Coll. Antropol. **42** (2018) 3: ??–??
Original scientific paper

Saw Mark Analysis of Three Cases of Amputation and a Craniotomy from the Seventeenth and Eighteenth Centuries Hospital Necropolis of Forlì Campus (Forlì, Italy)

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ABSTRACT

The seventeenth-eighteenth century hospital necropolis of Forlì Campus (Forlì, Italy) was discovered during the Forlì Campus construction work in 2014. Three cases of limb amputation and a craniotomy are examined using the forensic approach of saw mark analysis in order to understand features of the surgical instruments employed and to gain insight into the position of the surgeon during the cutting actions. With the aid of high definition photographs and moulds, we analyzed the cut surfaces of each sample, also using stereomicroscopy and SEM (Scanning Electron Microscopy). A qualitative and quantitative approach was used in the analysis of the kerf features (e.g. breakaway spur and notch, tooth scratches and hop, exit chipping), and empirical evidence was compared against comparisons coeval surgical essays. We hypothesize that a linear hand-powered push saw and an alternated push saw with a 2mm distance between the teeth were used for amputations. The craniotomy was executed presumably using a linear hand-powered saw with the set of the blade circa 1.3mm wide. Through the application of forensic methods on individuals from archaeological context we describe early cases of surgical practice in a more technical way.

Key words: *hospital necropolis, amputation, craniotomy, saw mark analysis, microscopy, surgical instruments features*

Introduction

Surgeons operating across Europe gained scientific respect during the eighteenth century, when they were able to obtain a doctorate. Until then, surgery had been mostly performed by barbers[1]. The progress of modern medicine was also supported by the foundation of clinical hospitals[2] where doctors were able to benefit from observations made on both dead and living patients to improve their understanding of pathological conditions, and to train students in the use of instrumentation and in implementing new techniques[2,3].

Empirical evidence of surgical incisions is common in anatomical collections[4] and in reports on remains from archaeological contexts[5,6], especially those related to hospitals[7,8]. However, only a few detailed analyses of cut surfaces were done[4,9].

Here we present three cases of amputation and one case of craniotomy observed in skeletal material recovered during excavation of a graveyard associated with the hospital of Forlì Campus (Forlì, Italy). Saw mark analysis, with particular reference to striations left on bones, was performed to interpret the process these archeological remains underwent. This type of tool mark analysis, developed in the 1970's[10,11] in a forensic context for identifying the technical characteristics of saws used in cases of dismemberment, elucidates features of surgical instruments. The aim of this study is to apply saw mark analysis, that is typical

Received for publication July 17, 2018

of forensic research, to an archaeological sample. It offers insight into the position of the surgeon during the procedure, and may generate sound hypotheses on the specific clinical practice that were carried out on individuals.

The study context

The sampled cemetery occupies an area of approximately 900 m^2. The graveyard was uncovered during the construction of the new Forlì Campus (Forlì, Northern Italy) (Figure 1a) (University of Bologna). This context was excavated between April and July 2014 and was dated to the seventeenth and eighteenth centuries based on stratigraphy. Unfortunately, no more precise information about dating is available to the authors. Approximately 271 single burials and six ossuaries were discovered. The burials were disposed in rows and can be grouped into two clusters based on their orientation. The earliest burials present with an East-West orientation, while later burials exhibit a North-South orientation (Figure 1b). The graves were narrow and long with an irregular bottom which affected the position of the body.[1]

Since 1223 the area was part of a building complex including the charity hospital *Domus Dei* (Figure 1c) and Saint James church. It was located just outside the walls in the south-east area of the town[12]. As a charity hospital, the institution acted for helping poor, invalid people and orphans. In the fourteenth century it was included inside the town walls[13]. During the sixteenth century, *Domus Dei* became the most important sanatorium in Forlì and the presence of a surgeon was documented in 1612[12]. Since then, the number of resident surgeons progressively increased and reached four units in 1800[14]. Over time, the hygienic conditions of the structure drastically worsened as testified by accounts of a terrible smell coming inside a wide recovery room from the anatomical room on the lower floor[12]. During the first half of the eighteenth century, the community decided to rebuild the hospital. According to the *Décret Impérial sur les Sépultures* issued by Napoleon in 1804 the graveyard was abandoned. The hospital was definitely closed at the beginning of the twentieth century. Unfortunately, all its archives were destroyed during World War II (1939-1945)[15] making it impossible to retrieve further information on patients and medical activities.

Materials and Methods

Materials

During the preliminary analysis of skeletal remains four individuals with evidence of surgical cuts were identified (Table 1). The remains are generally well preserved. [Table 1]

Individual 2 burial 1 (Case 1) (Figure 2a) lied prone in a single grave located in the South-Eastern portion of the excavation area (number 1 in Figure 1b).

Individual 1 burial 121 (Case 2) was instead found in a single grave located in the North-Eastern zone of the excavated area (number 2 in Figure 1b). The body lied supine, with the left leg not in connection and resting in lateral position. The proximal third of the femur was missing. According to the archaeologists that conducted the excavation, Case 2 was a primary burial. It can be then safely assumed that the resected limb belonged to the same individual (Figure 2b).

Individual 4 burial 24 (Case 3) is only represented by bones of the left arm, namely the distal diaphysis and epiphysis of a humerus, a complete radius, ulna, pisiform, lunate, capitate, hamate, metacarpals (II, III, IV), and proximal phalanges (I, II). The remains were discovered under other three individuals buried in the same grave (Figure 2c) located close to the southern limit of the excavated area (number 3 in Figure 1b).

Finally, Individual 2 burial 68 (Case 4) lied prone (Figure 2d) in a double burial (number 4 in Figure 1b) under Individual 1. They were buried in opposite directions and their bones were not commingled.

