Materials Research Proceedings **15** (2020) 250-255 https://doi.org/10.21741/9781644900574-39

Digitally Excavating the Hidden Secrets of an Egyptian Animal Mummy: a Comparative Neutron and X-ray CT Study

Carla A Raymond[1, a] , Joseph J Bevitt[2, b]

[1] Department of Earth and Planetary Sciences, Macquarie University, NSW (AU)

[2] Australian Nuclear Science and Technology Organization (ANSTO), Lucas Heights, NSW (AU)

[a]carla.raymond@hdr.mq.edu.au, [b]jbv@ansto.gov.au

Keywords: Neutron Tomography, Mummification, Segmentation, Non-Invasive, Non-Destructive, Cultural Heritage

Abstract. Here we present further analysis and interpretation of our recently published work (Raymond et al. 2019) on a mummified cat (IA.2402) on loan from the Australian Institute of Archaeology (AIA) in Melbourne, Australia. This was the first published case to implement X-ray and neutron CT to votive animal mummies, and is the first in a series of similar studies undertaken at ANSTO. The application of neutron CT to this type of artefact was ideal to non-destructively study mummification techniques and learn about its hidden contents. Using a combination of X-ray and neutron CT provided valuable insight, both individually and collectively, revealing: a partial animal skeleton, an amulet, several layers of coarse and fine textile, and folded padding. Combining both techniques also allowed for complementary study of bones, soft tissue, and textile components. Use of multiple segmentation tools in 3D reconstruction and visualization software VG Studio Max 3.0 enabled detailed digital excavation of the sample, allowing for identification of species, age at death, and how textiles were used to shape and wrap the mummy. Results revealed the animal remains belong to a small, juvenile feline.

Introduction

The ancient Egyptians are known for mummification of both humans and animals alike, however, the process of mummification is not well documented. The mummification of animals as votive offerings was a industrial scale process, and reached a peak popularity between the Late period to Roman Period (664 BC – 395 AD). The current understanding of mummification comes from a small selection of tomb paintings at Thebes and Giza that illustrate the process (Ikram 2011), and the recollections of contemporary sources – Herodotus (5th century BC) and Porphyry (3rd century AD). With the increased interest in all thing Ancient Egypt in the 1800s, “Egyptomania” took the Victorian world by storm and so began a number of unwrapping parties (Shaw 2004). These events were for not for research, rather for finding treasures and amulets in the wrapping, and the prestige that was associated with such an event (Ikram & Dodson 1988; David 1997; Smith 2016). In recent years, Distinguished Professor Salima Ikram, from the American University in Cairo, and her team have been working on understanding the mummification process by experimentation on modern animal cadavers (Ikram 2011). This notion of experimental mummification will help in the understanding of the process, and has already shed much light on the conditions required, ie. quantities of natron, and frequency for change of natron salts for optimal desiccation. In conjunction with this method of study, it is also important that the archaeological community finds other appropriate, and minimally to non-destructive techniques to study and understand ancient mummification methods. Neutron tomography was chosen for this case study of a votive animal mummy, as a comparative and

Materials Research Proceedings **15** (2020) 250-255 https://doi.org/10.21741/9781644900574-39

complementary technique to X-ray CT. This project formed part of the authors Master of Research thesis (Raymond, unpublished, 2017), and recent *Archaeometry* publication (Raymond et al. 2019).

Figure 1. Mummified cat (IA.2402) with green and red painted markings and brown resinous material.

The Sample - Mummified "Cat" *IA.2402*

The mummified votive offering IA.2402 was thought to contain the skeleton of a kitten, due to the appearance (Figure 1) and size of the bundle (29.2 cm x 4.8 cm x 7.8 cm). Mummy bundles that contains complete adult skeletons tend to be between 36 cm to 88 cm tall. This mummy has been in the AIA collection since the 1950s, however how it came to be in the collection is less clear. Acquired by Sir Charles Nicholson in 1856-7 on an expedition to Egypt, the cat has no recorded provenance or age. The mummy bundle is quite unusual, particularly the painted green and red markings across the body and head of the mummy (Figure 1), and no similar painted examples have been found in online catalogues at this time. The external wrapping exhibits a corkscrew pattern, downward towards the base, and is secured with the brown resinous material. A detailed object description, images and acquisition story can be found in Raymond et al 2019.

