting post-mortem lesions during the bioarchaeological recovery phases of the hypogeal cemetery of the church of Santa Maria Maggiore in Vercelli, northern Italy, has made it possible to investigate this diagnostic problem. In particular, it was possible to evaluate the expression of both autopsy and dissection cuts. The crania belonged to four males and one female, all with complete circumferential incisions and therefore referable to craniotomies. Considering both the diversity of the cuts -justifiable by the use of a different surgical instrumentation- and the location of the individual osteological findings -result of tampering after funerary disuse-, it was decided to develop a study on the post-mortem stigmata with the aim of distinguishing autopsy cuts from those caused by the practice of dissection.

For the study of craniotomies, we considered both macro- and micro- characteristics of the cuts, using a morphological approach that included high-magnification photographs and the production of casts of the incisions and cutting surfaces.

We studied features of the osteotomies -as direction of striae, color of the surfaces and the precision of the cutting planes followed- and of individual incisions like false stars, evaluating dips on the kerf floor, shape of walls and the presence of bone islands.

In the light of the surveys carried out, we were able to divide the sample into three cases/scenarios: i) two crania deriving from an ordered bone grouping, removed by anthropic action from the original context of the position, which were didactic samples, with post-mortem cuts of the modern era; ii) two other crania, belonging to a caisson-ossuary and neatly arranged inside it, would seem to be compatible with anatomical dissection; iii) the last subject, belonging to a reduction, would fall into the autopsy category, a hypothesis supported by the suspected presence of a debilitating pathology.

1. Introduction

While the presence of skeletal indicators of post-mortem procedures is frequently observed in paleopathological investigations, its significance diminishes when examining the description of the identified pathology. The difficulty in differentiating the stigmata left on the bones in seemingly similar investigative practices of the human body such as autopsy and anatomical dissection represents an important limitation in this investigation.

The discovery of five crania of adult individuals, four males and one female, with post-mortem cuts during the bioarchaeological recovery phases of the hypogeal cemetery of the church of Santa Maria Maggiore in Vercelli allowed us to investigate this diagnostic problem.

In this paper, we aim to present the differential study of the cuts and blade marks found on the osteological sample, observing both the morphology of the grooves and considering the different depositional situations in which the recovered individuals were found.

The interest in this research arises not only from the particularity of the sample but also from the desire to trace the history of the territory in which this context is inserted.

* Corresponding author.
E-mail address: roberta.fusco@uninsubria.it (R. Fusco).

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There is one hypothesis around the use of the underground cemetery for anatomical samples, which is that there was a medical school in the city. Despite the absence of records in historical and hospital archives regarding this medical institution, a right femur bearing the inscription "femore" (*femur*) in nineteenth-century calligraphy has been recently unearthed from the cemetery. This discovery implies the possibility that the femur served as an instructional artifact, providing potential confirmation for the presence of the speculated school.

1.1. Anatomical dissection

Anatomical dissection is a destructive practice, aimed at examining the structures of the human body for educational purposes (Rebay-Salisbury et al., 2010; Dittmar et al., 2015).

The treatise of *Anathomia* (1316) by Mondino De' Liuzzi represents an authentic testimony of the first anatomical dissections performed in Italy during lessons in human anatomy and physiology, which, according to sources, were organized in four days. On the first day the abdominal viscera were extracted; on the second the neck and chest cavity were studied; during the third day the cranium was investigated, with special regard to the brain and nerves; and finally, on the last day the four limbs were dissected (Cecchetto et al., 2017; Ciliberti et al., 2020; Brenna, 2021).

From the thirteenth century, dissection had a rapid growth, linked to the increased general interest, being recognized as a means for justice and public health, but also as a useful tool for teaching and research in anatomy. In the nineteenth century this practice became further used, as research had been directed towards the study of pathologies and especially their aetiology, so this application was necessary for a rigorous scientific investigation, based on direct observations of the human body (Mitchell, 2012).

Due to the shortage of study subjects and adverse weather conditions for body preservation, there arose a necessity to achieve more with limited resources. This circumstance is why numerous abnormal signs of various medical techniques practiced on dissected remains can be found, with the added aspect that bodies - or rather, parts of them - could be physically distant from each other, given that they were sometimes buried at different times.

1.2. Autopsy

Autopsy is a technique that can be defined as minimally invasive, since it often investigates only the portion of interest (pathology or injury), since the objective is to determine the cause of death.

Initially, according to some sources, the interest in this practice was for legal purposes only, as evidenced by the forensic autopsies allowed by Pope Innocent III (1198–1216), if the cause of death was considered doubtful, as well as the so-called "holy autopsies", under the guidance of the ecclesiastical authorities, practiced on bodies of alleged saints to further confirm their beatification (Charlier et al., 2014).

From the fifteenth century, however, the same wealthy families asked more and more often for a thorough investigation into the death of a beloved one, also to prevent and treat hereditary diseases that could affect the progeny (Park, 1994; Mitchell, 2012; Giuffra et al., 2016).

At the end of the eighteenth-century autopsy practice assumed greater importance as post-mortem dissection, determining the development of the branch of medicine that would take the name of "pathology", thus acquiring importance in the study of pathological anatomy (Valentin and d'Errico, 1995; Rebay-Salisbury et al., 2010; Mitchell, 2012).

1.3. Autopsy and anatomical dissection: The cuts

The signs produced by autopsy and dissection procedures are in both cases grooves of scalpel, blades, knives and saws, post-mortem lesions caused by the use of instruments suitable for both the removal of soft tissues and the incision of the bones to access internal cavities (Dittmar et al., 2015).

Although the purposes are different, autopsy and dissection present similar procedures, such as thoracotomy and circumferential craniotomy, however, "unusual" cuts may also be mainly related to the diagnostic suspicion of the individual case to be investigated (Nystrom, 2017).

Craniotomy is defined as "surgical incision into the skull" (Collins Dictionary) involving the separation of the upper part of the cranium (cap) and is obtained by horizontally dissecting the cranial vault to examine the brain.

Although in history there have been many different protocols about the opening of the cranial vault, it is possible to summarize the key points thanks to what is reported in *De humani corporis fabrica* (1543) by Andrea Vesalio, and later also by Pierre Dionis (1708) in "*Cours d'operations de chirurgie demontrées au Jardin royal. Chez les Freres t'Serstevens et Antoine Claudinot, Brussels*" (Giuffra et al., 2016): i) to remove the skullcap it is necessary to cut the scalp with a metal blade, usually a scalpel, severing the skin from the aponeurosis and epicranial muscles, to completely detach the scalp or retract the scalp up to the neck; ii) after that, it will be possible to begin with incisions of the cranium using a saw. The cut usually begins at the level of the frontal bone, proceeding on one of the temporal bones and then on the other side; finally, the body is turned, so that the occipital bone can be severed (Giuffra et al., 2016).

1.4. Autopsy and anatomical dissection: Purpose

Skeletal evidence of post-mortem procedures is not uncommon in paleopathological studies; however, this aspect is often placed in the background, compared to the description of the pathology found. In addition, it is also possible to imagine a certain degree of uncertainty in differentiating the stigmata produced by an autopsy from those resulting from a dissection.

Today, however, thanks to a greater attention in the study of osteoarchaeological finds and an evident chronological extension of the bioarchaeological contexts explored (until the twentieth century), the literature presents a series of new analyses focused on the univocal differentiation of these post-mortem practices (e.g. Dittmar et al., 2015; Scianò et al., 2021).

