Preservation and reproduction of an ancient human humerus through X-ray Microscopy and 3D Printing

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INTRODUCTION

The combination of X-ray microscopy (XRM) and three-dimensional virtual reconstruction has made it possible to digitise and restore broken artefacts, allowing them to be preserved and studied without causing damage [1]. By scanning, capturing and virtually stitching together the 3D reconstructions of individual broken pieces, damaged relics can be visualised as if they were whole and intact objects, and reproduced as physical copies through 3D printing, so that printed copies can be displayed for public viewing while the originals are preserved [2]. XRM's ability to non-destructively examine archaeological artefacts is critical to providing a faithful reconstruction of the object's interior and exterior.

Our work demonstrates the application of these reconstruction principles to an artificially modified human humerus from the II-I millennium B.C., bent into the shape of a snake for ritual purposes related to the ancient "snake cult" (Iron Age) [3]. After scanning and software processing, the pieces were printed in PLA as a single object and made available to the public, giving new life to a unique piece of history. [4]

Figure 1. 3D model rendering from the humerus' photogrammetric survey directly at the site of discovery (LCG2 complex at Dibbā—Musandam, Oman, II-I millennium BC). It had been curved to resemble a snake.

EXPERIMENTAL SETUP

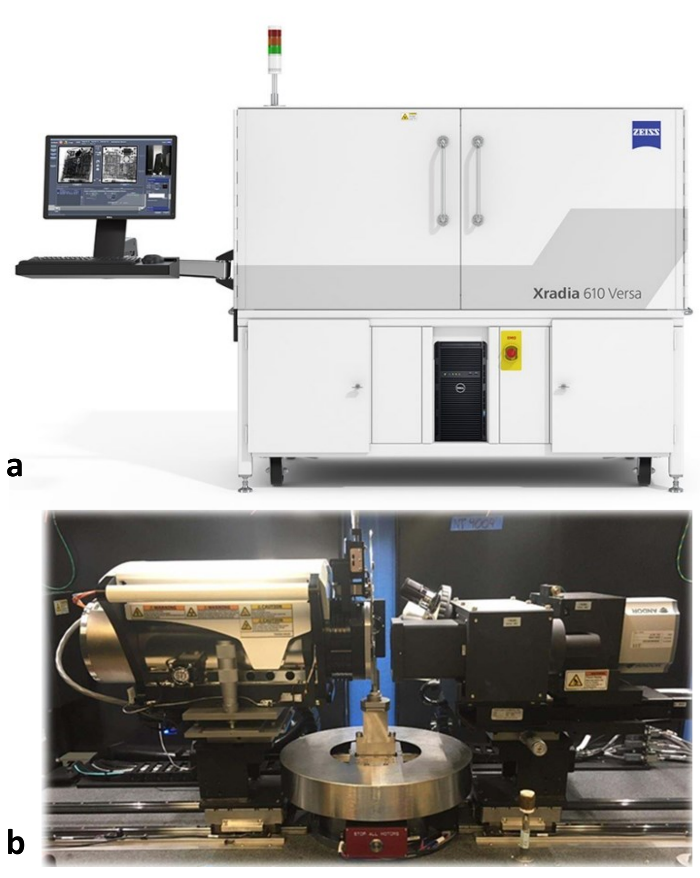


