The role of the Computerized Tomography versus laboratory micro-excavation in the study of ancient cineraria. Ancillary or complementary?

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Abstract

Cremation is one of the most common treatments of a dead body in the prehistoric and ancient historic societies and it represents a challenge for physical anthropologists. The cinerary urn is a complex artifact that is the result of a series of funerary rites that includes the cremation ceremony, the selection of cremated remains, their position in the urn and the presence of funerary goods. Currently micro-excavation is considered a very precise method in the study of ancient cineraria. However, the Multi-Detector Computerized Tomography (MDCT) analysis allows a non-destructive archaeological and anthropological assessment of the urn. This technique appears to be, in a certain way, very similar to the traditional laboratory procedures of micro-excavation. This procedure allows for the possibility of a morphological study of the urn and of the funerary goods. The internal stratigraphy, the consistency of the ossilegium, the spatial arrangement of the cremated bone fragments, the metric and the morphological study of the bone fragments, and the paleopathological aspects can also be analyzed. Hereby we present our methodological experience with MDCT on several urns of different age, culture and geographical origin, comparing the MDCT data with the micro-excavation results.

Introduction

Cremation, as a mean of disposal of dead bodies is one of the most common funerary rites in ancient societies. The earliest cremation is dated to 40,000 years ago in Australia (Bowler et al., 1970), while in Europe this practice is already sporadically present in the Neolithic Age. However, from the beginning of the Bronze Age that cremation is regarded as the most important funerary practice in many parts of Europe, persisting at least until its complete Christianization.

From a symbolic point of view, cremation emphasizes the deep hiatus represented by death. The two main funerary practices, inhumation and cremation, can denote different mentalities and orientations in facing death. In cremation fire represents the medium both for the deification of the deceased and for the purification of the corpse (Peroni, 1992). Obviously, this definition is simplistic because there are prehistoric and historic cultures, such as the Etruscan and Roman, who practice both types of funeral rites and in which it is often difficult to distinguish clear preferences in terms
of beliefs or social status. For these reasons, the study of the cremation cemeteries and of the cinerary urns is of particular importance in the context of cultural anthropology.

From a bioarchaeological perspective, there is a need for a holistic approach to the study of cremated remains. Due to transformations undergone by the bones as a result of the cremation process, multiple specialists from different disciplines are required. Unlike interment and, in part primary cremation (for example the Roman *bustum*), secondary cremation with burial in an urn is a ritual process divisible into several phases: preparation of the corpse, deposition on the pyre, cremation, extinguishing of the fire, separation of the cremated remains from the residues of the pyre, collection of the fragments, deposition, transport, and burial. During each of these steps some voluntary or accidental actions are carried out (for example voluntary fragmentation or choice of the cremated remains, accidental presence of roots crossing the urn etc.). All these actions can strongly affect the appearance, quantity and texture of the bones inside the urn. The urn, ultimately, is a complex artefact which is able to provide useful information about the sequence of funerary rites and about the biology of the cremated remains contained within the urn.

The study of a cinerarium involves many specialists, each of which is interested to in a particular aspect of this artefact. For example, the cinerary vessel may be an object of interest for the archaeologists or for the art historians. Generally, the cinerarium is eventually disassembled and distributed between the specialists. The consequence is the definitive loss of information contained within the whole “cinerarium system”, for example, the presence of an internal logical stratification, or the spatial relationship between bone fragments (and their anatomical significance) and the funerary goods.

Figure 1. Two-screen Picture Archiving and Communication System (PACS). Left screen: MPR and 3D reconstruction of the cinerarium. Right screen: scan sequence.
Despite the existence of various systems to recovery and study the cremated remains, the micro-excavation in laboratory is the one that grants an accurate stratigraphic study of the content of the cinerarium. During micro-excavation the cremated remains are carefully removed from the urn avoiding further fragmentations. If the soil matrix is not too hard, it is also possible to document the stratigraphy inside the urn by determining the sequence of cremated remains layer by layer, and noting the presence of ashes, pebbles, or soil. The stratigraphy is also particularly useful in case of multiple individuals within the same urn or in orientating funerary goods. However, laboratory micro-excavation is very time-consuming not only because of the digging technique but also because of its lengthy graphic and photographic documentation.