As mentioned above, autopsy and dissection share some characteristics (e.g. medical equipment used and some standard cuts, such as craniotomy), but are mainly distinguished in purpose, execution and number of cuts.

The recovery of some anthropological finds at the cemetery of the church of Santa Maria Maggiore in Vercelli (Piedmont, northern Italy) has made it possible to investigate this aspect, that is, to distinguish autopsy cuts from dissections.

In this work, we present a comparative study of the cuts referable to complete craniotomies in five crania discovered in the underground cemetery of Santa Maria Maggiore. The analysis takes into consideration both the diversity of the cuts (justifiable by the use of different surgical instrumentation) and the location of the individual osteological finds (the result of tampering after the original funerary depositions) to develop a study on post-mortem stigmata to distinguish autopsy cuts from dissection ones.

2. Materials and methods

2.1. The site

The co-cathedral of Santa Maria Maggiore in Vercelli (Piedmont, northern Italy, Fig. 1) was built in the 18th century at the behest of the Jesuits, replacing the church of the Santissima Trinità that extended north of the current basilica and in 1780 taking its name from the oldest basilica that stood a few meters to the south (Destefanis et al., 2022;

Fig. 1. Map of northern Italy, indicating the site of Santa Maria Maggiore, Vercelli, Piedmont.

Licata et al., 2023; Fusco et al., 2023).

The cemetery was opened in 1777, also hosting the human remains transferred from the ancient basilica, and remained active until the early decades of the 19th century (Tibaldeschi, 1996).

From an architectural point of view, the underground space is organized with vaulted structures, also exploiting some pre-existing

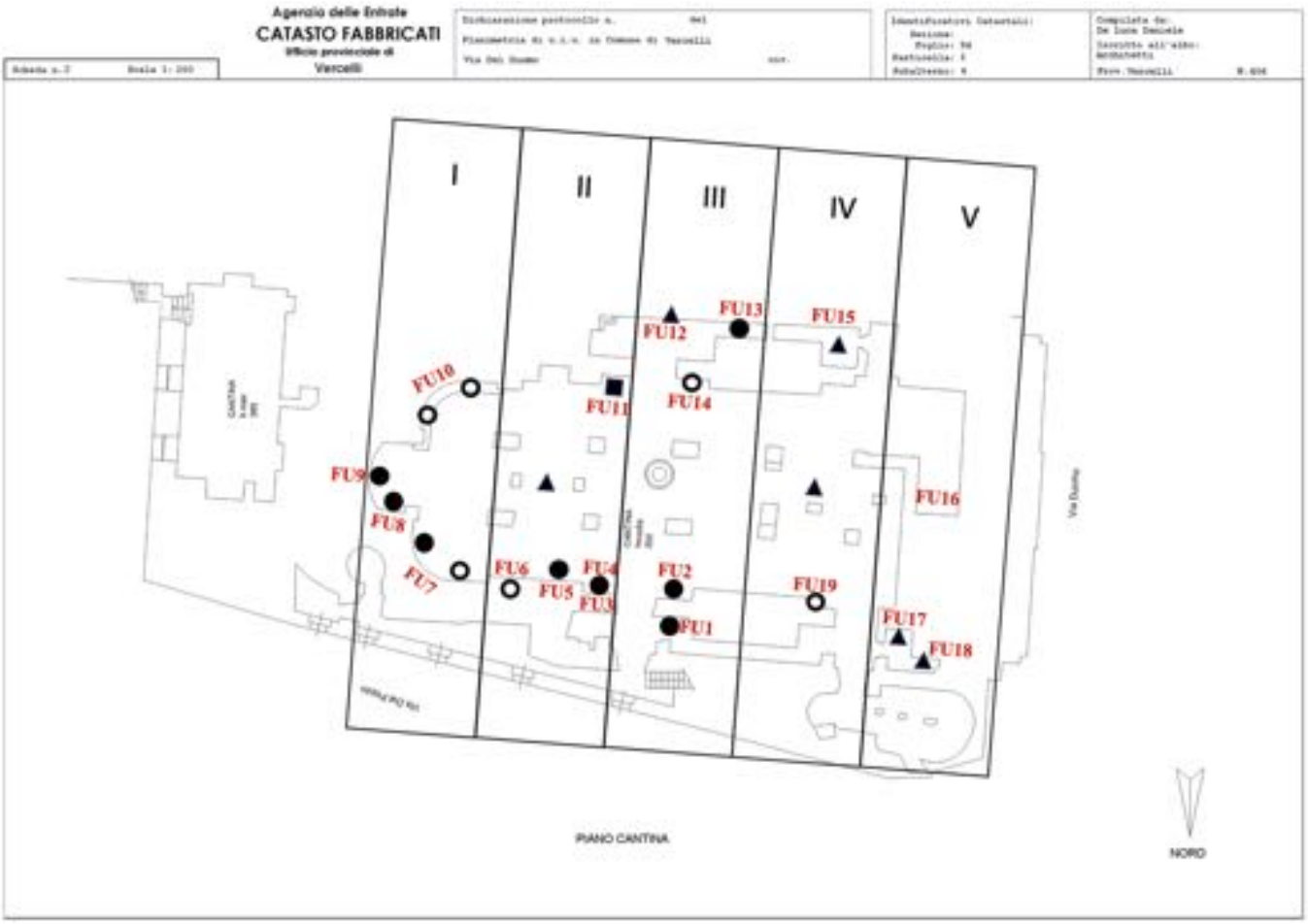

Fig. 2. Planimetry of the cemetery of Santa Maria Maggiore indicating the sectors in Roman numerals, the type of burial and the numbers of the Funerary Units. ▲ Ossuaries; ● Mummies - burials in primary deposition; ○ Burials in primary deposition; ■ Intentional bone grouping.

architectural elements, probably having different functions, and seems to develop from a central nucleus that corresponds to sector III (Fig. 2). Along the perimeter there are several areas intended for funerary use, including masonry structures, burial chambers, private chapels and, in a central position, two large underground ossuaries.

Since September 2020, the anthropology division of the University of Insubria, invited by the Archdiocese of Vercelli and the Superintendence of Archaeology, Fine Arts and Landscape for the Provinces of Biella, Novara, Verbano Cusio Ossola and Vercelli, has been handling the recovery and the analysis of the bioarchaeological finds of the cemetery.

To facilitate understanding and cataloguing the finds, the cemetery was divided into sectors I to V, as well as the tomb structures, called "Funerary Units (FU)", which were numbered from 1 to 19 (Fig. 2) and each find has been assigned a serial number.

Below we present the three sectors of the hypogeal cemetery interested by our investigation:

2.1.1. Sector II, FU 11

Commingled remains were grouped and divided by anatomical districts, above a masonry structure. This arrangement derives from the emptying of the well located in the center of the cemetery, an action made during some studies on the aquifer that took place about ten years ago.

The arrangement documented from our first entry into the crypt - before recovery - was organized as follows: on the left long bones and on the right crania and mandibles.

From this unit come the crania *II-FU11-1* and *II-FU11-2*.

2.1.2. Sector III, FU 12

This unit was located behind a wall, identifiable from the outside by a buffered arch and visible thanks to a breach. The wooden ossuary-chest extends along the entire length of the compartment and is smaller than the extension of the arch.

