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Fatal trauma in a mummified shrew: Micro-CT examination of a little ancient Egyptian bundle

Stephanie Panzer[a,b,*], Andreas G. Nerlich[c], Rainer Hutterer[d], Roxane Bicker[e], Sylvia Schoske[e], Markus Greinwald[b], Marianne Hollensteiner[b], Peter Augat[b]

[a] Department of Radiology, Berufsgenossenschaftliche Unfallklinik Murnau, Prof-Küntscher-Strasse 8, D-82418 Murnau, Germany
[b] Institute of Biomechanics, Berufsgenossenschaftliche Unfallklinik Murnau and Paracelsus Medical University, Salzburg, Prof-Küntscher-Strasse 8, D-82418 Murnau, Germany
[c] Institute of Pathology, Städtisches Klinikum München-Bogenhausen und München-Schwabing, Englschalkingerstrasse 77, D-81925 Munich, Germany
[d] Zoologisches Forschungsmuseum Alexander Koenig, Leibniz-Institut für Biodiversität der Tiere, Adenauerallee 160, D-53113 Bonn, Germany
[e] Staatliches Museum Ägyptischer Kunst München, Gabelsbergerstrasse 35, D-80333 Munich, Germany

A R T I C L E I N F O

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A B S T R A C T

Micro-computed tomography examination was used to identify the content of a little ancient Egyptian mummy bundle and to analyze pathologies and the cause of death. The bundle contained a complete shrew with preservation of the skeleton and soft tissues. The species of the adolescent shrew was classified as *Crocidura religiosa*. The skull revealed bilateral impression fractures of the skullcap indicating probably one hit on each side. The skull base was fractured and the left petrous bone broke out. The alignment of the spine was interrupted between the first and second thoracic vertebra resulting in a complete obstruction of the spinal canal and disconnection of the preserved spinal cord. The adjacent dorsal soft tissues of the shrew were markedly thickened and contained an irregularly bordered area that was filled with air. This finding was suggested to represent the residual cavity after haemorrhage that was replaced by air during the desiccation within the mummification process. This fatal spinal trauma was most probably caused by a mousetrap. After death, the shrew's body must have been effectively desiccated before wrapping with multiple textile layers. The procedure of capturing and killing of a shrew prior to the production of a votive mummy as described in this study represents a tessera in the knowledge of ritual practices within the ancient Egyptian animal cult.

1. Introduction

While many are familiar with ancient Egyptian mummification, few are aware that many animal species were also included in this ritual (Ikram, 2019). Archeological material of animal mummies can then be divided into four categories: food offerings, pets, sacred animals, and votive mummies (Ikram, 2005a; McKnight et al., 2015). Votive mummies are the largest category and most animal mummies in museum collections around the world represent this type (McKnight et al., 2015). They were dedicated as offerings at the shrines of specific gods to whom these animals were sacred. The climax of making these mummies was during the Late (664–333 BCE) and Greco-Roman Period (332 BCE-395 CE) and resulted in millions of animal mummies (Ikram, 2015, 2005a; McKnight et al., 2015). The energy that had been put in the above ground construction of the pyramids in the Old Kingdom, was then mirrored in the construction of underground catacombs for dead animals in the Late period, however on a smaller scale (Fitzenreiter, 2013; Ikram, 2015). At that time, animal cults had an especially enormous impact on religious and economic aspects of the Egyptian life (Ikram, 2015). Yet, it remains unclear how these millions of animals were obtained for sacrifice. It has been proposed that feeding sites or breeding stations as well as industrial-scale production of sacrificial animals in long-term dedicated facilities originated during this time period (Ikram, 2015; Wasef et al., 2019). Also, a recent study on mitochondrial genomes of Sacred Ibis mummies revealed a mitogenomic diversity that suggested a sustained short-term taming of the wild Ibis

* Corresponding author at: Berufsgenossenschaftliche Unfallklinik Murnau, Prof-Küntscher-Straße 8, D-82418 Murnau, Germany.
E-mail addresses: stephanie.panzer@bgu-murnau.de (S. Panzer), andreas.nerlich@extern.lrz-muenchen.de (A.G. Nerlich), r.hutterer@leibniz-zfmk.de (R. Hutterer), roxane.bicker@smaek.de (R. Bicker), sylvia.schoske@smaek.de (S. Schoske), markus.greinwald@bgu-murnau.de (M. Greinwald), marianne.hollensteiner@bgu-murnau.de (M. Hollensteiner), biomechanik@bgu-murnau.de (P. Augat).