Experiment

The mummy was scanned using the neutron tomography beamline (DINGO) at the Australian Nuclear Science and Technology Organisation (ANSTO) in Lucas Heights, Australia. A series of 720 radiographs at 95μm were collected over 180°, using a 20 cm x 20 cm ^{6}LiF ZnS scintillator (0.050 mm), and ANDO iKON-L CCD camera. Total scan time was 6 hours. Image processing was done using Image J (NIH) and Octopus 8.2(Octopus Imaging). The 3D volume was rendered and visualised using VG Studio Max 3.0 (Volume Graphics GmbH).

X-ray scans were acquired by Prof John Magnussen and his team at Macquarie Medical Imaging in Sydney, Australia, using both a Newtom 5G (Newtom, Italy) cone-beam (CBCT) scanner, and a GE HD750 (General Electric, Milwaukee, USA) dual-energy (DECT) multi-detector (MDCT) scanner. Scans were acquired in a matter of seconds and processed using InteleViewer 4-11-1-P130 for various filters (bone and soft tissue), and reconstructed in 3D using RadiAnt DICOM Viewer 3.4.2. For more detailed parameters, please refer to Raymond et al. (2019).

Results and discussion

The neutron and X-ray scans both revealed that there were remains inside the mummified bundle and enabled further investigation into species and age at death. The X-ray data had greater contrast for studying the bones and other highly absorbing materials on (Figure 2b) and within the wrapping (Figure 3). The first component that stands out is the tiny (4.5 mm x 3.9 mm), bright object in Figure 3a, beside the paws of the animal. This is interpreted to be an amulet of religious or ceremonial significance as it was a common practice to include such talismans in the mummification process. However, there are no definitive features discernible at this resolution, thus it cannot yet be confirmed. The high contrast of the skeletal remains (two legs and a disarticulated tail) enabled a detailed study of the epiphyses (growth plates) and any indications

Materials Research Proceedings **15** (2020) 250-255 https://doi.org/10.21741/9781644900574-39

of trauma that may have caused the animals demise. Segmentation of the skeleton was achieved using thresholding, setting an upper and lower limit for grayscale displayed. It was determined from the epiphyses that this animal was approximately 11 months old at death, confirming the initial hypothesis, however there were no indications of fatal trauma to the remains to infer cause of death.

