Application of CT imaging to humanistic studies: the case of an Egyptian cat mummy

Michela Amendola
Institute of Applied Physics "Nello Carrara"
Italian National Research Council
Sesto Fiorentino, Italy
amendola.michela98@gmail.com

Donatella Lippi
Department of Experimental and Clinical Medicine
University of Florence
Firenze, Italy
donatella.lippi@unifi.it

Fabrizio Argenti
Department of Information Engineering
University of Florence
Firenze, Italy
fabrizio.argenti@unifi.it

Roberto Carpi
Department of Radiology
Azienda USL Toscana Centro
Firenze, Italy
roberto.carpi@uslcentro.toscana.it

Costanza Cucci
Institute of Applied Physics "Nello Carrara"
Italian National Research Council
Sesto Fiorentino, Italy
c.cucci@ifac.cnr.it

Salima Ikram
Department of Sociology, Egyptology and Anthropology
The American University in Cairo
AUC Avenue, P.O. Box 74 New Cairo 11835, Egypt
salima@aucegypt.edu

Guido Landi
Department of Experimental and Clinical Medicine
University of Florence
Firenze, Italy
guido.landi@stud.unifi.it

Tommaso Mori
Department of Biology
University of Florence
Firenze, Italy
tommaso.mori@unifi.it

Alessandro Riga
Department of Biology
University of Florence
Firenze, Italy
alessandro.riga@unifi.it

Chiara Zini
Department of Radiology
Azienda USL Toscana Centro
Firenze, Italy
chiara.zini@uslcentro.toscana.it

Andrea Barucci
Institute of Applied Physics "Nello Carrara"
Italian National Research Council
Sesto Fiorentino, Italy
a.barucci@ifac.cnr.it

***Abstract*—Research on Ancient Egyptian animal mummies has grown in significance over past decades thanks to the accessibility of new medical imaging technology. In particular, computed tomography (CT) has shown an important role, allowing to find out the secrets hidden underneath the bandages of the mummies. The aim of this paper is to show the importance of CT imaging in the study of ancient Egyptian animal mummies, focusing in the particular case study of a cat mummy preserved at the *Museo Etnologico Missionario di San Francesco di Fiesole* (Firenze, Italy). Starting from an historical perspective on CT applications in the context of Egyptian animal mummies, this work describes both how the CT examination was performed and the extraordinary information, such as anatomical information and bioarchaeological parameters like sex, age-at-death, and pathological conditions that could be recovered from this imaging technique in this particular case. Moreover, through CT digital images a three-dimensional model of the mummy was created, moving towards an expansion of the museum experience thanks to Artificial Intelligence, virtual and augmented reality. This kind of model can also be 3D-printed. Concluding, this study highlights how this CT scan's power creates new possibilities for the scientific community and beyond, becoming an essential resource in humanistic studies.**

***Index Terms*—Egyptology, Cat mummy, Computed Tomography, Technology, 3D printing, Humanistic studies.**

2023 8th IEEE History of Electrotechnology Conference (HISTELCON) | 979-8-3503-3464-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/HISTELCON56357.2023.10365988

I. Introduction

Technology has represented a significant breakthrough in the modern world. Thanks to techniques like Computed Tomography (CT) and Magnetic Resonance (MR), imaging methods in clinical routine have greatly evolved [1]. The goal of CT is to allow the reconstruction of the density of an object by means of x-ray beams, which are able to pass through the volume of an object. In this way, CT can build cross-sectional images, which are named "slices", of that object [2]. The final result of computed tomography is a digital image that consists of a matrix of elements, known as a pixel, which summarize the information of a volume element (known as voxel) of a particular area of interest [2]. Consequently, CT scan is widely used in radiology departments [1]. Having demonstrated a relevant and innovative impact on the acquisition of digital images and being a non-invasive technique, CT has started to be used for the study of Egyptian mummies [3]. Studies involving mummies from ancient Egypt, both humans and animals, have greatly benefited from the capacity of CT to evaluate bioarchaeological parameters, like sex, age-at-death, and pathological conditions [3], [4].

The first CT examination of a human Egyptian mummy was realized in Toronto in 1977 [5], whilst the first examination of animal mummies with CT is dated to 1987 [6]. Today this technique allows different kinds of studies, such as the recognition of fetal anatomy in the mummy [7], or the digital unwrapping to reveal the physical features and understand the mummification method [8], [9].