From this unit come the crania *III-FU12-1* and *III-FU12-23*, found at the bottom of the case, in the furthest part from the breach, carefully positioned side by side, but with a jaw that seemingly can be articulated to *III-FU12-1*. Inside the chest, still under study, at a first analysis there are about fourteen adult individuals and three subadults. Being an ossuary it is not possible to reconstruct and assign the various districts to individuals, but from the two skulls examined it was possible to reconstruct the partial biological profile.

Overall, the deposition is defined as secondary and it is an intentional rehash.

2.1.3. Sector V, FU 17

This FU is located on the left, inside a private chapel and consists of a brick funerary structure covered with a thick layer of mortar which, in part, still retains the rounded roof.

Here were placed two wooden boxes one above the other, the most superficial of which contained two adult individuals and three subadults placed in secondary deposition and probably coming from the ancient church of Santa Maria Maggiore (Licata et al., 2023).

Of the two complete skeletons, the one of interest is *V-FU17-1*, showing a complete craniotomy.

2.2. Sex and age estimation

In cases where the skulls were not associated with the skeleton, for the estimation of sex and age we used a revision of the Acsádi-Nemeskéri and the Meindl-Lovejoy method (Acsádi et al., 1970; Meindl et al., 1985); in the case of V-FU17-1, having an individual complete also with post-cranial skeleton, for the estimation of sex, we used the method of Buikstra and Ubelaker and for age the method of Brooks and Suchey and Lovejoy (Lovejoy, 1985; Brooks et al., 1990; Buikstra et al., 1994).

2.3. Study of cuts referable to craniotomies

For the precise description of the cuts, distances were taken from the principal cranial points using a sliding or curved branches compass.

For the study of osteotomies, after consulting the specific literature, some macro- and microscopic features were considered, using a morphological approach.

- *False starts*: they occur when the blade scratches more or less superficially the outer table of the bone and then starts again near the initial cutting point. Each false start includes two edges, two vertical walls and a floor and can represent either the beginning of a cut or a restart (Nogueira et al., 2016; Pelletti et al., 2017; Nogueira et al., 2018; Bernardi et al., 2020b; Scianò et al., 2021).
  - o *Dips on the kerf floor*, also named concave or convex "lesion profile" or identified by letters (U, V, and W). The "U" shape belongs to the class of saws for cutting metals; the "V" shape can derive from knives with symmetrical or asymmetrical blades and cutters; the "W" shape (concave and convex) belongs to the class of saws for cutting wood (Cerutti et al., 2016; Nogueira et al., 2016; Nogueira et al., 2018).
  - o *Shape of the edges (kerf walls)* is divided into: "narrow-wide", characteristic of blades with alternating sets; "necking in the middle" or hourglass, typical of wavy sets; "straight" (Symes et al., 2010; Nogueira et al., 2016; Bernardi et al., 2022).
  - o *Bone islands*: small intact bone spurs, present between the two parallel signs produced by alternating movements of the blades (horizontal and vertical movement). Two models of bony islands were outlined: "longitudinal" (along the entire false start) and "oval" (in groups of two or three in a false start) (Bernardi et al., 2020a; Bernardi et al., 2021).
- *Breakaway spurs*: projection of bone at the end of the cut indicating the exit of the blade due to the pressure applied. Often, they are indicative of the point that corresponds to the end of the cut, being the result of the use of a lever (chisel or scalpel) to remove the skullcap (Symes et al., 2010; Nogueira et al., 2016; Scalise et al., 2018; Bernardi et al., 2020b).
- *Detachment of superficial bone lamellae*: the pressure exerted by the saw can produce the detachment of surface lamellae both on the external and internal table (Valentin et al., 1995).
- *Cutmarks*: they are thin streaks attributable to the use of blades. Their position was assessed using either a curved branch compass or a sliding one, based on the position on the cranium (Valentin et al., 1995).
- *Continuity of the cutting plane*: the use or not of guides to make the starting point coincide with the end point of the osteotomy was evaluated (Signoli et al., 1997; Mitchell et al., 2011; Mitchell, 2012; Giuffra et al., 2016; Scalise et al., 2018; Scheelen-Nováček et al., 2019).
- *Color*: based on this characteristic it is possible to assert whether the cuts were made on finds still having soft tissues or on already dry bone, on skeletonized individuals (Scheelen-Nováček et al., 2019). In this work we will always talk about post-mortem, but we will emphasize the difference between the two cases just mentioned: we will refer to an event that occurred just after death, in which the color of the cut is the same as the rest of the cranium (since all the surfaces have been exposed for the same time in the same environment), or to an intervention after skeletonization, so the color of the cut is lighter than the rest of the cranium, having been exposed to the environment at a later time (Pechníková et al., 2011; Cattaneo et al., 2017).
- *Color spots*: the presence of pencil marks or abnormal color spots has also been considered (Mitchell et al., 2011; Mitchell, 2012; Dittmar et al., 2015; Kausmally, 2015).

All these morphological aspects have been studied thanks to the

production of casts of individual cutmarks or false starts with Provil® novo Light Fast Set (from Heraeus Kulzer GmbH), vinyl polysiloxane used for high-resolution dental impressions (Tesi et al., 2022).

This set consists of two tubes; one containing the base and the other the catalyst in the form of paste/gel form. To obtain a silicone-like cast that is dry yet flexible, it is necessary to dose the two phases of this product. To achieve a paste that dries quickly but remains sufficiently liquid to penetrate the grooves of our incisions, two different pressures must be applied to the plungers of the tubes. The pastes are then quickly stirred to obtain a single compound, which is applied using a spatula to the point of interest. The cast is then left to solidify on the cut or surface and when dry it is carefully removed to avoid damaging the underlying bone or the cast itself.

3. Results

Here we present the results obtained, dividing the sample studied into the three different FU of discovery. These are 5 crania, 4 of which are well preserved, while 1 consists only of the splanchnocranium, the portion under the cut of the craniotomy.

Drawing from the literature, a summary table (Table 1) was created containing all the characteristics associated with the various post-mortem practices that can only affect the cranium.

II-FU11-1 (Fig. 3) belongs to a male individual aged between 30 and 40 years. The cranium is intact, except for the loss of the upper part of the left temporal bone (affected by the cut) and a small portion of the right one, in its most frontal part.

Despite structural integrity, however, the fragility of the bone surface characterized by signs of desquamation of the outer layers of the cortical is evident, so, in order not to compromise the specimen, it was decided to make only two casts.

From cast 1 (Fig. 4A–B), an incision on the right parietal, the profile of the floor is "U" shaped and the walls have longitudinal streaks. Cast 2 (Fig. 4C–D) is the imprint of a false start on the right temporal line and presents, instead, wavy walls and an oval bone island.

The craniotomy is classifiable as horizontal (for the plane followed) and is almost linear.

The cutting surface almost lacks of streaks, it is uniform (Fig. 3. E) (without bone spurs, except for a protrusion at the level of the temporal bone) and shows a high level of eburnation (polishing of the cutting surface, indicative of an energy transfer).

Moreover, the surface of the cut shows a different color from the rest of the cranium, as well as the inside of the cap.

Finally, it is possible to note the absence of thin blade marks on the cranium and numerous pencil marks and reddish-brown spots of considerable size on the cranium surface.

II-FU11-2 (Fig. 5) belongs to a female individual aged between 45 and 55 years. The cranium is almost complete, missing only part of the zygomatic bone, the zygomatic process and the right sphenoid. Similar to *II-FU11-1*, *II-FU11-2* presents a worse situation of bone surface desquamation, so it was decided not to realize casts.