Methods

Sex determination and assessment of age at death were carried out using different methods[16-20]. Saw mark analysis was performed evaluating both qualitative and quantitative diagnostic features of the kerfs. This approach included macroscopic evaluation of the cut section and microscopic observation of specific portions of each cut such as kerf walls and floors, breakaway spurs and notches, false starts, tooth hop, exit chipping, and orientation of striations[21-26]. The timing of injury (e.g. ante-, peri-, or

TABLE 1
RESULTS OF THE ANTHROPOLOGICAL ANALYSIS OF THE INDIVIDUALS WITH EVIDENCE OF SURGICAL CUT

Case	Individual	Burial	Sex	Age	Incision
Case 1	Individual 2	Burial 1	Male	30-39 years	Amputation
Case 2	Individual 1	Burial 121	Male	30-39 years	Amputation
Case 3	Individual 4	Burial 24	Indeterminable	Adult	Amputation
Case 4	Individual 2	Burial 68	Male	30-39 years	Craniotomy

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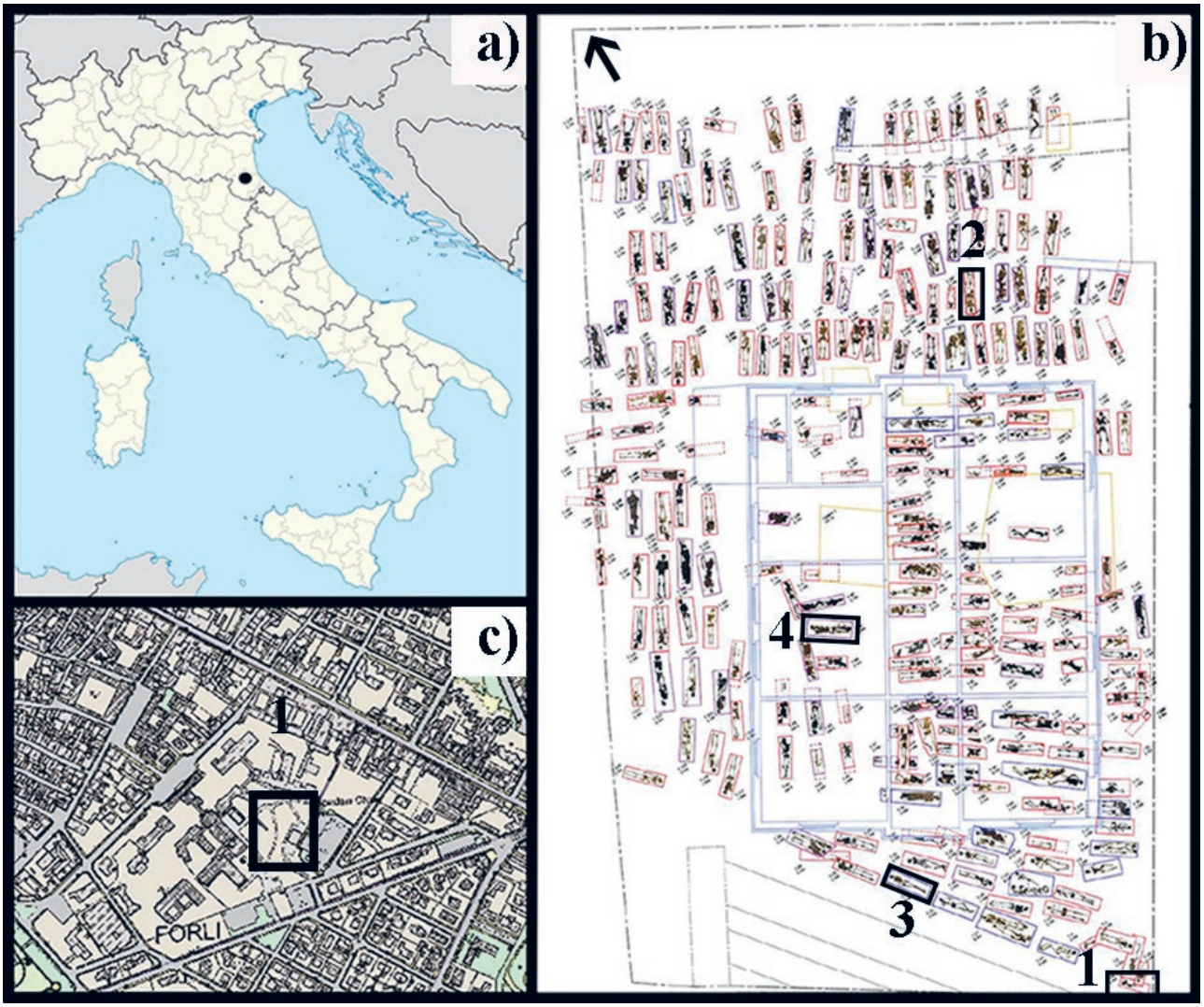

Fig. 1. The position of the town of Forlì in the North-East of Italy (a). The plan of the necropolis and the location of Case 1 (1), Case 2 (2), Case 3 (3), Case 4 (4) (b). The ancient location of Domus Dei hospital (1) and the position of the archaeological area (black rectangle) in Forlì (c).

post-mortem) was evaluated according to the possible presence of bone remodelling[21,27].

An Olympus SZ61 stereomicroscope with an Olympus Soft Imaging SC100 lens and an Olympus KL300 annular light source was employed in combination with Analysis Get It image software in order to observe cut sections directly on the specimens. An optical fibre light source (Euromex EKU) was used for creating oblique lighting.

Surface morphology of nine moulds and of one original specimen was observed by using Scanning Electron Microscopy (SEM) Inspect S FEI with a Philips New XL-30 microprobe, equipped with a secondary electron detector (ETD) and a backscattered electron detector (BSD). Images and measurements were collected over a small area of the specimen by means of a motorized and computer-controlled SEM stage for X, Y, Z movements. Rotation and Tilt function were also possible. The sample was at a working distance of 10-15 mm. Images were taken with an accelerating voltage of 20kV, and magnification was settled according to the type of information being sought.

The nine high resolution moulds of sections were made using silicone (President® Plus, Coltene, Switzerland) to cope with the reduced working space offered by SEM.