The study of urns by Multi-Detector Computed Tomography (MDCT) has a rather limited response both in the literature and in practice. Computerized Tomography (CT) is often used as a tool to plan micro-excavations or as a way to check for the presence of the funerary goods and their location within the urn (Anderson and Fell, 1995; Becker et al., 2003; Lynnerup et al., 1997; Tout et al., 1980). Between the years 2003 – 2005, MDCT was introduced in clinical radiological practices. This high-definition CT scan obtains a rapid acquisition of the entire object with high spatial resolution and the possibility to obtain thin orthogonal, oblique, or 3D reconstructions (Fig. 1). MDCT can be considered a valuable tool for non-destructive analysis of the artefacts by scientists dealing with archaeology and cultural heritage (Conlogue et al., 2004; Lynnerup 2010; Rühli et al., 2004; Ryan and Milner, 2006), and more recently the method has been successfully used on urns of various cultures (Harvig et al., 2012; Minozzi et al., 2010) urns and sometimes with the aid of ultrashort echo time RM (Cavka et al., 2015). These studies have highlighted the validity of the method, which allows a quick and efficient evaluation of the container, goods, depositional structure of the cremated remains and, to some extent, the cremated remains themselves. Recently it has been suggested the usefulness of MDCT not only as an aid to micro-excavation but also as an independent non-destructive analysis able to obtain comparable results with the micro-excavation itself (Cavalli, 2012, Turchetti et al., 2016, Cavalli et al., 2017).

The purpose of this work is to verify, through the comparison between micro-excavation and MDCT executed on the same sample of urns, the advantages of integrated application of the two methods. Moreover, since one of the purposes of Paleoradiology is to carry out, where possible, non-destructive analysis on ancient biological artefacts (for example mummies), verify, at least from the theoretical point of view, if it is possible to hypothesize a complete study of the cinerarium on the sole basis of MDCT. It must be reminded that a CT scan can be archived, duplicated and transmitted via network or with Picture Archiving and Communication Systems (PACS) with no loss or modification of its data (Nelson, 2020) and that its elaboration depends only on the various software strategies applied, that are continuously improved in time thanks, mainly, to clinical radiological research.

**Materials and methods**

For the purpose of this study, 41 funerary vessels of various proveniences were scanned with MDCT. After the scan, eight urns containing cremated remains were completely micro-excavated. One urn, with the cinerary vessel completely intact, was partially microexcavated (Table 1).

**MDCT scan**

Most of the urns were examined with a 16-slice CT (Toshiba Aquilion 16©, Toshiba Medical System), with a definition of half a millimeter isometric voxel, except for the Etruscan urns which were examined with a 16-slice CT (GE LightSpeed 16©, General Electric) with a definition of 0,625 mm isometric voxel. Acquisition parameters were: 120 kV, 350 mA, filtered back projection reconstruction with noise reduction filter and density enhancement filter.

The images were stored in our PACS system (Suitestensa©, EBit – ESAOTE Group) and processed with built-in PACS visualization facilities and various, medical and non-medical software (Vitrea©, Vital Images Inc.; Amira©, VSG; ImageJ). Before micro-
excavation, a whole sequence of slices perpendicular to the direction of micro-excavation were reconstructed with Maximum Intensity Projection (MIP) protocol, 10 or 20 mm thick, depending on the dimension of the cinerarium.

**Image segmentation**

For the morphological and densitometric study of container and cremated remains a segmentation of the various components of the image was performed, with the purpose of isolate them and obtain a tridimensional representation.

Image segmentation is defined as the partitioning of an image into nonoverlapping, constituent regions that are homogeneous with respect to some characteristic such as intensity or texture. Many image segmentation techniques are available in the literature. Some of these techniques use only the grey level histogram, some use spatial details while others use fuzzy set theoretic approaches (Verma et al., 2015).

In our case the segmentation of the components of the cinerarium was obtained by combining thresholding and edge-based methods, manually correcting possible inaccuracy. At the end of the process every object was 3D transformed via triangular meshing and archived.

**Cremated bone probes**

Eight bovine femoral diaphysis bone fragments of about 100 cm$^3$ of volume was obtained from the same bone and cremated in couple in oven at controlled temperature, respectively at 300, 600, 800 and 900 °C for 120' . These samples were scanned with MDCT before the cinerarium scan and for each the maximum intensity value was calculated, in Hounsfield Units (Villa et al., 2012).