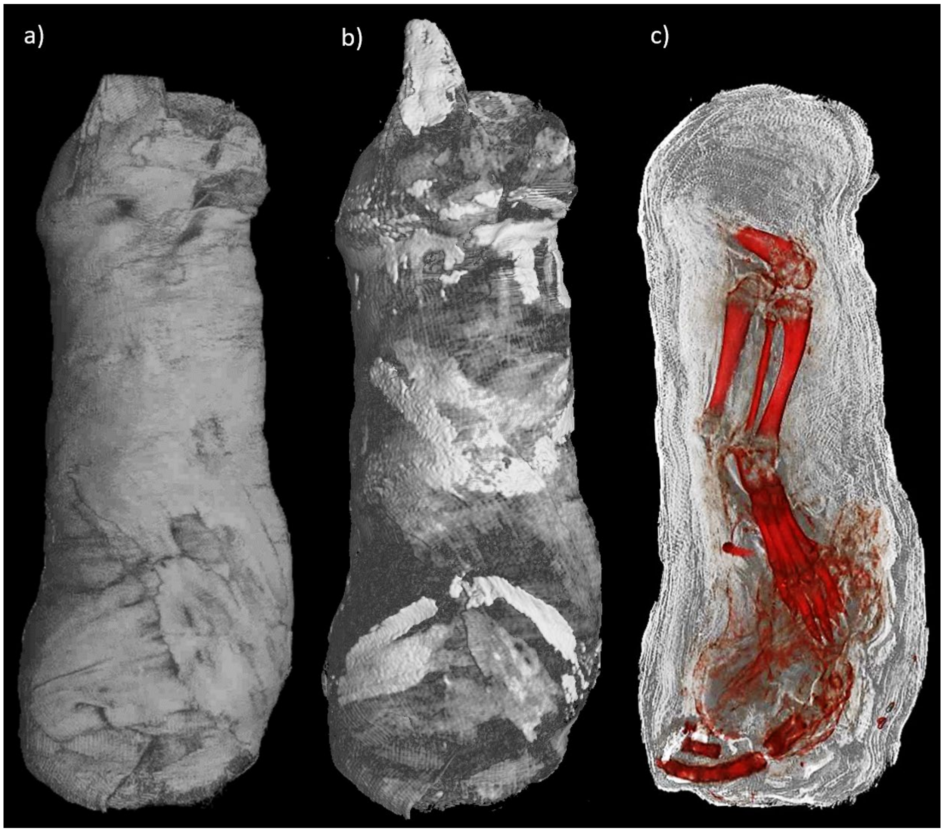

Figure 2. 3D Reconstructions of a) neutron and b) x-ray CT scans; c) X-ray reconstruction (red overlay) on neutron reconstruction, to illustrate the orientation of skeletal remains within the wrappings. These visualisations were made with VG Studio Max 3.0.

Further segmentation of the X-ray results also allowed for speciation of the remains; firstly by visualising the whole tail, it was possible to count the number of caudal vertebrae present. A total of 23 vertebrae were identified (Figure 4), which classified the remains as feline. In addition, by using manual segmentation, it was possible to identify a small bone called the calcaneus (highlighted in green in Figure 5b and c), the shape of which is distinctive of feline species (Van Neer et al. 2014). This manual segmentation process is intensive and slow, involving a selection tool across all three orthogonal planes. Once the region of interest (ROI) was well segmented, it was extracted, and the shape was clearly matched to the species *Felis silvestris*. The segmented ROI of the skeleton was later made into an STL. file, and 3D printed for educational uses at the Macquarie University Museum of Ancient Cultures, and the AIA. This has been a valuable outcome of the project, as it has made the findings accessible to the greater public, and to young students who can now discover the wider implications of when science and archaeology are combined in a complimentary way.

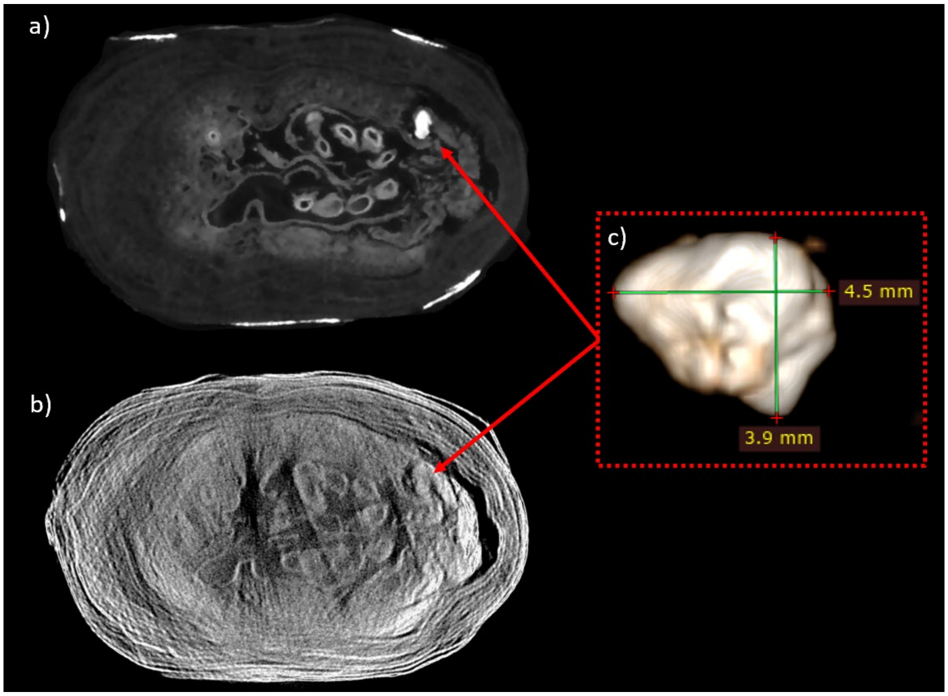

Figure 4. Coronal slices through the mummy revealed a highly x-ray attenuating object close to the paws, seen clearly in x-ray slice (a), however not so in the neutron results (b). c) Is a 3D visualisation of the object, made with RadiAnt DICOM Viewer 3.4.2.

The reconstructed neutron CT results were incredibly informative about the way the bundle had *been* wrapped and shaped using folded textiles. In Figure 2a the corkscrew nature of the external bandages is clearly illustrated, with the end of the bandage flicking back upward. This wrapping direction is not particularly clear on the X-ray CT reconstruction (Figure 2b), beneath the pigment markings. The neutron CT scans also revealed that the "head" and ears of the mummy were shaped using wads of folded textiles, seen above the dashed yellow line in Figure 5a and 2c. In the X-ray reconstruction, this detail was limited to areas of higher and lower density (Figure 5b).