Results

Case 1

Both legs of this male aged between 30-39 years were amputated at the same level on the distal portion of the femoral diaphysis (Figure 3a). The sectioned bones show no sign of healing. Small and superficial cut marks were observed on the anterior surface of the left bone diaphysis, close to the kerf walls (Figure 3b). The striae on the prox-

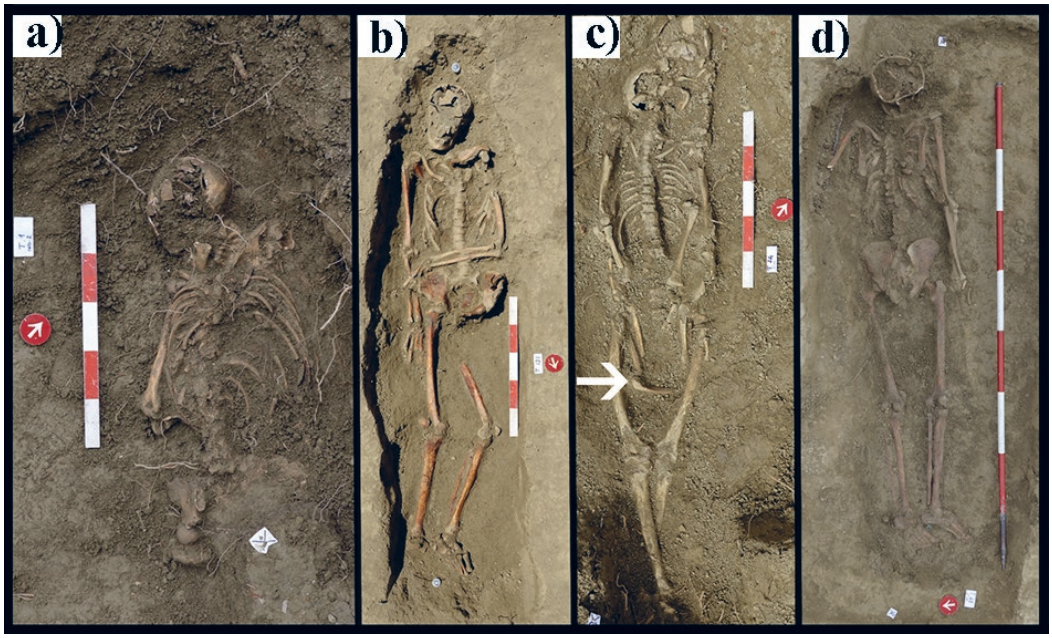

Fig. 2. The pictures of in situ individuals. Case 1 (a), Case 2 (b), Case 3 (white arrow, c), Case 4 (d).

imal section of the right femur were disposed in a non-uniform pattern (Figure 4a). The kerf floor is clearly recognizable by the presence of the breakaway spur crossing the *linea aspera*, while the exit chipping can be observed on the medial margin of the cut (Figure 4a). The morphology of the distal section is almost specular to the proximal one, with the breakaway notch placed on the posterior portion of the cut surface (Figure 4b). When both sections are compared, the proximal one appears more ribbed than the distal one. Similarly, the proximal cut surface recorded on the left femur shows striae disposed in a non-uniform pattern (Figure 4c), with the breakaway spur on the posterior-lateral portion of the section. The morphology of the distal section of the left femur, including the breakaway spur, appears to be almost specular to the proximal one (Figure 4d), even though the distal one seems more ribbed. Observations made using SEM show the presence of a tooth hop (2 mm long) on the distal part of the right femoral section and tooth scratches (4 mm long) on the proximal one (Figure 5a-b).

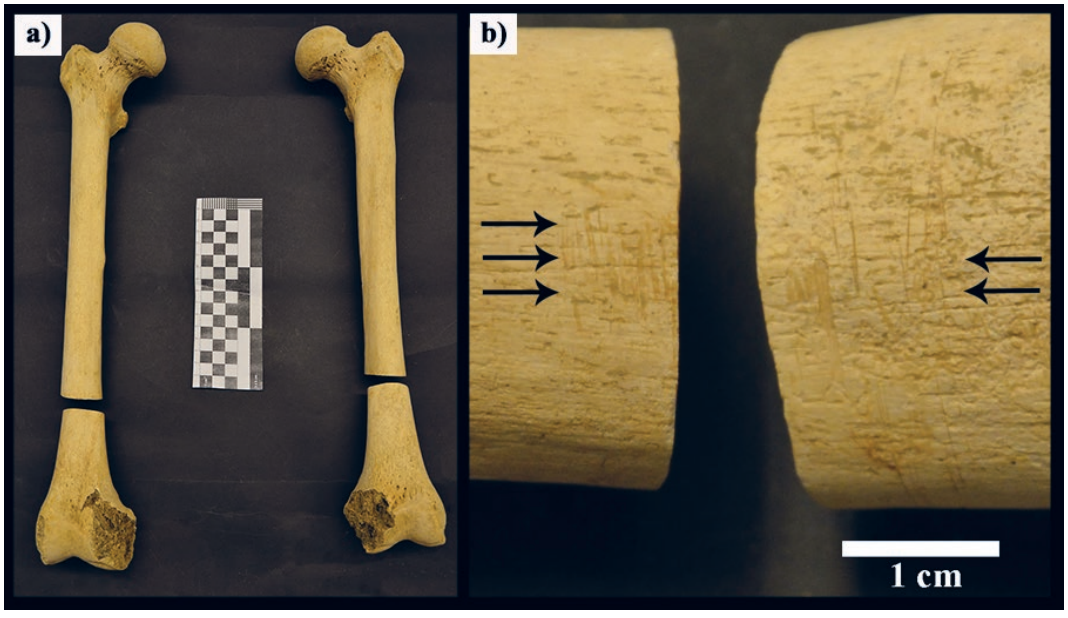

Fig. 3. The amputated femurs of Case 1 (a). Cut marks close to the sections on the anterior portion of the left femur (b).