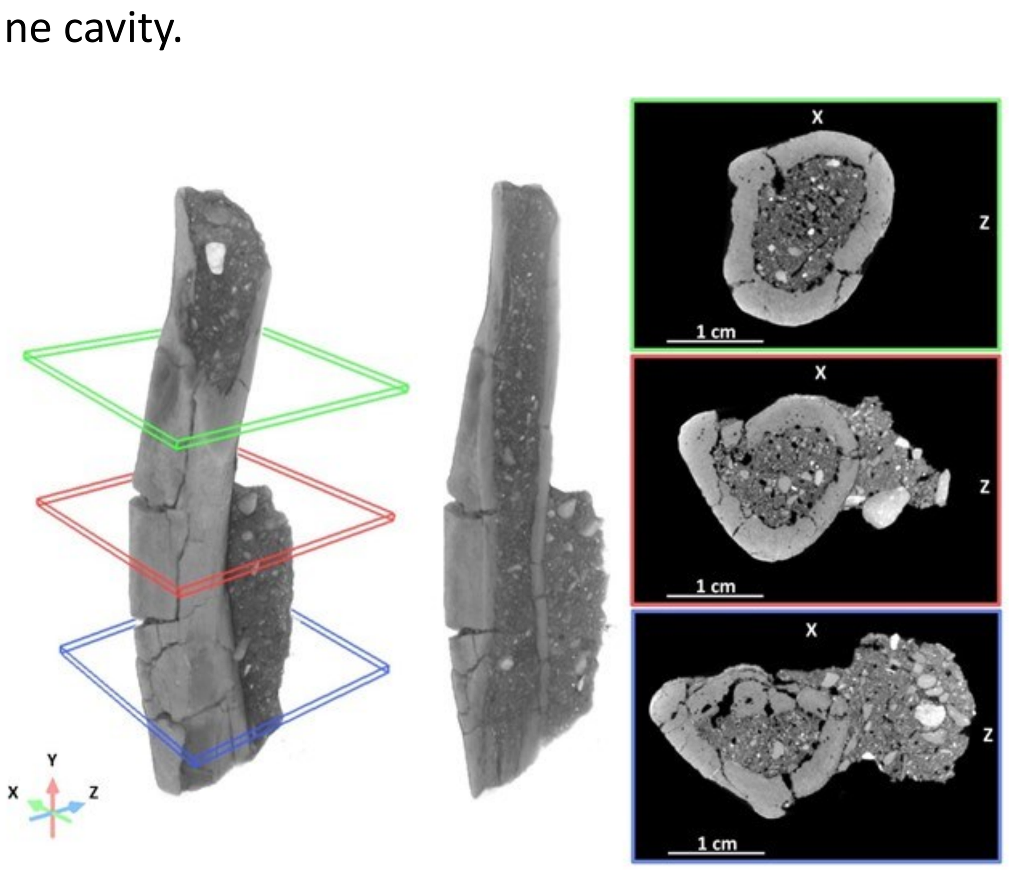
Figure 2. (a) ZEISS Xradia Versa 610 X-ray microscope with (b) the view of the internal chamber.

- The analysis was performed using a ZEISS Xradia Versa 610 X-ray microscope (Fig. 2a) available at the Research Centre on Nanotechnology Applied to Engineering (CNIS) of Sapienza University of Rome. The voltage and power of the X-ray source were 80 kV and 10 W with an exposure time of 2.5 s and a 0.4x objective. The experimental setup of an XRM investigation consists of an X-ray source, a detector that collects the transmitted X-ray beam, a sample chamber located between these two components, where the sample holder is positioned to ensure its mechanical stability and rotation (Fig. 2b).
- The bone arrived at our laboratory broken into 5 pieces and a distinct XRM scan was performed on each of these samples (Fig. 3).
- The reconstructed 3D datasets were imported into Dragonfly Pro (V. 2022.1 Build 1259) software for segmentation, alignment, and mesh export, using the Displace function from Object Research Systems (ORS).
- The result of such assembling has been sliced with the software PrusaSlicer with variable (0,2-0,05) mm thickness and printed in PLA, with a Prusa MK3S+, as a whole object sectioned in two halves kept together by a magnet, making it possible to open the bone and observe its inner structure.

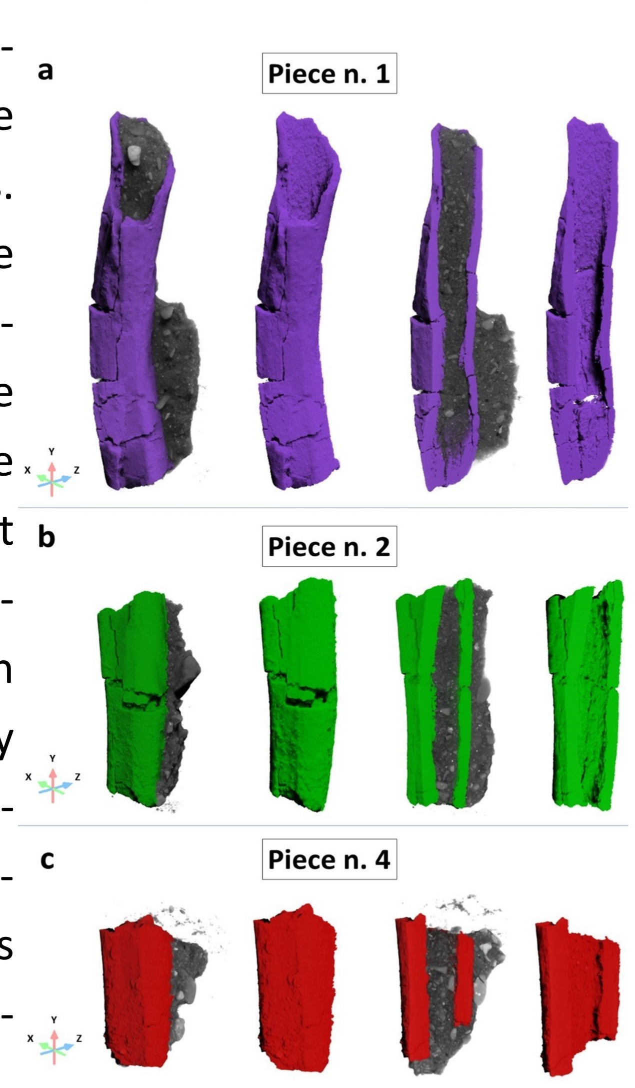
Figure 3. (a) Remains of an ancient human humerus sent to our laboratory for analysis and (b) sampling of the 5 main parts, each subjected to tomographic analysis.