The horizontal line of the craniotomy is almost perfect and the cutting surface is smooth, precise, with few marks of the blade teeth and highly polished (Fig. 5E).

The last two details that can be extrapolated from the evaluation of the cutting surface are the color, different from the rest of the cranium, and the detachment of the internal table in the frontal region.

Other signs of the cranium surface are the lack of thin blade marks, but the presence of numerous pencil marks (above the eye sockets, around the squamous suture and writings in red and blue on both parietals) and reddish-brown spots also of considerable size.

III-FU12-1 (Fig. 6) is a perfectly conserved cranium that belongs to a male individual aged between 40 and 50 years.

Thanks to the excellent conservation of this sample, we were able to proceed with the creation of multiple casts of false starts, the surfaces of the cut and the marks of small blade left on the surface. From the casts of

Table 1
Summary of the characteristics compatible or not with autopsy, dissection or anatomical preparations (teaching-museums) with bibliographical references.

	Autopsy	Dissection	Anatomical preparations (teaching-museums)
Practice	Conservative	Destructive	Both
Cutmarks:	Yes	Yes	Yes/No
Retraction or removal of the scalp (Valentin e d'Errico, 1995; Signoli et al., 1997; Anderson, 2002; Mitchell, 2012; Dittmar et al., 2015; Kausmally, 2015; Scheelen-Nováček et al., 2019; Scianò et al., 2021)			
Muscle detachment (cuts on temporal lines) (Valentin e d'Errico, 1995; Signoli et al., 1997; Anderson, 2002; Mitchell et al., 2011; Mitchell, 2012; Scheelen-Nováček et al., 2019)	Yes	Yes	
Random, with no therapeutic value (Mitchell, 2012; Scheelen-Nováček et al., 2019)	No	Yes	
Present, but without craniotomy (Dittmar et al., 2015)	No	Yes	
Craniotomy	**Transverse** (Valentin e d'Errico, 1995; Mitchell, 2012; Scheelen-Nováček et al., 2019)	**Horizontal, coronal-sagittal**	**Transverse, horizontal, coronal-sagittal, absent** (Dittmar et al., 2015)
Orbit-level cuts (Mitchell et al., 2011; Dittmar et al., 2015; Kausmally, 2015)	No	Yes	Yes/No
Cuts at the level of the zygomatic arches (Kausmally, 2015)	No	Yes	Yes/No
Cuts on the glenoid fossa (Mitchell et al., 2011; Mitchell, 2012)	No	Yes	Yes/No
Bisection of the mandible (Mitchell et al., 2011; Kausmally, 2015)	No	Yes	Yes/No
Temporal line cuts (Mitchell, 2012; Dittmar et al., 2015)	No	Yes	Yes/No

(*continued on next page*)

Table 1 (*continued*)

	Autopsy	Dissection	Anatomical preparations (teaching-museums)
Lever fractures (Ríos et al., 2014)	Yes	Yes	Yes/No (possible to assume not, since they had to be intact)
Pencil marks (Signoli et al., 1997; Mitchell et al., 2011)	Few, sometimes the cutting circumference	Yes	Yes
Dyes and waxes (Mitchell et al., 2011; Mitchell, 2012; Dittmar et al., 2015; Kausmally, 2015)	No	No	Yes/No

This table was then used as a guideline for considering the cuts detected on our sample.

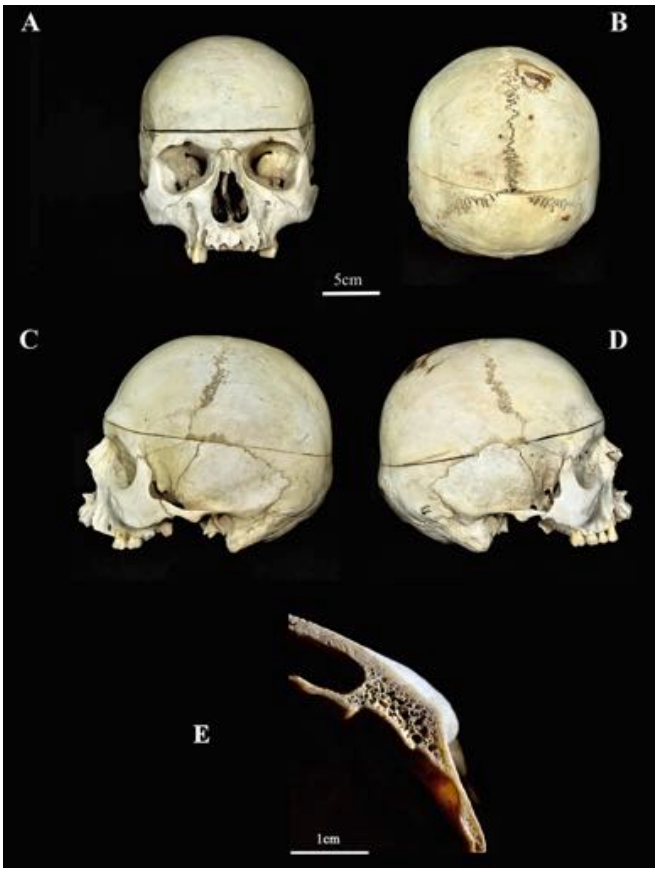

Fig. 3. II-FU11-1. A: anterior view; B: occipital view; C: left lateral view; D: right lateral view; E: raking light photo of the cutting surface, at the right portion of the frontal bone.

the false starts it was possible to notice that the impressions left by the blade are all "W" shaped, but with rounded tips (Fig. 7). The greater magnification of the details allowed us to highlight narrow and wide profiles and partial oval bone islands (Fig. 7A–C).

This cranium shows a transverse craniotomy. Along the entire surface, characterized by parallel streaks, there are numerous bone spurs.

Finally, another detail that emerged from the qualitative evaluation of the cutting surface is its color, equal to the rest of the cranium and inside the cap.

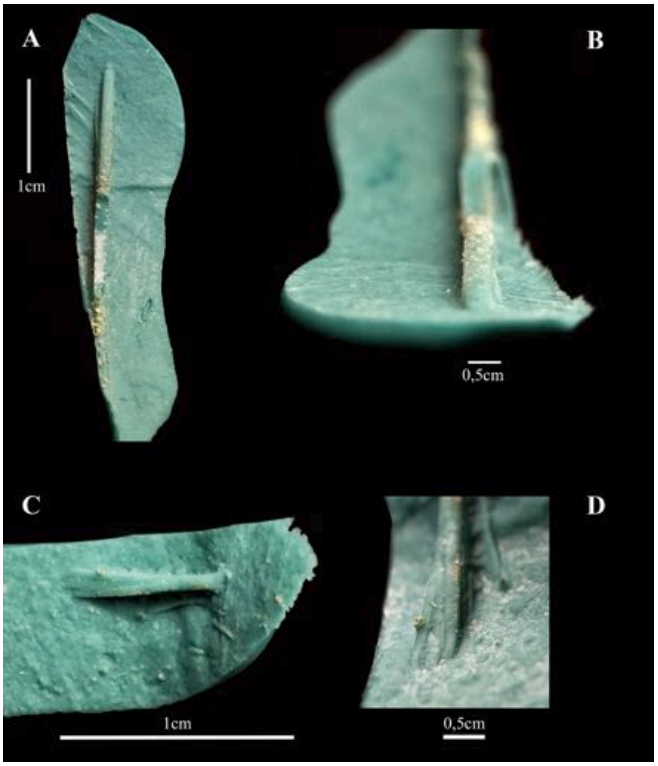

Fig. 4. A: cast of the false start on the right parietal; B: magnification of 4.A; C: cast of the false start on the right temporal line; D: magnification of 4.C.