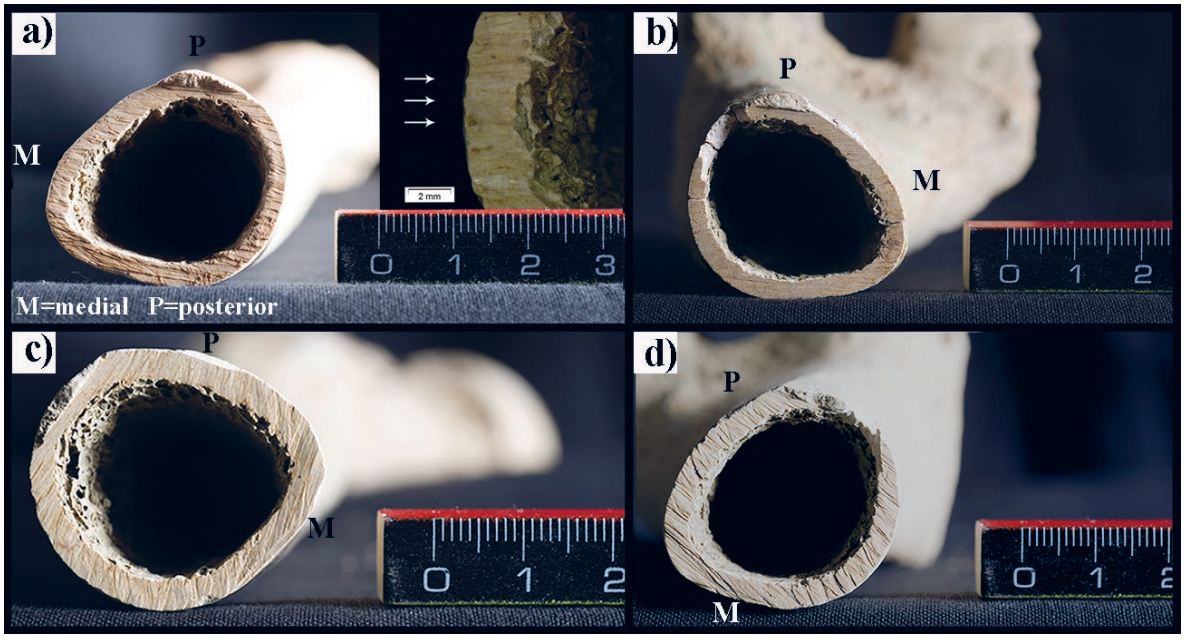

Fig. 4. Proximal and distal sections of the right (a-b) and left (c-d) femur of Case 1, in prone position, respectively. The magnification of exit chipping (white arrows) on the medial side of the proximal right section in figure (a)-black rectangle.

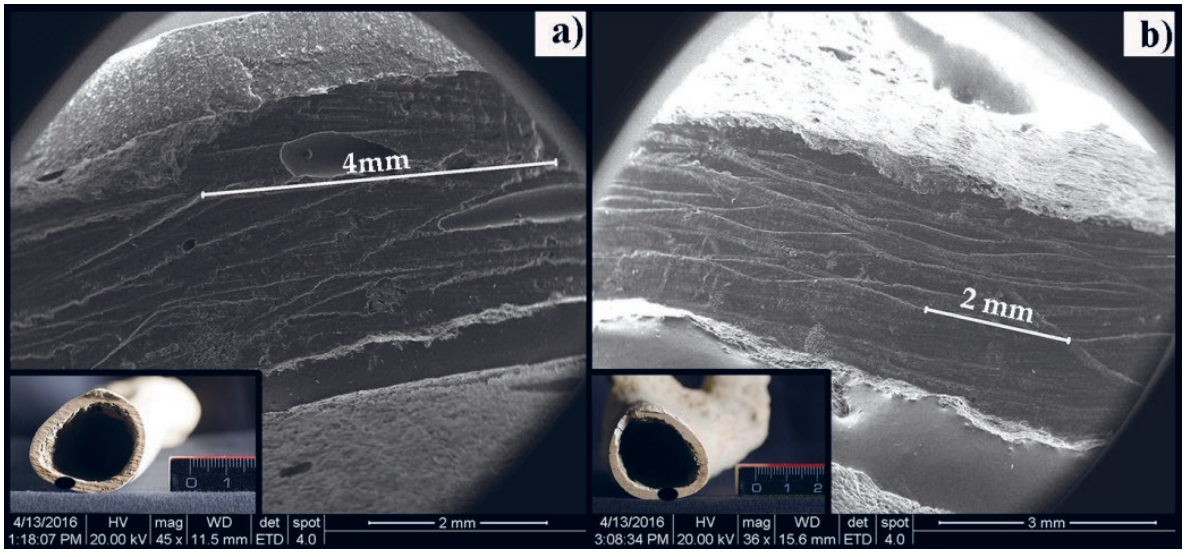

Fig. 5. The SEM images of tooth scratch measure on the anterior portion of the right proximal section (a) and the dip to dip measure of tooth hop on the anterior portion of the right distal section (b).

Case 2

Case 2 is also represented by a male individual aged between 30 and 39 years. His left femur was amputated at the middle diaphysis and the proximal portion is missing (Figure 6a). The striae on the section are disposed in a uniform pattern, parallel to the kerf floor, identified by the presence of the breakaway spur on the posterior-medial portion of the section (Figure 6b). The exit chipping is visible on the anterior-medial area of the cut (Figure 6c). The linear marks appear to be denser in the first part of the cut, larger in the middle (Figure 6d) and narrower near the breakaway spur.

Case 3

Case 3 consists of an amputated arm belonging to an adult individual, as suggested by the presence of a complete epiphyseal closure[28]. The amputation was executed approximately on the humeral mid-shaft (Figure 7c). The