Above all, CT has revolutionized the study of mummies [10], enabling a better understanding of the Ancient world, representing an essential resource for humanistic studies. The work presented in this paper aims to show the importance of CT imaging in the field of Egyptology, focusing on a case study of a cat mummy. Starting from the description of the mummy under investigation we will see the details of the CT acquisition along with the extraordinary discoveries that this technique allows to explore, enabling us to formulate some hypotheses regarding the age at death, the sex, and the potential causes of death.

II. The historical impact of CT in the study of animal mummies

The first studies of ancient Egyptian animal mummies, using CT scan technology, were realized between 1979 and 1987 [5], [6], [11]. In the study of Falke et al. (1987) [6], they examined a mummified cat contained in a sarcophagus. They implemented CT technique to reveal what was inside the sarcophagus. Their CT scan presented high resolution, having a slice thickness of 9 *mm*. As a result, they were able to identify the bones and the presence of resin coating and wooden texture inside the sarcophagus. Nowadays, CT has evolved to achieve sub-millimeter resolutions. Indeed, X-ray micro-computed tomography (micro-CT) allows to study at higher resolution mummified remains, such as animals [12], [13]. For example, in one study [13], authors used a micro-CT to identify the well-preserved skeleton of a shrew, evaluating the content of bundle in detail and highlighting several injuries along the skeleton. This study contributed to increase the importance of the implementation of this technology. Also the study conducted by Malgora *et al.* [4] describes the application of CT to study of wrappings, allowing to investigate the hidden contents of animal mummies. The usage of CT and micro-CT has demonstrated the importance of these methods, inspiring our study. This paper shows the application of CT technology for the study of an Egyptian cat mummy.

III. The cat mummy

The cat mummy object of this research comes from Luxor (Egypt), and it is currently part of the Egyptian collection preserved at the *Museo Etnologico Missionario di San Francesco di Fiesole* (Firenze, Italy), where it is exposed since 1923 (Fig. 2). However, the site of the discovery in Egypt is still unknown.

Fig. 1. A picture of the cat mummy from the *Museo Etnologico Missionario di San Francesco*, Fiesole (Florence, Italy).

The process of mummification was considered extremely important by the ancient Egyptians, since they believed in the Afterlife [14]. For this reason, they embalmed not only people, but also animals as pets, votive offerings, and sacred animals [15]. In particular, cats have always played an important role in the Egyptian religion, as it is demonstrated by the numerous feline necropolis which were discovered in Bubastis, Speos Artemidos, and Saqqara [15]. They were deemed as a "bridge" between heaven and earth [16], thus they were sacrificed in temples dedicated to the goddess Bastet, who represented the goddess of feline, fertility, and love [17]. This cat mummy is 38 cm wide and 10.3 cm long. Apparently, there is no "decoration" on the wrapping, though this is under investigation. According to the ancient way of embalming of animals, our mummy is wrapped in wide strips of linen; the wrapping on the body is still in good conditions. In order to explore the interior of the cat mummy, we used a CT imaging. This technique has shown that we are dealing with a whole skeleton, even though some bones have experienced numerous breaks over the years.

IV. Methodology of the study

In order to appreciate fine details necessary to formulate some hypothesis regarding the age at death, the sex and the possible cause of death, we employed a clinical Siemens CT scan with a resolution of 0.3 *mm* x 0.3 *mm*, as shown in Figure 2. This kind of acquisition allows for the creation of a digital three-dimensional model (Figure 2b), which can be explored by experts and also 3D-printed.

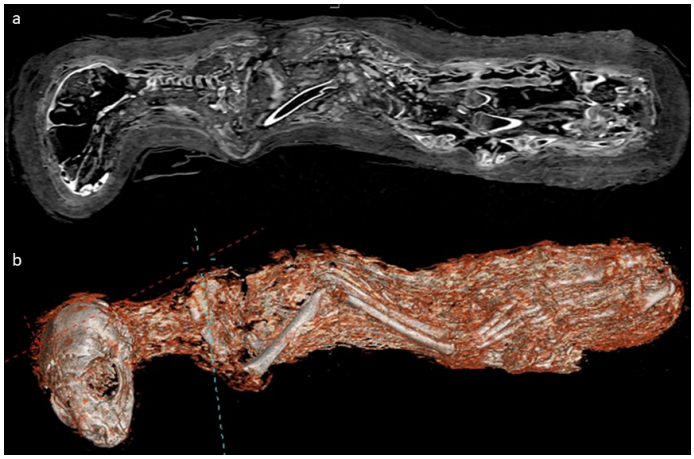

Fig. 2. a) CT image Sagittal view of the cat mummy. b) Digital three-dimensional model obtained from the CT. In white and grey the bones, in orange remaining parts of wrapping linens.