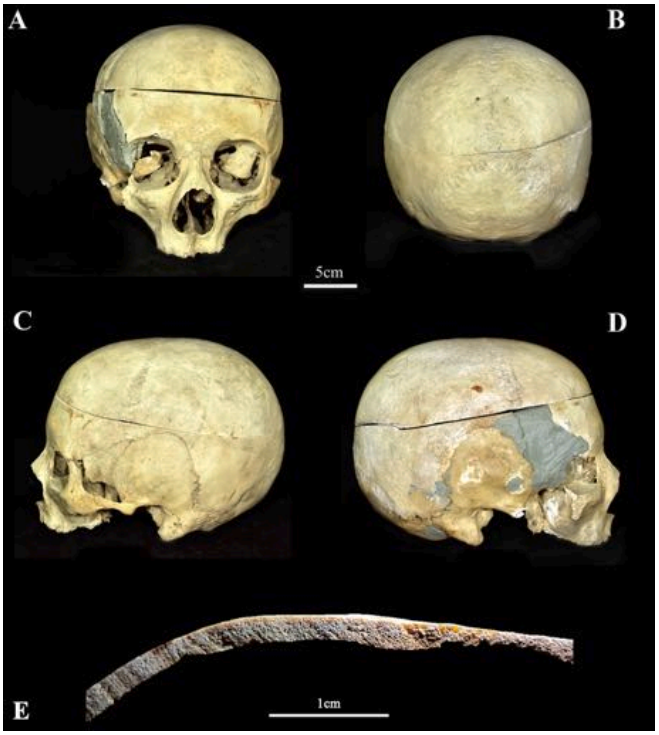

Fig. 5. II-FU11-2. A: anterior view; B: occipital view; C: left lateral view; D: right lateral view; E: raking light photo of the cutting surface, at the right parietal.

III-FU12-23 (Fig. 8) belongs to a male individual aged between 40 and 50 years. This is the least preserved specimen of all, presenting, partially, only the portion of the cranium below the cut of the

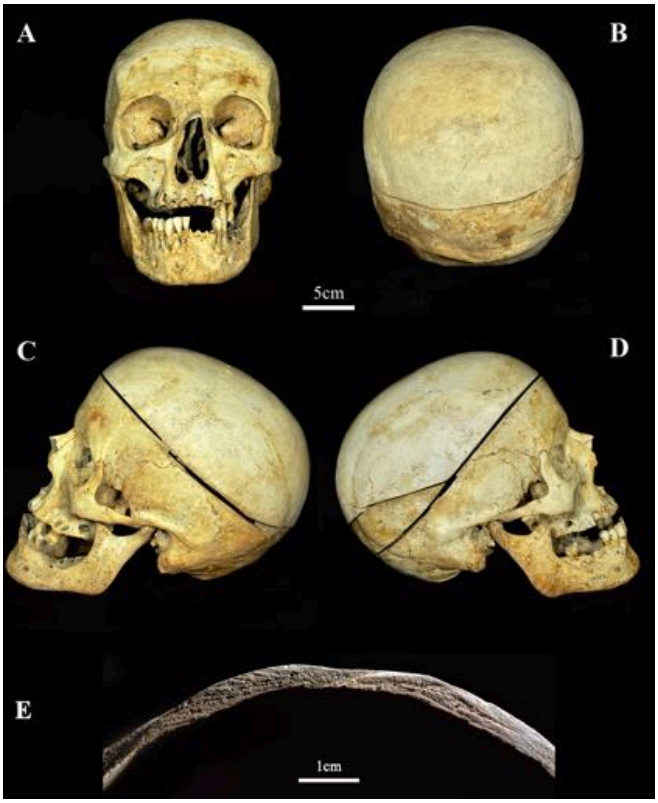

Fig. 6. III-FU12-1. A: anterior view; B: occipital view; C: left lateral view; D: right lateral view; E: raking light photo of the cutting surface, at the occipital bone.

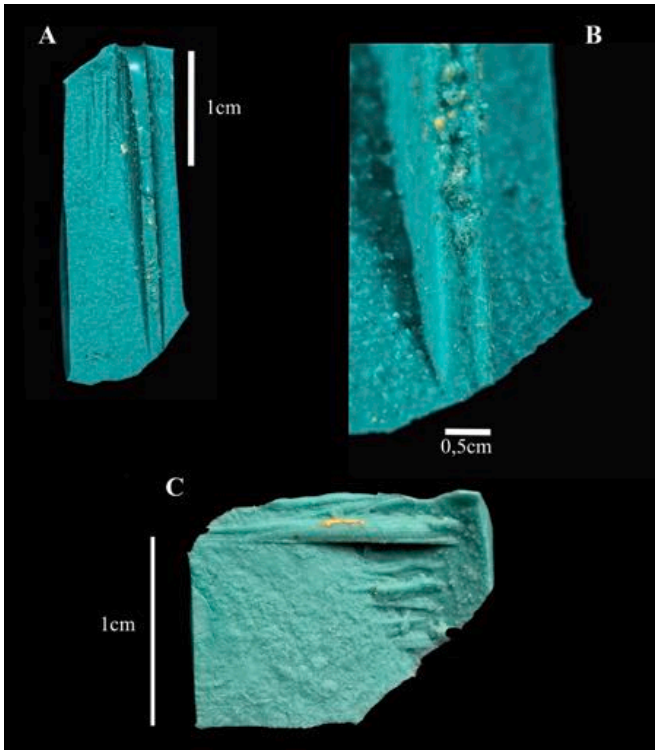

Fig. 7. A: cast of a false start and an incision (showing alternating narrow and wide aspects and oval bone islands), involving part of the occipital bone and parietal bone; B: magnification of 7.A; C: cast of a false start notch on the left temporal line.

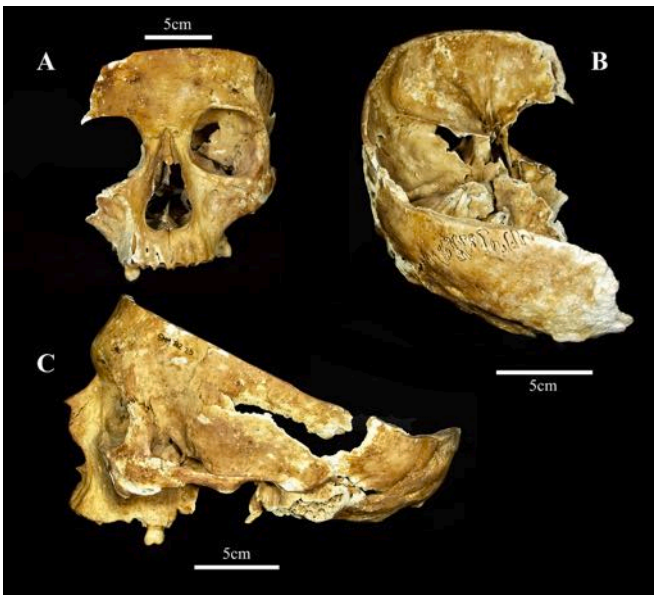

Fig. 8. III-FU12-23. A: anterior view; B: occipital view; C: left lateral view.

craniotomy. Specifically, the parts remained are the frontal bone (complete left orbit, right orbit missing right margin), the maxilla, the left side (intact zygomatic bone, fragmented temporal scale, absence of mastoid process, fragments of parietal bone) and the occipital bone.