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Table 1. Cinerary urns studied with MDCT and micro-excavation

<table>
<thead>
<tr>
<th>Provenience</th>
<th>Acr</th>
<th>Age</th>
<th>Culture</th>
<th>MDCT and Micro-excavation</th>
</tr>
</thead>
<tbody>
<tr>
<td>«Sodo» (Camucia – Italy)</td>
<td>S</td>
<td>VII-IV c. B.C.</td>
<td>Etruscan</td>
<td>1</td>
</tr>
<tr>
<td>Casenovole (Italy)</td>
<td>C</td>
<td>II c. B.C.</td>
<td>Etruscan</td>
<td>1*</td>
</tr>
<tr>
<td>Sorano (Italy)</td>
<td>S0</td>
<td>Late VI c. B.C.</td>
<td>Etruscan</td>
<td>1</td>
</tr>
<tr>
<td>Brežice (Slovenia)</td>
<td>BZ</td>
<td>Early Iron age</td>
<td>Celtic</td>
<td>1</td>
</tr>
<tr>
<td>Poštela (Slovenia)</td>
<td>P</td>
<td>Early Iron age</td>
<td>Celtic</td>
<td>3</td>
</tr>
<tr>
<td>Novine (Slovenia)</td>
<td>N</td>
<td>Early Iron age</td>
<td>Celtic</td>
<td>1</td>
</tr>
<tr>
<td>Beram (Croatia)</td>
<td>B</td>
<td>Late Iron age</td>
<td>Celtic</td>
<td>1</td>
</tr>
</tbody>
</table>

*Partial micro-excavation. Acr = acronym.*

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Figure 2. Phases of virtual rendering of the vessel. (a) Thresholded Volume Rendering of the whole artefact. (b) Coronal section. (c) The same section after segmentation: the components of the vessels are isolated. (d) 3D triangular mesh rendering of the vessel, without and with its lid (e). Early Iron age urn from Novine (Slovenia).
The vessel was segmented and isolated (Fig. 2). The quality of the ceramic was observed, while sampling and magnifying thin sections of the bottom and walls of the urn was conducted in order to measure their relative density (Fig. 3).

**Stratigraphic analysis**

The identification of the internal stratigraphy of the urn and the subsequent classification of the layers was obtained by MPRs, orthogonal to the major axis of the urn. Any sign of perturbation (soil infiltrated by fractures of the urn, presence of roots, etc.) was recorded, while the top layer of cremated remains was identified and its texture also noted (Fig. 4).

**Grave goods**

When present, any element of the grave goods was identified, segmented, 3D-rendered, classified and measured (Fig. 5) within the MDCT scan.

**Cremated remains**

Using multiplanar and oblique projections, the fragments of burnt bone were numbered and then identified as a specific skeletal element (Fig. 6). Any diagnostic fragments, that is fragments identified as belonging to a skeletal segment useful for anthropological or paleopathological analysis were subjected also to accurate segmentation, meshing, 3D rendering, and measuring (Fig. 7). Diaphyseal fragments were also subjected to measurement of their maximum density to X-rays and compared with the maximum density of the cremated bone probes (Table 2).
Laboratory micro-excavation

On the basis of the axial images provided by MDCT, the cinerary urn was placed on a support, and carefully micro-excavated with the aid of wooden probes and soft brushes in one cm layered sections. The bone fragments and any other material were recorded and removed after exposure. The fragments recognizable in MSCT sections were numbered and photographed in situ. All the material, layer by layer, was put in different containers to be subsequently examined. At the end the

<table>
<thead>
<tr>
<th>CREMATED PROBES</th>
<th>URN CREMATED REMAINS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cremation Temperature °C</td>
<td>Maximum voxel density (U.H.)</td>
</tr>
<tr>
<td>300</td>
<td>1755</td>
</tr>
<tr>
<td>600</td>
<td>2141</td>
</tr>
<tr>
<td>900</td>
<td>3165</td>
</tr>
<tr>
<td>1200</td>
<td>3588</td>
</tr>
<tr>
<td>S</td>
<td>2240</td>
</tr>
<tr>
<td>C</td>
<td>2250</td>
</tr>
<tr>
<td>So</td>
<td>2405</td>
</tr>
<tr>
<td>N</td>
<td>2198</td>
</tr>
<tr>
<td>BZ</td>
<td>2632</td>
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<tr>
<td>B</td>
<td>2076</td>
</tr>
<tr>
<td>P G19</td>
<td>1962</td>
</tr>
</tbody>
</table>

Table 2. MDCT cremated cortical bone maximum voxel value. Comparison between cremated probes and urn cremated remains. The cremation maximum temperature was colorimetrically determined after micro-excavation.
soil was sieved, after eventual dehydration, to verify the completeness of bone recovery.