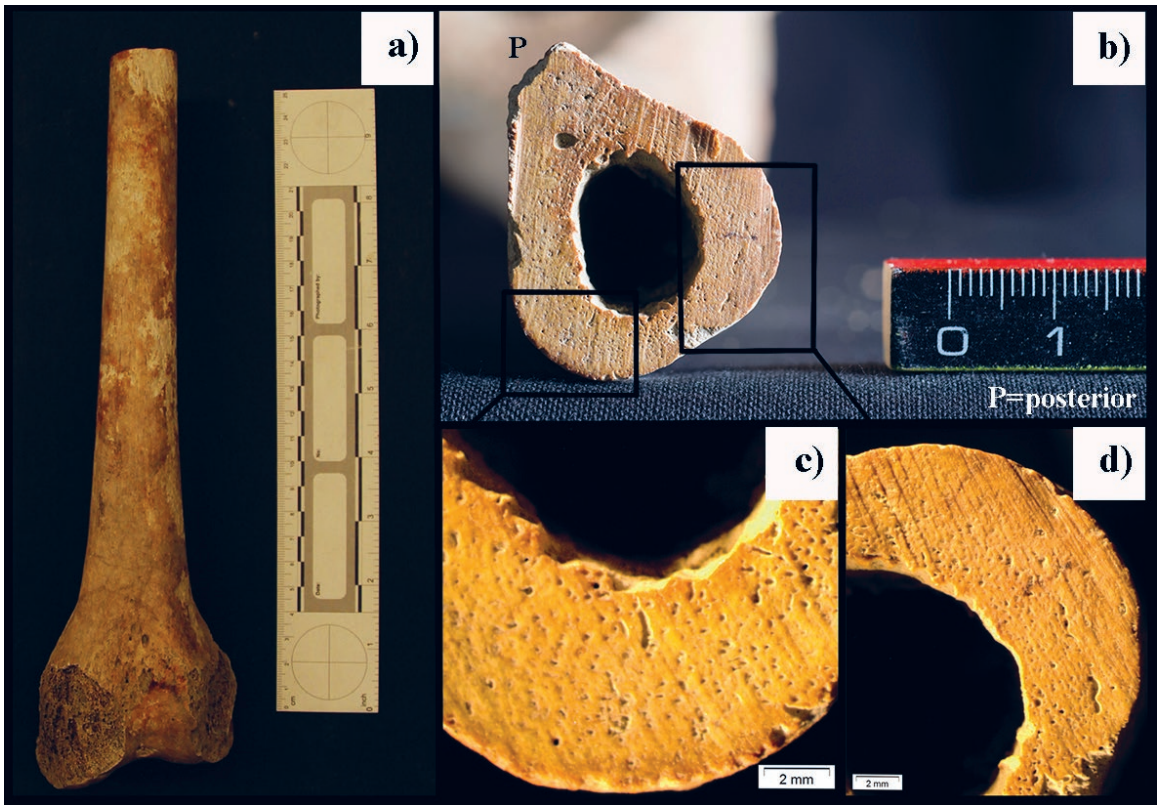

Fig. 6. The amputated femur of Individual Case 2 (a). The section of the bone in prone position (b). Stereomicroscopic images of exit chipping on the anterior-medial area of the section (c) and of the starting portion of the kerf (d).

pattern of the striae is generally uniform, denser on the lateral portion of the surface, larger in the middle and narrower on the medial part of the cut, where the break-away notch is placed (Figure 7d). Exit chipping is located on the anterior-medial edge (Figure 7d). A peri-mortem lesion is present on the ulnar diaphysis and located 1.8 cm under the radial notch. The lesion presents a complete fracture with indented edges and the lack of a bone flake on the posterior part of the diaphysis (Figure 7a). The surface of the lesion shows no sign of healing and exhibits irregular striae (Figure 7b).

Case 4

The last case study is another 30-39 years old male. His cranium exhibits a horizontal cut crossing the frontal

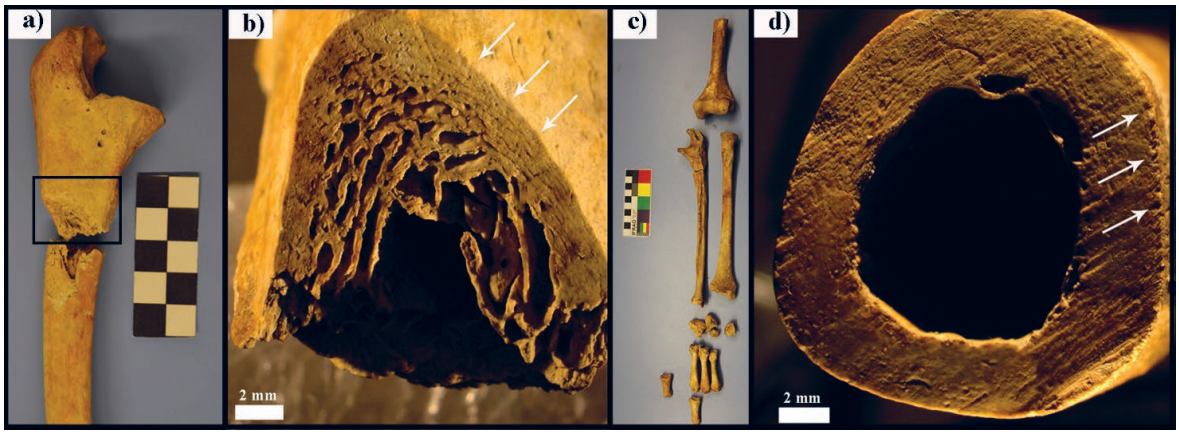

Fig. 7. The fracture and lesion on the ulna (a). The surface of the ulnar lesion characterized by some striae (b) (white arrows). The remains of Case 3 (c). The section of the amputated humerus and exit chipping indicated by the white arrows (d).