Here we have another transverse craniotomy, in which the cut is straight along the circumference.

The last detail that emerged from the evaluation of the cutting surface is the color, equal to the rest of the cranium.

V-FU17-1 (Fig. 9) is a perfectly conserved cranium that belongs to a male individual aged between 40 and 50 years. Thanks to the excellent conservation of this sample, we were able to proceed with the creation of the casts of false starts and of the surface of the cut.

From the casts of the false starts it was possible to detect that the imprints left by the blade are both vaguely "W" (Fig. 10A–B) and "U" (Fig. 10C) shaped, while the walls are straight, without undulations.

Cast number 1 (false start notch on the right temporal bone; Fig. 10A) shows the impressions left by the individual teeth of the saw.

The cranium presents a transverse craniotomy, which circumference does not appear to be precise, presenting numerous drifts of the plane. The orientation of the striations on the cranial section varies along the entire circumference (Fig. 9E). The cut presents countless bone spurs (on the front, temporal scales and occipital bone) and notches for the changes of the cutting planes.

A last detail that emerged from the evaluation of the cutting surface is the color, equal to the rest of the cranium. Another detail not to be overlooked is then the lengthening of the left styloid process of 48 mm.

4. Discussion

Through the observations exposed in the results it was possible to reason about the purposes of the individual craniotomies.

First of all, it was necessary to try to identify the technique and the instruments used based on direct observation of bone surfaces and casts produced; subsequently, through the considerations on the types of depositions, it was possible to arrive at a final hypothesis on the sample in our possession.

For the find *II-FU11-1*, cast 1 (Fig. 4A–B) displays an incision with the profile of the floor "U" shaped and the walls with longitudinal streaks, leading us towards a tool used for cutting metals (Cerutti et al., 2016). Cast 2 (Fig. 4C–D) presents wavy walls and an oval bone island, which for Symes represent a good indicator of an alternating set (blades in

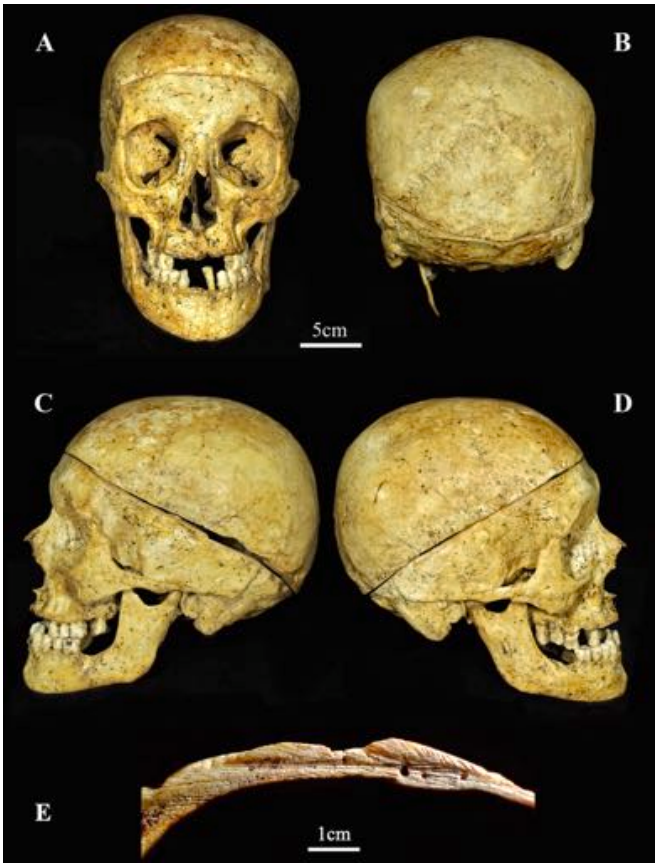

Fig. 9. V-FU17-1. A: anterior view; B: occipital view; C: left lateral view; D: right lateral view; E: raking light photo of the cutting surface, at the occipital-right parietal.

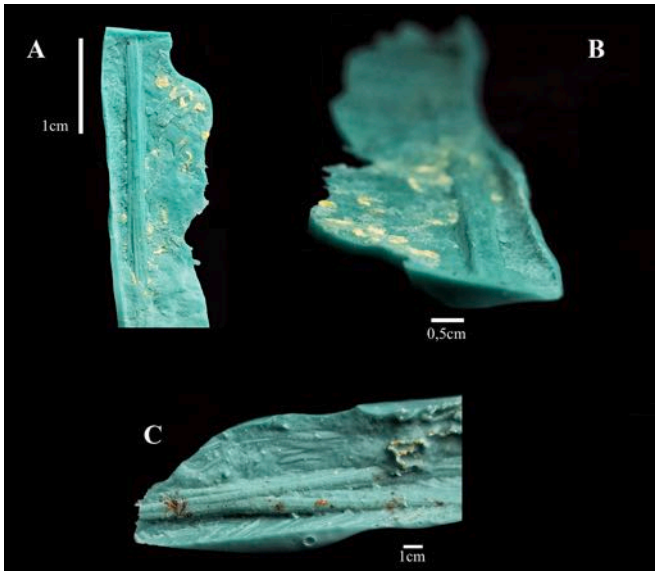

Fig. 10. A: cast of the false start on the right temporal bone; B: magnification of 10.A; C: cast of a false start notch on the left temporal line.

which the teeth are arranged at opposite angles, that is, each tooth points alternately to the left and to the right) (Bernardi et al., 2020a; Bernardi et al., 2022).

Regarding the cutting surface, the almost total lack of streaks (Fig. 3E), the uniformity of the cut and the presence of a high level of eburnation would validate the hypothesis about the use of an electric saw (Bernardi et al., 2020b).

In general, the craniotomy almost linear, so it is conceivable that a guide for the circumference was used (Signoli et al., 1997; Mitchell, 2012; Giuffra et al., 2016; Scalise et al., 2018; Scheelen-Nováček et al., 2019).

The trend of the streaks, the false starts or slips of the blade and the presence of a bone spur have allowed us to formulate hypotheses regarding the path of the cut. The action begins on the right temporal bone, which shows signs of a superficial false start or a simple notch of the beginning of the action; subsequently, the action is resumed on the front, with the false start above the right orbit, crossing the left parietal, up to the occipital; finally, the cut reached the right parietal, re-joining the cut planes and this allowed the detachment of the cap (hypothesis reinforced by the presence of a bone spur in the back of the temporal, at the point where it meets the cutting line).

Moreover, the surface of the cut shows a different color (white/lighter) from the rest of the cranium, as well as the inside of the cap, so we can assume that the craniotomy was performed after the skeletonization of the corpse.

The absence of thin blade marks on the cranium, generally produced during scalp removal and detachment of muscles in anatomical dissections, allows us to further hypothesize the modernity of the incision.

In the case of *II-FU11-2* due to the sensitivity of the osteo-archaeological find, it was not possible to proceed with the realization of casts and consequently to advance hypotheses regarding the type of saw used.

The cutting surface has high levels of polishing, with few marks of the blade teeth (Fig. 5E), compatible with the use of an electric saw (Bernardi et al., 2020b).