The cremated remains were identified, recorded, measured and subsequently ultrasonicated for 120 seconds, air dried for two days at room temperature and then weighed. The color of cremated bones was evaluated using different chromatic graduations (Shipman et al., 1984; Walker et al., 2008).

### Results

**Comparison micro-excavation / MDCT**

The micro-excavation performed with the axial MIP reconstructions consistently facilitated the operations of excavation and recovery of the materials even when the matrix in the urn appeared very compact, thus improving overall accuracy. The visual comparison of the actual stratigraphic layer with the corresponding CT reconstruction highlights how the interfaces between the materials contained in the urn are perfectly recognizable in both methods (Fig. 8).

The 1: 1 spatial correspondence between layers and CT reconstruction (Cavalcanti et al., 2004) has rendered it easy to find objects normally difficult to identify in micro-excavation as they resemble compounds of a similar material to that of the matrix (Fig. 9). The morphology of the cremated remains has a proper

Figure 7. Semi-automatic segmentation of a cremated fragment (mandibular right ramus and condyle) and 3D mesh rendering. Measures are in millimeters. Etruscan urn from Sorano (Italy).

Figure 8. Comparison between MDCT MPR 10 mm section and the corresponding micro-excavation layer. Etruscan urn from Camucia (Italy).
correspondence between micro-excavation and MDCT 3D reconstruction.

Despite the perfect correspondence between microexcavation and MDCT the number and the dimension of fragments obtained from the nine micro-excavations do not correspond to the numbers determined by MDCT, especially in case of soil hard and rich of pebbles. In the case of Table 3, for example, the MDCT showed 34 fragments more than 8 cm of maximum length where after microexcavation there was none. In this case the MDCT showed complete fractures of the fragments without their diastases, caused probably by the pressure of the soil (Fig. 10). However, is known that the micro-excavation tends to further fragment cremated bones (Bradtmiller and Buikstra, 1984; McKinley 1994, Ubelaker, 2009, Pankowská et al., 2015).

The colour of the cremated bones was noted during the micro-excavation as this provides information regarding the maximum temperatures reached in the pyre during the cremation process. The maximum temperature of exposition estimated in such way was compared with the one hypothesized comparing the MDCT density of the cremated remains with the one of experimental samples (see 2.1.2). The results are summarized in Table 2.

**MDCT analysis**

**Evaluation of the container**

MDCT assesses the integrity and morphology of the container, even in cases where the urn has not yet been cleaned of soil. Scans from the MDCT also enables evaluation of the overall condition of the vessel (for example the degree of collapse, the fracture lines, etc.) and eventually, after segmentation, allows for a virtual reconstruction of a three-dimensional printing of the vessel (Fig. 11). In instances of complex structures, MDCT is particularly useful in evaluating the morphology and the spatial arrangement of the objects (Fig. 12). MDCT scans also produce virtual thin sections of the vessel, allowing for the assessment of its wall structure (such as the homogeneity of the ceramic mixture, etc.) (Fig. 3).

Table 3. Dimension and number of fragments measured by MDCT and after micro-excavation in Novine urn (N).

<table>
<thead>
<tr>
<th>Fragment size</th>
<th>Total number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 4 cm</td>
</tr>
<tr>
<td><strong>MDCT</strong></td>
<td>2094</td>
</tr>
<tr>
<td><strong>Micro-excavation</strong></td>
<td>2306</td>
</tr>
</tbody>
</table>
Grave goods analysis

MDCT easily detects the presence of radiopaque objects with metallic density within the urn, which allows the accurate study, through segmentation, of the metallic grave goods contained within the urn (Fig. 5). Non-metallic objects are recognizable from their structure and shape such as the ceramic loom weight (Fig. 13). Because the resulting image (whether it is planar or three-dimensional) maintains a 1:1 ratio compared to the original object, is possible to take accurate measurements.