CONTENTS AND RESULTS

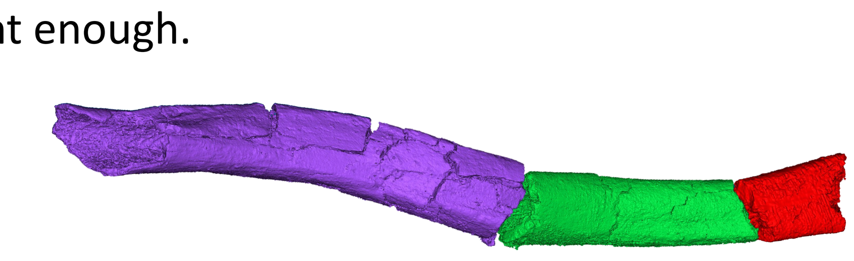
As an example, the XRM results for piece n. 1 are shown in 3D (left) and 2D slices in the XZ plane (right). Three planes (green, red and blue) were selected along the y-axis of the bone to visualise individual slices in the XZ plane. The scans showed that the humerus was covered in dirt, rocks and debris, some of which was trapped inside the bone cavity.



To enable proper reconstruction and 3D printing, the dirt and soil must be removed from the sample, but this could damage the object. The recommended approach is therefore to use 3D modelling to remove these phases. Looking at the digital cross-sections of the pieces after the removal of dirt and soil products, we can see that only the cortical region of the bone sample has been preserved.



The processed XRM data sets were aligned and stitched together. We were able to align and stitch three of the five pieces, corresponding to pieces n.1, 2 and 4, as none of the combinations of the five fragments were consistent enough.



Based on the alignment of the three pieces of bone, we were able to create a three-dimensional reconstruction of the bone sample using 3D printing technology.

CONCLUSIONS

In this work, we have demonstrated the successful application of reconstruction principles to an artificially modified human humerus. The combination of X-ray microscopy (XRM), a dedicated imaging workflow and three-dimensional virtual reconstruction, as well as 3D printing, has proven to be a powerful tool for digitising and restoring damaged artefacts with hidden features that are inaccessible using other techniques.

REFERENCES

[1] F. Cognigni, S. Dinarelli, M. Girasole, G. Longo, G. Fabi and M. Rossi, *3D X-ray Microscopy (XRM) investigation of exogenous materials inside mussels' organs*, IOP Conference Series: Materials Science and Engineering, no. 1265, November 2022.

[2] A. Tamberino, S. McAvoy, M. Howland, B. Liss, K. Bennallack and T. Levy, *3D Printing for Cultural Heritage Preservation and Education*, 2017.

[3] L. Fattore, A. Nava, F. Genchi, D. Mancinelli and E. Maini, *L'area sacra di Daba (Musandam, Oman, II-I millennio a.C.).I morti oltre la morte. L'analisi tafonomica e l'interpretazione dei processi culturali e naturali sulle ossa di LCG2*, 2015, pp. 375-385.

[4] F. Cognigni, V. Alemanno, L. Fattore, E. Stornelli, F. Genchi and M. Rossi, *Preservation and Reproduction of an Ancient Human Humerus through X-ray Microscopy and 3D Printing*, Journal of Physics: Conference Series, IOP Publishing, 2023