The clear horizontal line of the craniotomy could perhaps result from a pencil drawn circumference, as pencil marks are still visible (Signoli et al., 1997; Mitchell, 2012; Giuffra et al., 2016; Scalise et al., 2018; Scheelen-Nováček et al., 2019).

Lacking a portion and tracks of saw teeth on the surface cut, it is impossible to say with certainty what was the direction and the starting and ending point of the craniotomy, but the presence of a bone spur on the right parietal would represent the end point of the osteotomy. The cutting action could then have started on the right side to continue on the front, where a slip of the blade or correction of the trajectory is visible; subsequently, the action continued counterclockwise up to the occipital portion and the right parietal.

The evaluation of the color of the cutting surface, different from the rest of the cranium (white/lighter), and the detachment of the internal table in the frontal region, which occurs with dehydration and alteration of the bone, can lead us to assume that the craniotomy was performed after the skeletonization of the corpse. The absence of thin blade marks on the cranium supports the modernity of the cut.

As for *III-FU12-1*, from the casts of the false starts it was possible to notice that the impressions left by the blade are all “W” shaped (Fig. 7), a form frequently observed (in the literature) in cases of saws for wood; however, our profile resembled in all casts a “W” with rounded tips, compatible with an oscillating electric autopsy saw (Bernardi et al., 2020a). From the literature, the typical false start injury created by an electric oscillating autopsy saw includes walls alternating narrow and wide aspects and oval bone islands (Bernardi et al., 2020a). In our case, the greater magnification of the details allowed us to highlight narrow and wide profiles and partial oval bone islands (Fig. 7A–C) (Symes, 1992).

Despite this preliminary conclusion, along the entire surface there are numerous bone spurs, corresponding to many changes of plane or restarts, parallel traces of the blade (Fig. 6E) and absence of polished surfaces, details in contrast to what would be expected from a circular autopsy saw, electrically powered, which would have left streaks with a curved/semi-circular trend and a higher eburnation level (as observed in *II-FU11-1* and *II-FU11-2*).

As for the instrument used, we found some discrepancies between contemporary autopsy instrumentation marks and the historical period in which the cut was performed, leading us to an in-depth historiographical reflection on the invention of electrical instrumentation and on the characteristics noted so far.

The first rudimentary electric surgical instruments appeared with Eugène-Louis Doyen (1859–1916) and Thierry de Martel (1875–1940) only at the end of the nineteenth century, in an era distant from the funerary use of the cemetery (abandoned in the early nineteenth century) (Kirkup, 1995; Goodrich, 2000; Phillips et al., 2011; Goodrich, 2014; Nica et al., 2020). Starting from the assumption that FU12 could be placed temporally between the seventeenth and eighteenth centuries, historically we can exclude the use of an instrument electrically powered, too modern for the dating that is attributed to the ossuary.

Following this preliminary historical consideration, from the morphological point of view we then analyzed as a whole the casts made on this individual and the appearance of the cutting surfaces.

From the casts, with "W" profiles with rounded tips, we have preliminarily hypothesized the use of an oscillating autopsy saw with electric action, as described in Bernardi et al., (2020a). In the same article, another feature is highlighted: the trend of streaks on the floor of the notches, described as an "undulating pattern" (Bernardi et al., 2020a). In our case the most superficial notches present striae as well with wavy pattern and bone islands, compatible with the use of an alternating set (Bernardi et al., 2020a; Bernardi et al., 2022).

If we take into consideration instead the cutting surface of the craniotomy, with a circular oscillating saw for autopsies we would expect to find: streaks that are of semi-circular trend and the surface with a high degree of eburnation attributable to high energy transfer due to the electrical action of the instrument (Symes et al., 2010). What we found instead are parallel streaks and a low degree of eburnation of the cutting surface (Fig. 6E), allowing us to discard the hypothesis of the use of electrical instrumentation also through morphological analysis.

Following this examination, we can therefore hypothesize the use of a manual saw that employed an alternate set of blades.

This cranium shows a transverse craniotomy, probably carried out by non-expert hands and certainly without the use of any guide to trace the circumference, since qualitatively we can observe that, while on the front the cut is straight, along the entire circumference numerous inaccuracies are visible, such as the sliding of the blade and sudden changes in the inclinations of the plane (Signoli et al., 1997; Mitchell, 2012; Giuffra et al., 2016; Scalise et al., 2018; Scheelen-Nováček et al., 2019).

Following this clarification, we can postulate some hypotheses regarding the particularity of the profiles left by the blade. The first is that a flexible chain osteotome[1] (not studied in articles in the literature concerning cutmarks, which take into consideration only modern instrumentation and use long bones for their purely forensic objective e.g. Martlin et al., 2021; Bernardi et al., 2022) was used to cut, therefore leaving streaks with an "unusual profile" and very regular, despite the numerous trajectory errors.

Alternatively, this regularity in the streaks on the surface and the polished appearance are to be attributed to the numerous restarts of the cut that have allowed to proceed several times with "cleaner" cuts that, due to the transfer of energy during the various actions, present an intermediate degree of eburnation.

Continuing with the analysis of the results, due to the presence of multiple breakaway spurs, it is not possible to determine exactly the starting or ending point of the craniotomy. However, we can hypothesize that the cut began on the frontal counterclockwise and, with some abrupt restart, continued up to the posterior portion of the right parietal. The action re-started from the front, clockwise, up to the occipital, where the last cut was then made to join the two non-matching planes that had been created.

The color of the cut surface, the same as the rest of the cranium and the inside of the cap, leads us to hypothesize that the craniotomy was performed before the deposition of the remains. This supposition is corroborated also by the presence of small blade cuts present along the temporal lines, especially on the left, attributable to the detachment of the muscles from their aponeurosis, to facilitate the removal of the scalp and therefore allow the circumferential cut (Valentin et al., 1995; Signoli et al., 1997; Mitchell, 2012; Dittmar et al., 2015; Kausmally, 2015; Scheelen-Nováček et al., 2019).

Since *III-FU12-23* is so fragmentary, it was not possible to draw any conclusions about the type of blade used and the starting and ending point of the cut. However, it was possible, to assume the counterclockwise direction of craniotomy, studying the surface of the circumferential cut.

The cut is straight along the circumference and is characterized by at least three distinct actions. The first one starts from the front and proceeds to the posterior portion of the left parietal; the second is a small notch on the left parietal; finally, the third completes the semi-circumference up to the left mid lambdoid suture (the circumference had to continue along the occipital and the right parietal, but the lack of this last portion does not allow us to fully visualize the cutting plane).

Here we have another transverse craniotomy and the fact that it is so precise could suggest the use of a guide along the entire head circumference (Signoli et al., 1997; Mitchell, 2012; Giuffra et al., 2016; Scalise et al., 2018; Scheelen-Nováček et al., 2019).

The color of the surface cut, equal to the rest of the cranium and the inside of the cap, leads us to suppose that the craniotomy was performed before the deposition of the remains.

The casts of the false starts of *V-FU17-1* are both vaguely "W" (Fig. 10A–B) and "U" (Fig. 10C) shaped, while the walls are straight, without undulations, compatible with both a straight and an alternating blade or a "raker set" (Nogueira et al., 2016; Bernardi et al., 2020b; Bernardi et al., 2021; Licata et al., 2023 unpublished). The straight walls may be due to a further passage of the blade in the same point, to the speed, the pressure exerted and the depth of the notch, therefore not significant for the identification of the type of set used (Nogueira et al., 2016; Bernardi et al., 2020b).