Study of cremated remains

MDCT allows for a careful study of the cremated remains. Their morphological classification and structural study is generally possible with MPR although, for segments with complex geometry, an accurate image segmentation is preferable (Fig. 14). Nevertheless, it is possible to classify all segments anatomically identified in order to determine the minimum number of individuals present in each cinerary urn. This phase of analysis is obviously the most delicate and time-consuming, especially is many remains are present, but it doesn’t differ substantially from the normal diagnostic radiological iter, while considering the structural modifications of the cremated bone. The determination of sex and age of the individuals were completed if diagnostic skeletal traits were identified (McKinley, 2000). Pathological lesions can also be identified from MDCT scans which can determine the pattern of the lesion and its extension, considering the possible distortions induced from the heat of the pyre.
Cavalli

It's appropriate to remind that through the segmentation of the cremated fragments it is possible to determine with precision their volume: that might be considered as an alternative system to the weight determination (Pankowská et al., 2015).

**Discussion**

**MDCT and Micro-excavation**

The study of ancient cineraria is complex to the nature of the materials and to the different skills involved. The traditional system whereby the cremated remains are poured out of the cinerary vessel, in order to recover the grave goods, before analysis of the cremated remains, and conserving the container is increasingly being replaced by laboratory micro-excavation. Micro-excavation not only allows for the systematic recovery of the urn’s contents thereby reducing the fragmentation of the cremated bones, but it also enables the examination of location/orientation of the remains in the urn and to understand the sequence of its filling. MDCT is a simple and fast method that can be really useful if executed before microexcavation because it can provide not only a precise mapping of the stratigraphic organisation of the cinerarium, but also address with precision the microexcavation. It is indeed possible to obtain MIP reconstruction corresponding with the layer to remove that show in high contrast the presence and the disposition of the various components of the layer, their state and their nature (cremated remains, funerary goods, cinerarium fragments, etc.). Moreover, the correct use of MIP sections makes graphic documentation superfluous, or at least it makes it far simpler. Furthermore, the MDCT sensibility in discriminating the areas with different densities gives a precise 3D stratigraphic picture even when it is not possible to perform the microexcavation for the artefact’s characteristics and it is necessary to proceed with its simple emptying. The study of the possible fragmentation and collapse of the cinerarium, of its completeness and of eventual indicators of external interferences (like, for example, the presence of roots) can be without any doubt useful, both during

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**Figure 13.** Identification of an object from its shape. (a) MDCT 0.5 mm section. (b) Manual segmentation of the object and overlapping with the corresponding section. Fusarole. Etruscan urn from Camucia (Italy).

**Figure 14.** Identification and reconstruction of distal femoral epiphysis. (a) MPR 3D rendering of the urn and 3D mesh rendering of the segmentation of the distal femoral epiphysis. (b) 3D mesh rendering and (c) comparison with the same fragments after micro-excavation. Two adult subjects. Etruscan urn from Camucia (Italy).
the phase of recovery of the fragments during the microexcavation that during the phase of restoration. It is to be observed that in case of metallic goods that suffered a more or less complete mineralisation making them less cohesively of the ground they are in, the MDCT can give back a “whole” image of the object since the metallic salts maintain a high radio-opacity (Paribeni et al. 2010).

**MDCT vs. Micro-excavation**

Even if at the moment it is not possible to replace the MDCT to the microexcavation, it must still be noted the morphological and dimensional correspondence between MDCT and microexcavation, accurate also in the demonstration of the modifications of the bone due to heat (for example the conchoidal fractures). The possibility to obtain the volume of every single segmented bone might be usable instead of the determination of its weight, considering also the possibility to transform the volume in weight according with the density of the examined segment. About the cremation temperature, the measure of the X-rays density of the bone contained in the cinerarium and its comparison with experimentally cremated samples encourages further studies in such direction. However, the crystallographic modifications of hydroxyapatite at high temperatures are known (Shipman et al., 1984; Quatrehomme et al., 1998, Piga et al. 2008). The possibility to locate, select and 3D reconstructing the fragments of the cinerary vessel can give the possibility of a “virtual” restoration of it. The same can be said for the funerary goods elements.

The accurate segmentation of a cinerarium is still a delicate and time-consuming operation that at the moment makes it not very cheap. It has to be considered anyway the possibility to develop automatic systems for segmentation and classification, borrowing them to the clinical-radiological or forensic research.

**Conclusion**

MDCT appears particularly useful in the study of cinerarium as an auxiliary and complementary method to the microexcavation and as a documentation method of the state of the cinerarium before its study and restoration. While not being possible at the moment to perform a complete study on the base of the sole MDCT, the premises for its future, desirable feasibility exist.

**Acknowledgments**

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