V. Results of the Study

Thanks to CT scan it was possible to observe the content of the mummy bundle. The cat was positioned like most others: almost as if it were seated with forelimbs extended, the hindlimbs flexed and pushed toward the body with the tail between them, lying on the belly [18]. This is exactly what we found by examining the CT of the cat mummy. An example of the sagittal view is reported in Figure 2b). However, the skeleton's position and how it was handled could have compromised the bones' structural integrity; indeed, as demonstrated in Figure 3, the cat mummy has incurred several fractures, distributed along the whole body. Firstly, starting from the skull region, shown in Figure 3a, different cranial fractures can be observed, especially on the foramen magnum in the occipital bone area, likely related to the process of immolation [18]. Continuing the investigation, a noteworthy fracture may be remarked on the first cervical vertebrae, known as the atlas (Figure 3b). This fragmentation may be also caused by the killing process, which involves the strangulation by a twist of the neck or a blow to the head [18].

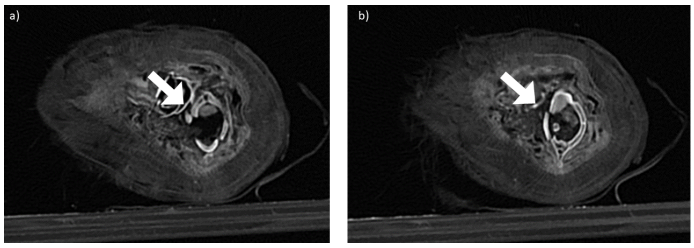

Fig. 3. Breakage of the *foramen magnum* (a) and of the first cervical vertebrae (b), as pointed by both white arrows. Seemingly, they could be caused by the killing process.

Two breakages worth highlighting are those present on the forelimbs: one fracture is present on both the left ulna and the left radius, which are shown in Figure 4, while the second fracture is on the right humerus, shown in Figure 5. The fractures are evident and, presumably, they were made post-mortem, since the repair process of the bones are not evident (or not visible at this resolution). Furthermore, numerous fractures, mostly near the posterior extremities, may also be seen. Unfortunately, it is not possible to say with certainty if the breaks were either caused by the mummification process or by the displacements of the mummy during travels, etc., which could have damaged the bones.

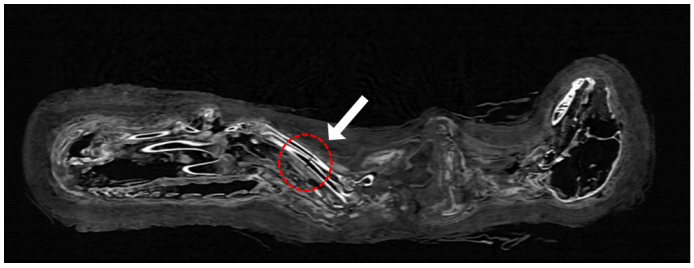

Fig. 4. Fracture on the ulna and radius of the left forelimb, presents inside of the red circle.

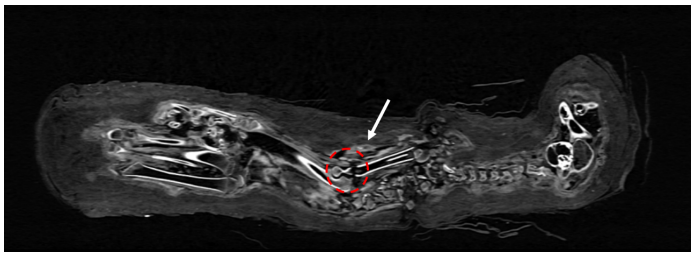

Fig. 5. Fracture on the right humerus, presents inside of the red circle.