The internal wrapping style and detail is significantly clearer in the neutron reconstruction; there are two clear layers of different grade textile, the outer is much coarser than the inner bandages (Figure 5a and d). This discovery is in agreement with the findings of Ginsburg (1999), who unwrapped a collection of small cat mummies from Saqqara which exhibited two distinct layers, the inner being tight and fine quality, and the outer being a coarser shroud.

Figure 3. Segmented skeleton showing disarticulated tail (breaks marked in blue) with 23 caudal vertebrae (indicated in yellow), metatarsals, and amulet (red).

In this case, the layer closest to the skeleton is a very fine threaded textile, as the individual threads are difficult to isolate in reconstruction (Figure 5d). The outer layer exhibits a much coarser, loosely weaved textile, to the extent that the individual threads can be identified (Figure 5d). The findings of Ginsburg, while undeniably informative and valuable, were destructive, however this case study has demonstrated that the same level of information can be gleaned by entirely non-invasive methods.

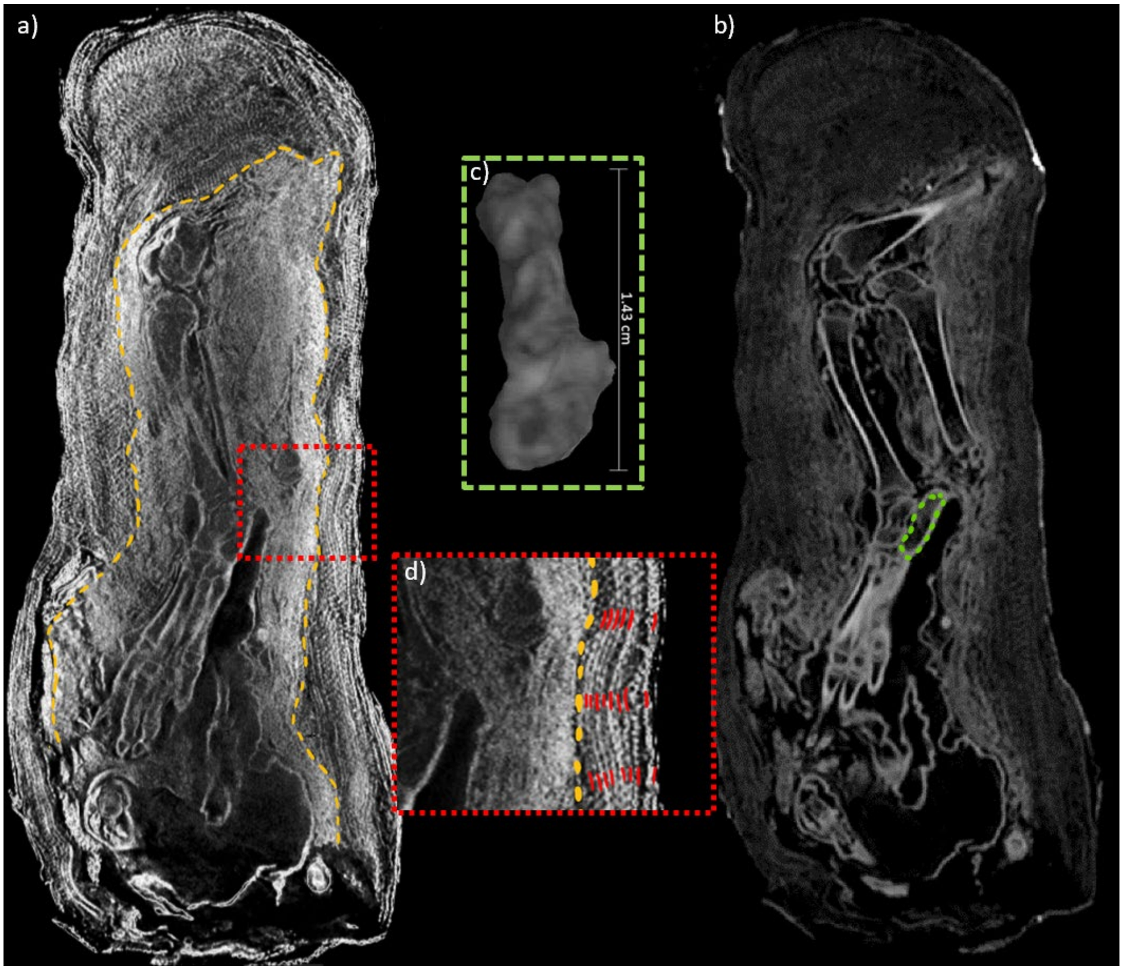

Figure 5. a) Neutron CT slice shows layers of textile wrapping; b) X-ray CT slice shows higher grayscale contrast; c) Segmented and visualised calcaneus bone [green area in b)]; d) Close up showing layered wrapping of varying tightness and coarseness [red box on b)].

Conclusions

Both X-ray and neutron CT scans provided invaluable insight into the contents and manufacture of this mummified votive offering, in a non-invasive way. The reconstructed volumes were most useful and informative when “digital excavation tools” were employed, as this enabled in-depth analysis of the remains. Using assisted and manual segmentation tools we were able to undertake a detailed study of this specimen including identification of the specimen age from epiphyses (equating to approximately 11 months old), as well as identification of species (*Felis silvestris*). We were also able to identify a possible amulet. The segmented ROIs further enabled production of outreach materials and 3D printed educational tools, which have broadened the general audience for CT imaging studies. Most importantly, the neutron CT reconstruction allowed for detailed and non-destructive investigation of wrapping and shaping techniques, showing two distinct wrapping layers and giving an unprecedented glimpse into ancient mummification practices. Overall, the combination of the two imaging techniques proved invaluable, as together they presented a comprehensive and complimentary study of all facets of the artefact.