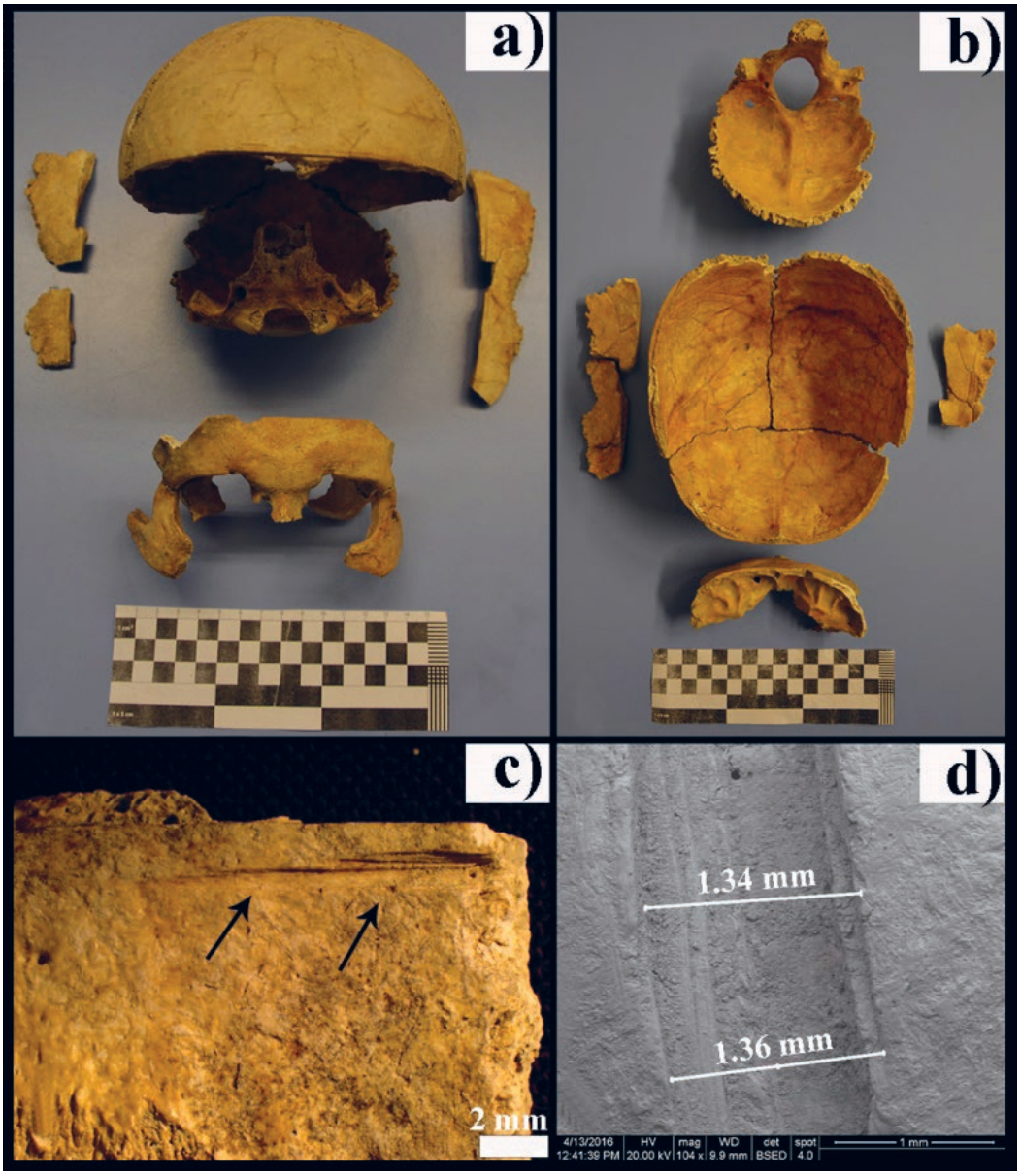

Fig. 8. Anterior view (a) and endocranial view (b) of the severed skull of Case 4. Stereomicroscope image of the false start on the right parietal bone (c). SEM image of the minimum kerf width measured on the false start (d).

and both parietal bones, while the occipital appears to be untouched. The incision is linear and continuous, but it does not impact the lambdoid suture (Figure 8a-b). No evidence of healing can be recorded. On the left parietal section, numerous groups of parallel striae can be observed. Striae located in the posterior area are oriented towards the endocranium and then become parallel to it (Figure 9a). On the frontal bone, the direction of striation follows the progressive curvature of the bone and clear shifts in direction can be seen near the frontal eminences (Figure 9b). The morphology of the splanchnocranium section is specular to the frontal one. The curvature of the incisions seems to remain constant also on the anterior area of the right parietal segment while, more posteriorly, the striae seem to recline towards the occipital segment (Figure 9c). False starts are visible on the frontal bone and on the upper and lower parietal fragments (Figure 8c). At the end of the cut on the parietal bones, the incision becomes more irregular, with linear marks blended and imprecise and the diploe irregularly broken (Figure 9d). Using SEM we estimated that the minimum kerf width on the false start of a right parietal bone segment is 1.34-1.36 mm (Figure 8c-d). On the external surface of the frontal bone, near the bregma, a deep and well-marked porosity is present. Such porosity surrounds a defined linear mark incising the cranial bone (Figure 10).

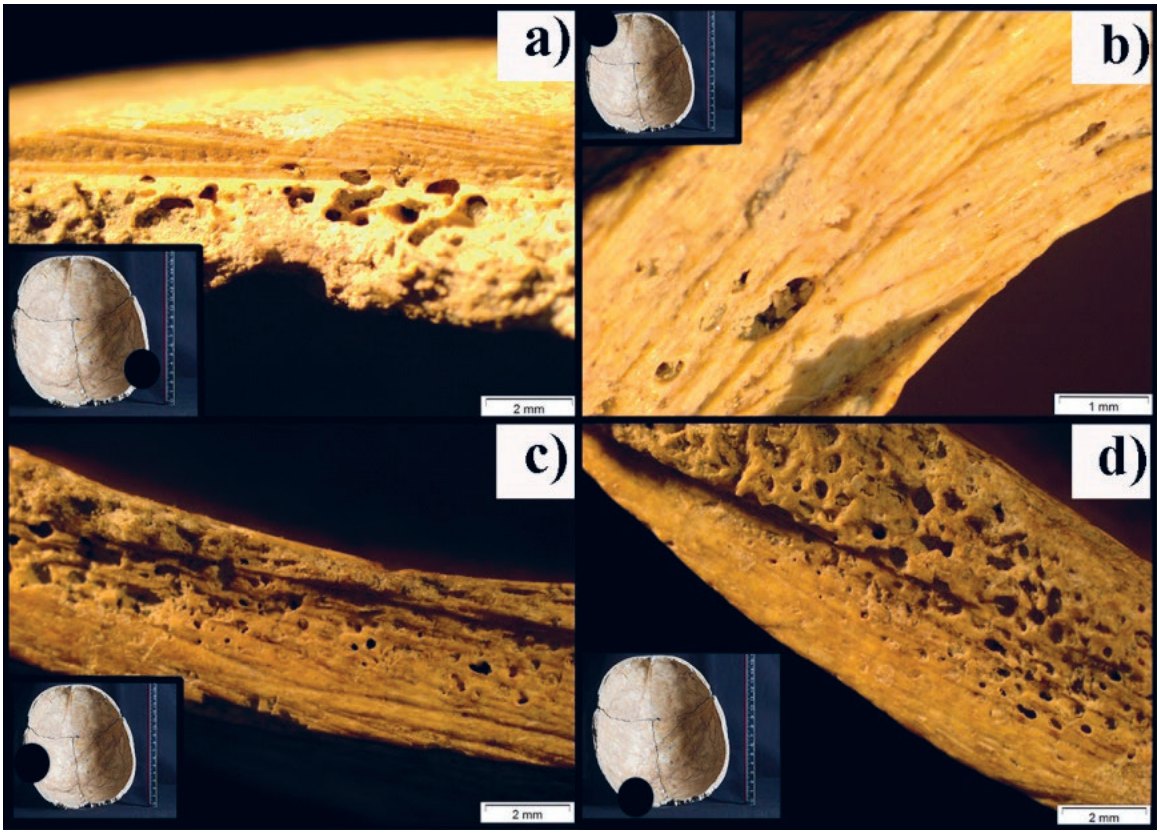

Fig. 9. Stereomicroscopic images of calotte sections of Case 4. Parallel striation on the posterior portion of the left parietal bone (a). Changes of striae inclination on the right frontal bone (b). Striae reclining towards the occipital on the right