Since the mandible is clearly visible in CT scan, it is possible to see that the molars are in the chambers and not yet in eruption. Considering that molars generally erupt between 5 and 7 months [19], [20], whereas other teeth seem to be already present, these findings suggest that the cat was young. Additionally, the proximal and distal epiphyses of the hindlimb bones are not fused, indicating an immature animal. The animal's dentition and long bone fusion indicate that the mummy may be that of a sub-adult cat, which was presumably younger than 5 months when it was killed [21]–[23]. Another characteristic to point out is the absence of organs inside. This process, called "evisceration", was usually practiced on human and animal mummies. It is worth noticing as all these hidden characteristics of the cat mummy could be observed non-invasively thanks to the power of CT scan, which enabled a deep exploration of the mummy in its integrity, without causing further damages.

VI. Conclusion

The purpose of this work was to discover the secrets hidden under the bundle of the Egyptian cat mummy, preserved into the *Museo Etnologico Missionario di San Francesco di Fiesole*, by utilizing the CT scan technique.

The use of CT scan was of paramount importance to this study, allowing researchers to learn critical information about

the cat mummy without unwrapping it, thus protecting the integrity of the sample. The quality of the images and the extraordinary information obtained, along with the possibility to use such results for research and dissemination in museums, show all the value of CT scan. This technology is advantageous for assisting the operations of these institutions because it is a non-invasive and non-destructive method. As a result, museums have begun to use it to uncover the true histories hidden beneath the bandages of the Egyptian mummies. In the last decades, this technology has advanced to become the standard diagnostic imaging modality for research regarding artifacts preserved in museum, greatly assisting discoveries in the field of humanistic studies. Regarding the case of this cat mummy, further research is surely still necessary, but many secrets have already been revealed. The application of computed tomography to animal and human mummies demonstrates the importance of using new investigation methods to discover the secrets of these treasures. The CT scan's power in turn has created new possibilities for the scientific community, especially for museums, which have started to involve Artificial Intelligence applications [24], [25] and virtual and augmented reality [26].

ACKNOWLEDGMENTS

We acknowledge the support of Valter Fattorini and the *Museo Etnologico Missionario di San Francesco di Fiesole* (Firenze, Italy), Nicolò Bechini (AUSL Toscana Centro, Firenze).

REFERENCES

[1] T. M. Buzug, *Computed Tomography*, pp. 311–342. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011.

[2] B. D. Nadrljanski M., Foster T., "Computed tomography," 2022. Available online.

[3] C. Wurst, A. Paladin, L. S. Wann, B. Frohlich, K. O. Fritsch, C. J. Rowan, M. L. Sutherland, J. D. Sutherland, D. E. Michalik, A. H. Allam, S. Zesch, W. Rosendahl, R. C. Thompson, G. S. Thomas, F. Seyfried, and A. R. Zink, "Minimally invasive bone biopsies of fully wrapped mummies guided by computed tomography and fibre-optic endoscopy: Methods and suggested guidelines," *Journal of Archaeological Science: Reports*, vol. 31, p. 102363, 2020.

[4] S. Malgora, D. Gibelli, C. Floridi, C. Martinenghi, L. McKnight, S. Ikram, J. Elias, C. Milani, G. Oliva, and M. Cellina, "Ct examination and 3d analysis of egyptian animal mummies," *La radiologia medica*, vol. 125, pp. 943–950, 2020.

[5] D. C. Harwood-Nash, "Computed tomography of ancient egyptian mummies," *Journal of computer assisted tomography*, vol. 3, no. 6, pp. 768–773, 1979.

[6] T. Falke, M. C. Zweypfenning-Snijders, R. Zweypfenning, and A. E. James Jr, "Computed tomography of an ancient egyptian cat.," *Journal of computer assisted tomography*, vol. 11, no. 4, pp. 745–747, 1987.

[7] K. White, D. Chiasserini, R. Loynes, A. David, B. van Dongen, K. Drosou, R. Forshaw, S. Fraser, P. Causey-Freeman, J. Metcalfe, *et al.*, "Enhancing mummy 'palaeobiographies' though the use of multidisciplinary techniques and approaches," *Journal of Archaeological Science: Reports*, vol. 47, p. 103784, 2023.