Acknowledgments
Many thanks extended to our amazing team: A. Prof Ronika Power, Mr Anthony Lanati, Dr Tyr Fothergill, Dr Yann Tristant, Prof John Magnussen, and Prof. Simon Clark for their time and input into this case study. We also want to acknowledge the generous loan of the cat mummy by the Australian Institute of Archaeology and particularly Dr Christopher Davey for trusting us enough to let us do this exciting research without knowing what effects this may have. Archaeometry and archaeological science will only go forward with the support and engagement of people like yourself. Further thanks and acknowledgments to ANSTO for considering our proposal and deeming it a worthy study.

References

[1] David, A., 1997. Disease in Egyptian mummies : the contribution of new technologies. *The Lancet*, 349, pp.1760–63. https://doi.org/10.1016/S0140-6736(96)10221-X

[2] Ginsburg, L., 1999. Les chats momifiés de Bubasteion de Saqqarah. *Annales du Service des Antiquités de l'Égypte*, 74, pp.183–191.

[3] Ikram, S., 2011. Experimental Archaeology: From Meadow To Em-Baa-Lming Table. In C. Grave-Browns, ed. *Experiment and Experience*. Cardiff: University of Wales Press, pp. 53–74. https://doi.org/10.2307/j.ctvvnbgg.8

[4] Ikram, S. & Dodson, A., 1988. *The Mummy in Ancient Egypt: Equipping the Dead for Eternity.*, London: Thames and Hudson.

[5] Van Neer, W. et al., 2014. More evidence for cat taming at the Predynastic elite cemetery of Hierakonpolis (Upper Egypt). *Journal of Archaeological Science*, 45(1), pp.103–111. https://doi.org/10.1016/j.jas.2014.02.014

[6] Raymond, C.A., 2017. *Mummification unwrapped: investigating an Egyptian votive mummy using novel, non-invasive archaeometric techniques*. Macquarie University. Available: http://hdl.handle.net/1959.14/1268641.

[7] Raymond, C.A. et al., 2019. Recycled Blessings: an Investigative Case Study of a Re-wrapped Egyptian Votive Mummy using Novel and Established 3d Imaging Techniques. *Archaeometry*. https://doi.org/10.1111/arcm.12477

[8] Shaw, I., 2004. *Ancient Egypt: A Very Short Introduction*, Oxford: Oxford University Press. https://doi.org/10.1093/actrade/9780192854193.001.0001

[9] Smith, S.T., 2016. Unwrapping the Mummy: Hollywood Fantasies, Egyptian Realities. In J. M. Schablitsky, ed. *Box Office Archaeology: Refining Hollywood's Portrayals of the Past.* Routledge, p. 256.