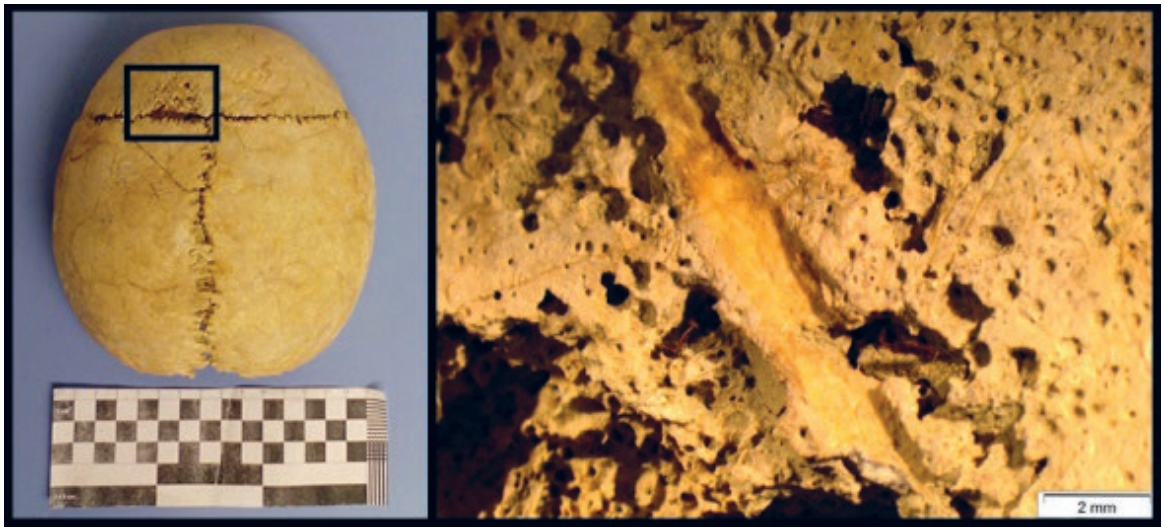

Fig. 10. Well-marked porosity surrounding a linear mark on the frontal bone of Case 4.

Discussion

Amputations

On the right femur of Case 1, the presence of the breakaway spur and notch crossing the *linea aspera* (Figure 4a-b) suggests that saw proceeded from the anterior to the posterior side of the bone, and that the inclination of the cutting stroke was perpendicular to it. The presence of the breakaway spur and notch on the posterior-lateral portion of the section of the left femur (Figure 4c-d) indicates that

the direction of blade progress was from the anterior-medial to the posterior-lateral side of the bone, so that the orientation of the cutting stroke, which is visible on kerf wall striations, was almost perpendicular to it[26]. The heterogeneous striations made by a wide toothed instrument are visible on the kerf walls (both proximal and distal) of both femora, showing the inconsistency typical of a linear hand-powered push saw (Figure 4). The hypothetical use of this kind of instrument and the related presence of the exit chipping on the medial portion of the right femoral section (Figure 4a) suggests that the performer was standing on the lateral side of the limb[26], as confirmed by the position of the kerf floor on the left side. The presence of deeper marks on kerf walls than on the opposite one suggests that the saw blade was asymmetrical and characterized by a more ribbed set on the left side[26]. Therefore, the surgical instrument could be the same for both amputations. The measure taken from dip to dip of the wavy marks made by blade hopping (tooth hop) indicates that the distance between teeth[10,22,26] corresponds to 2 mm (Figure 5b). Likewise, the width of tooth scratches (4 mm) (Figure 5a), could reveal the double distance between the teeth[11,26]. The femora were both amputated at the same level, soon after death and almost at the same time as there is no osseous tissue reaction. The absence of visible pathological conditions, which could justify the resections, does not facilitate to envisage the reason of this intervention. Cut marks are observable on the bone surface, around the left femur section, only in the Case 1 (Figure 3b). According to the description of Giovanni Ambrogio Maria Bertrandi (1723-1765)[29], the executer could sever the muscles and the periosteum with specific knifes in different moments or he could saw the membrane together with the bone. Even if it is impossible to know if the cut marks were made in the attempt to cut the muscles or the periosteum, it is probable that the resection included at least two cutting stages. The formation of the breakaway spur and notch at the end of the cut was well-known and, for this reason, surgeons used files or cutting forceps present in amputation kits[30] to remove them and facilitate the healing of the lesion[29]. On both the proximal femora of Case 1, the breakaway spur and notch are intact, ultimately suggesting that the individual was not presumed to survive the resection or, maybe, he was already dead at that moment. We could hypothesize that the individual died during the operation or that he was the subject of some exercise in the context of seventeenth and eighteenth century hectic medical practice.

On the left femur of Case 2, the position of the breakaway spur on the posterior-medial area of the section and the orientation of the striations (Figure 6b) suggest that the saw progressed from the anterior-lateral to the posterior-medial side of the bone maintaining the direction of the cutting strokes perpendicular to the blade progress. Despite the orderly appearance of the striae on the kerf wall, the different strength applied during cutting is recognizable on striation patterning (Figure 6d). The inconsistency of cut and the homogeneous striations suggest that a linear hand-powered pull saw was employed[26]. The position of the exit chipping on the anterior-medial area of the kerf contour (Figure 6c) is compatible with the use of this kind of saw which leaves such distinctive marks at the end of its active stroke[26]. Based on the position of the breakaway spur, of the exit chipping, and on the direction of saw motion, it can be hypothesized that the operator acted standing on the medial side of the leg. For this individual, as much as for the previous one, no evidence of pathological conditions that suggest the need for a resection can be recorded. The absence of the proximal portion of the amputated limb and the presence of the distal stump are anomalous. It cannot be excluded that this missing element was retained as a specimen as it has been hypothesized in other comparable contexts[5,31]. Consequently, it is difficult to identify this amputation as a possible dissection for proper medical practice.