Cast number 1 (false start notch on the right temporal bone; Fig. 10A) also allows us to highlight the marks left by the individual teeth of the saw, a detail that in other cases is not present, despite the greater number of false starts considered; this detail allows us to hypothesize that the saw used was of manual action.

Even the tooth impressions and small bone spurs, confirm the hypothesis that a handsaw was used, oscillated during cutting and oriented in different directions to facilitate the complete severing of the cranial section (Fig. 9E) (Licata et al., 2023 unpublished).

Hand saws therefore leave a series of peculiar marks since, unlike mechanical saws, they require only the strength of a human operator, which can lead to characteristic variability (Martlin et al., 2021).

The cranium presents an imprecise transverse craniotomy, presenting countless bone spurs (on the front, temporal scales and occipital bone) and notches for the changes of the cutting planes, so we can hypothesize that no guide has been used to facilitate the final joining of the osteotomy (Signoli et al., 1997; Mitchell, 2012; Giuffra et al., 2016; Scalise et al., 2018; Scheelen-Nováček et al., 2019).

Precisely because of the breakaway spurs we cannot say with certainty where the cutting action began and ended, but from the streaks and signs of false starts we can hypothesize that the action began on the left side and continued clockwise up to the occipital region; subsequently the cut is probably re-started from the left parietal counter clockwise, until it joins the previous cut, on the border between the left

[1] Research has shown that already at the end of the eighteenth century "flexible chain osteotomes" were used for craniotomies; this innovative tool seems to have been invented in 1785 by Aitken, a Scottish obstetrician, and then developed in the following years, up to modern chainsaws (Kirkup, 1995; Skippen et al., 2004; Johnson et al., 2010; Phillips et al., 2011; Hawk, 2016).

parietal region and the occipital one, as evidenced by the presence of a fracture on the cap, attributable to the use of a lever to separate the two portions of the cranium (Kausmally, 2015).

The color of the cutting surface is the same as the rest of the cranium and the inside of the cap, so it can be estimated that the craniotomy was performed before the deposition of the body

After considering the morphological characteristics of the individual cuts, we must now contextualize the findings integrating these data into our analysis.

The finds *II-FU11-1* and *II-FU11-2* constitute an orderly bone grouping recovered in the past from an original context unknown to date. This funerary deposit has led to the loss of any dating element (funerary inscriptions, tomb type and location of the original burial).

Since the cuts are of modern manufacture (given the use of an electric saw) it is evident that their realization may have taken place at a time far from the original deposition of the individuals in the cemetery of Santa Maria Maggiore and therefore it is deducible that these were performed on already dry bone.

Despite their alteration, the analysis carried out allowed us to hypothesize an educational use for these finds. This hypothesis derives not only from the modernity of the cuts and from the indirect sources on the history of these finds, but also for the presence of numerous pencil and pastel marks that highlight some points on the cranial surface, as well as along the circumference as in *II-FU11-2*.

The second grouping consists of the finds *III-FU12-1* and *III-FU12-23*. FU 12 is an ossuary-casquet, a secondary deposition which, in a first analysis, would contain 14 adult individuals and 3 sub-adults. In this context the remains were laid neatly, placing the two crania that make up our sample at the foot of the case. Even if the context of deposition remained unviolated, the lack of documentation on the presence of that funerary unit nor of inscriptions do not allow us to estimate a possible dating of the remains.

The study of the individual *III-FU12-1* leads us to hypothesize that it was subjected to the practice of dissection, considering the countless inaccuracies of the cut, and the context in which it was found, characterized by the subdivision of anatomical districts and therefore compatible with the burial of human remains post-anatomical dissection. To support the dissection hypothesis, we know that in the past it was common practice to dissect different parts of the body at different times, which led to deferred burial of anatomical districts (Dittmar et al., 2015).

Despite the numerous evidence in favour of the dissection hypothesis, it is not correct to define it as absolutely certain, as the cranium *III-FU12-23* is missing most of the occipital, parietal and temporal right portion and part of the frontal bone.

The studies conducted so far on this funerary unit, however, tell us how only these two finds show signs due to post-mortem practices, suggesting the result of a dissection.

Despite that, we cannot exclude a further possibility, namely that this deferred multiple deposition was the consequence of the different translations of ossuaries (documented by written sources) coming from the old church of Santa Maria Maggiore. This other possibility would reopen the way to the hypothesis of autopsy practice.

At last, *V-FU17-1* comes from the private chapel, from a reduction in a wooden box that respects the integrity of the individual. From the studies carried out on the context, it has been possible for now to restrict the dating of the find between the seventeenth and nineteenth centuries.

Taking into consideration only the cranium, we first studied how the blade left evident signs of multiple changes of direction, consistent with the desire to damage the brain as little as possible (Valentin et al., 1995; Scalise et al., 2018). Later, we focused on the lengthening of the styloid process that may have predisposed the subject to Eagle syndrome. The presence of a pathology, overt or suspected, usually leads to the direct association of cuts of post-mortem operations with autopsy, as assumed for this case (Licata et al., 2023).

Finally, if we also consider the post-cranial skeleton, the absence of further cuts and paleopathological signs adds more plausibility to the hypothesis of diagnostic finding by autopsy because of the lengthening of the styloid process and distances the case from the dissection interpretation.

In the light of the surveys carried out and having considered the context of origin, or in any case in which the finds were recovered, we have divided the sample studied into 3 distinct cases. Although in some cases the final hypothesis is ambiguous (FU12), the context and morphological analyses of the cuts were fundamental for reaching a conclusion concerning the sample of skulls with craniotomies of the church of Santa Maria Maggiore in Vercelli.

5. Conclusion

This work wanted to highlight the skeletal evidence of post-mortem procedures on an archaeological sample, found in the underground cemetery of Santa Maria Maggiore in Vercelli, focusing attention on the possibility of a univocal differentiation of these practices.

Although it must be taken into account that it is not always possible to work on intact finds, often having only fragmented or incomplete samples available, and that not all the differentiating characteristics of the practices can be found simultaneously on the crania, this study has nevertheless allowed us to draw preliminary conclusions on the type of post-mortem investigations to which the subjects of our sample have been subjected to in the past (Licata, 2017).

Our considerations were based on a sample consisting exclusively of crania, which, despite being a limiting choice, still allowed us to evaluate a combination of numerous morphological criteria of the cuts, making it possible to highlight the differences between different types of saws and blade sets that numerous studies had brought to light in experiments on “fresh” long bones.

Currently, there is no univocal protocol that differentiates post-mortem practices, both specifically referring to the cranium and the post-cranial skeleton.

Over the years it will therefore be desirable to continue this type of morphological analysis and studies concerning the history of medicine to try to reach a univocal answer on the cuts found also on osteo-archaeological finds, not of forensic competence.

Our interest will also be bringing to light all the burials and finds in the cemetery of Santa Maria Maggiore, thus continuing the search for further possible samples that will enable us to better understand the history of post-mortem procedures and of the context itself.

CRediT authorship contribution statement

Arianna Vanni: Conceptualization, Data curation, Writing – original draft. **Roberta Fusco:** Investigation, Supervision, Writing – review & editing, Writing. **Chiara Tesi:** Investigation, Supervision, Writing – review & editing, Writing. **Marta Licata:** Conceptualization, Funding acquisition, Investigation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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