[8] S. N. Saleem, S. A. e.-R. Seddik, and M. El-Halwagy, "Scanning and three-dimensional-printing using computed tomography of the "golden boy" mummy," *Frontiers in Medicine*, vol. 9, 2023.

[9] S. N. Saleem and Z. Hawass, "Digital unwrapping of the mummy of king amenhotep i (1525–1504 bc) using ct," *Frontiers in Medicine*, p. 2292, 2021.

[10] R. Gaugne, S. Porcier, T. Nicolas, F. Coulon, O. Hays, and V. Gouranton, "A digital introspection of a mummy cat," in *2018 3rd Digital Heritage International Congress (DigitalHERITAGE) held jointly with 2018 24th International Conference on Virtual Systems & Multimedia (VSMM 2018)*, pp. 1–8, IEEE, 2018.

[11] W. Pahl, "Computed tomography (ct) in naturally preserved human bodies—preliminary note," *Journal of Human Evolution*, vol. 10, no. 2, pp. 163–164, 1981.

[12] R. Johnston, R. Thomas, R. Jones, C. Graves-Brown, W. Goodridge, and L. North, "Evidence of diet, deification, and death within ancient egyptian mummified animals," *Scientific Reports*, vol. 10, no. 1, pp. 1–14, 2020.

[13] S. Panzer, A. G. Nerlich, R. Hutterer, R. Bicker, S. Schoske, M. Greinwald, M. Hollensteiner, and P. Augat, "Fatal trauma in a mummified shrew: micro-ct examination of a little ancient egyptian bundle," *Journal of Archaeological Science: Reports*, vol. 34, p. 102679, 2020.

[14] K. Jeremiah, *Eternal remains: World mummification and the beliefs that make it necessary*. First Edition Design Pub., 2014.

[15] S. Ikram, *Divine creatures: animal mummies in ancient Egypt*. the American University in Cairo press, 2015.

[16] R. Ciliberti, A. Tosi, M. Licata, *et al.*, "Feline mummies as a fertilizer. criticisms on the destruction of archaeozoological remains during the 19th century," *Archaeofauna*, vol. 29, pp. 129–135, 2020.

[17] A. Zivie and R. Lichtenberg, "The cats of the goddess bastet," *Divine Creatures: animal mummies in ancient Egypt*, pp. 106–19, 2005.

[18] S. Ikram, J. Kaiser, and R. Walker, *Egyptian Bioarchaeology*. Sidestone Press Leiden, 2015.

[19] A. Werner, "Science in archaeology: A comprehensive survey of progress and research edited by don brothwell and eric higgs. london: Thames and hudson, 1963. 581 pp., 95 pls., 92 figs., 66 tables. 90s.," *Antiquity*, vol. 38, no. 150, pp. 158–160, 1964.

[20] P. Orsini and P. Hennet, "Anatomy of the mouth and teeth of the cat," *Veterinary Clinics of North America: Small Animal Practice*, vol. 22, no. 6, pp. 1265–1277, 1992.

[21] T. P. O'Connor and T. O'Connor, *The archaeology of animal bones*. No. 4, Texas A&M University Press, 2008.

[22] I. Balsa and D. Robinson, "Part 1: Musculoskeletal development & pediatric bone diseases," *Spine*, vol. 14, p. 20, 2016.

[23] K. L. Perry, A. Fordham, and G. I. Arthurs, "Effect of neutering and breed on femoral and tibial physeal closure times in male and female domestic cats," *Journal of Feline Medicine and Surgery*, vol. 16, no. 2, pp. 149–156, 2014.

[24] A. Barucci, C. Cucci, M. Franci, M. Loschiavo, and F. Argenti, "A deep learning approach to ancient egyptian hieroglyphs classification," *IEEE Access*, vol. 9, pp. 123438–123447, 2021.

[25] T. Guidi, L. Python, M. Forasassi, C. Cucci, M. Franci, F. Argenti, and A. Barucci, "Egyptian hieroglyphs segmentation with convolutional neural networks," *Algorithms*, vol. 16, no. 2, p. 79, 2023.

[26] R. Wojciechowski, K. Walczak, M. White, and W. Cellary, "Building virtual and augmented reality museum exhibitions," in *Proceedings of the Ninth International Conference on 3D Web Technology*, Web3D '04, (New York, NY, USA), p. 135–144, Association for Computing Machinery, 2004.