Humeral striations of Case 3 are oriented anterior-posteriorly, while the breakaway spur is visible on the medial side of the kerf (Figure 7d). These elements suggest that the direction of sawing was lateral to medial. The homogeneity of fine marks, the differential density of striations, and the inconsistency of the cut (Figure 7d), suggest that a linear hand-powered pull saw was used. The irregularities on the anterior-medial part of the kerf contour (Figure 7d) are compatible with the formation of the exit chipping by a pull saw at the end of its active stroke[26]. Based on this evidence, and considering the position of the breakaway spur, we suggest that the surgeon was located at the medial side of the limb during the dissection. Ulna shows a deep and smooth lesion, probably caused by a sharp-edged weapon which dynamically hit the forearm provoking the formation of a flat, regular surface. The section is characterized by the presence of irregular striations possibly produced by blade flaws (Figure 7b)[26,27], parallel to the direction of the blow[26]. Based on the position of the lesion and the absence of any cut marks on the radius, we could suppose that at the moment of the impact the forearm was supine[32] and the applied force was so intense to provoke a complete fracture of the diaphysis (Figure 7a)[26,33]. Overall, the location of the injury is compatible with a defence wound[32,34]. In the eighteenth century, amputation was considered necessary when the limb structure and its functionality were seriously compromised[29]. Therefore, it is likely that the trauma and the complete fracture of the ulna justified the need for surgery.

Craniotomy

Striae orientation of cut sections documented for Case 4 suggests that the direction of the cutting stroke followed the curvature of the cranial bones all along the cut. The blade progress was perpendicular to the strokes[26] and the inclination of the instrument was adapted to the physiological curvature of the cranium in order to excise the calotte without damaging the brain. The variable inclination of the instrumental marks along the surface of the cut and the greater linearity of the kerf margins on the left side compared to the right parietal bone (Figure 9a-d), suggests that the operator started cutting the skull from left to right. Due to the absence of incisions on the occipital bone (Figure 8a-b), we could suppose that the calotte was separated along

the unfused lambdoid suture (which is a suitable way of removing the bone without rotating the body on the table). Considering the absence of fractures on the occipital bone (Figure 8a-b), it is also possible that the person who made the cut was not interested in removing the calotte, but only in incising it. The accuracy and linearity of the cut suggest the use of a rim clamped to the head as a guide[31,35]. Considering the importance given to anatomical investigation and autopsy during the eighteenth century[36], we could also hypothesize that the reason of this cutting action was the hyperostotic action of the osseous tissue near *bregma* (Figure 10). The osteoclastic and osteoblastic activity of the bone could represent a healing response to cranial trauma incurred some weeks before death[37]. Even if it is highly probable that this was a post-mortem craniotomy, the missed intersection of the occipital allows us to differentiate this case from others carried out in the seventeenth and eighteenth centuries that involved the whole perimeter of the cranium[35,38]. Furthermore, there are no signs on the ectocranial surface (e.g., other kinds of cut or colour marks) that might suggest its retention for anatomical lectures[4].

The inconsistency of the cut due to the reciprocating motion and the lack of a gradual changing of the patterns along the kerf, suggests that a linear hand powered saw was used[26]. Measurements taken by SEM suggest that the blade could be approximately 1.3 mm wide (Figure 8d)[26]. The reduced dimension of early skull blades in comparison to other resection tools can be explained with the need to make the utensil capable of following the curvature of cranial bones without compromising any internal tissues[39], as further documented by Johannes Scultetus (1595-1645) in his treaty *Armamentarium Chirurgicum*[40], where he described a series of surgical instruments for severing skull bones which included *ferrulae rectae*, short-toothed, handled blades.

Conclusions

The cemetery of Forlì Campus provides one example of craniotomy and three cases of anatomo-surgical amputation. The purpose of this study was to apply a typical forensic analysis to archaeological samples in order to understand some instrumental features and the position of the surgeon during the operation. Case 1 and 2 could be interpreted as practical activities associated with medical training typical of the seventeenth and eighteenth centuries. As far as the craniotomy is concerned, the cut did not damage the occipital bone (Figure 8a-b) and no other peculiar signs were observed on the skull, with the exception of the hyperostotic reaction near *bregma* (Figure 10). These characteristics could connote it as both an autopsy or a training session. On the other hand, Case 3 probably corresponds to a surgical intervention following the sharp force trauma on the ulna (Figure 7a-b). This is the only clear case of surgical practice that could be observed in the sample.

The cut surfaces of Cases 2 and 3 show several similarities (e.g. the position of the breakaway spurs, the patterns of striations density, etc.) suggesting that similar resecting tools and cutting methods were used. Overall, all these surgical procedures appear congruent to the processes descripted in the coeval essays, i.e. the position of the executor during the operation was usually next to the limb but the specific side depended on the case[29].

Further analysis on additional burials of the same cemetery will allow us to expand current knowledge on the hospital medical activity.

Conflict of Interest

The authors have no conflict of interest to declare.

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ANALIZA TRAGOVA PILE U TRI SLUČAJA AMPUTACIJE I KRANIOTOMIJE IZ SEDAMNAESTOG I OSAMNAESTOG STOLJEĆA, BOLNIČKO GROBLJE FORLÌ CAMPUS (ITALIJA)

S A Ž E T A K

Tijekom izgradnje novog sveučilišnog kampusa u gradu Forlì u Italiji je 2014. godine otkriveno bolničko groblje iz 17. i 18. stoljeća. U okviru istraživanja ispitana su tri slučaja amputacije ekstremiteta i jedna kraniotomija pomoću forenzičke analize tragova pile kako bi se bolje razumjela obilježja upotrijebljenih kirurških instrumenata i dobio uvid u položaj kirurga tijekom zahvata. Pomoću fotografija visoke razlučivosti i odljeva analizirali smo površine reza svakog uzorka, uz primjenu stereomikroskopije i SEM-a (Scanning Electron Microscopy). Kvalitativni i kvantitativni pristup su upotrijebljen u analizi osobina rezova (npr. izbočine i usjeci, tragovi zubaca, izlazne strugotine), a empirijski dokazi su uspoređeni s tadašnjim kirurškim prikazima. Pretpostavljamo da je za amputaciju korištena linearna potezna ručna pila i jedna izmjenična ručna pila s razmakom od 2 mm između zubaca. Kraniotomija je vjerojatno izvedena upotrebom linearne ručne pile s oštricom širine oko 1,3 mm. Kroz primjenu forenzičkih metoda na ljudskim ostacima iz arheološkog konteksta opisujemo rane slučajeve kirurške prakse na tehnički način.