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for the ritual practice that was usually performed annually (Wasef et al., 2019). With this multitude of animal sacrifices occurring during this time period, Herodot (2017) had reported on the great respect of the ancient Egyptians for their animals. However, modern examinations of animal mummies have indicated violent deaths in many cases (Armitage and Clutton-Brock, 1981; Fitzenreiter, 2013; Ikram, 2005a; Ikram and Iskander, 2002; McKnight et al., 2015; Zivie and Lichtenberg, 2005).

Shrews had an important role within the ancient Egyptian animal cult, and shrew mummies were found in several animal cemeteries along the Nile river (Brunner-Traut, 1965; Fitzenreiter, 2013; Herodot, 2017; Ikram, 2005a, 2005b). So far, seven species of mummified shrews from ancient Egypt have been identified, amongst them the Sacred Shrew, ***Crocidura religiosa*** (I. Geoffroy Saint-Hilaire, 1862) (Hutterer, 1994; Woodman et al., 2017). Shrews were venerated as sacred animals of the Egyptian god Horus (Brunner-Traut, 1965). As discussed by Brunner-Traut (1965), they might have represented the night side of the light god Horus according to their natural characteristic of being known as a "blind mouse". The eyes of shrews are tiny and they mostly rely on their main senses of touch, hearing, and smell, with some species using echolocation (Siemers et al., 2009). Shrews also have an extremely high basal metabolic rate even when corrected for their small body size and live close to their physiological limits (Schmidt-Nielsen et al., 2009). Consequently, they have a voracious appetite, must eat very frequently and are active throughout the day and night, except for shorter periods of torpor (Vogel, 1974), which could be how the name shrew, as derived from hieroglyphs, means glutton (Brunner-Traut, 1965).

"Paleoradiology is the study of bioarcheological materials using modern imaging methods, such as x-ray radiography, computed tomography (CT), magnetic resonance imaging, and micro-CT" (Chhem and Brothwell, 2008). The first CT examination of a human ancient Egyptian mummy was reported in 1979 (Harwood-Nash, 1979), and since then CT has developed into the "gold-standard" of paleoradiology. Non-destructive cross-sectional imaging allows assessment of the skeleton, soft tissues, and internal body cavities and has the capacity to overcome superimposed embalming materials. Post-processing programs then allow the user to make reconstructions in any desired plane and to create three-dimensional models (McKnight et al., 2015; Panzer et al., 2015, 2013). However, CT imaging in very small mummies was reported to have only questionable benefit and the need for high-resolution micro-CT has been expressed (Atherton-Woolham and McKnight, 2014; McKnight et al., 2015). The first micro-CT system was developed by Ford Motor Company physicist Lee Feldkamp to evaluate structural defects of ceramic automotive materials in the early 1980s (Boerckel et al., 2014). Since then, micro-CT has become a standard and essential tool in most diverse scientific research including paleopathology (Berruyer et al., 2020; Boerckel et al., 2014; Chhem and Brothwell, 2008; Johnston et al., 2020; Laloy et al., 2013; Schanandore, 2018; Shelmerdine et al., 2018; Slabbert et al., 2015). With improvement of technology and image quality, the interest in soft tissues has grown in paleoradiological studies (Panzer et al., 2017, 2015, 2014, 2013; Romell et al., 2018). Soft tissues are the substances that make a skeleton into a mummy and they allow for a further diagnosis and understanding beyond the osteology (Aufderheide, 2003; Panzer et al., 2017).

In this study we examined a little ancient Egyptian mummy bundle using micro-CT. We aimed to identify the content of the bundle, to document and illustrate the findings, and to discuss them in the cultural context of ancient Egypt.

2. Materials and methods

2.1. Object to study

The little ancient Egyptian mummy bundle and the associated coffin come from a private collection and are in the Staatliches Museum Ägyptischer Kunst München as a permanent loan (Figs. 1, 2). Both date to the Late Period of ancient Egypt (664–332 BCE).

Fig. 1. Photograph of the ancient Egyptian mummy bundle (©Stephanie Panzer).

Fig. 2. Photograph of the wooden coffin (height 3.3 cm, width 4 cm, length 8.5 cm) with stylized carved shrew on the cap (©Staatliches Museum Ägyptischer Kunst München).

2.2. Micro-CT

Micro-CT (μCT 80; SCANCO Medical AG, Brüttisellen, CH) scanning was performed at a tube setting of 45 kV and 88 micro ampere with a slice-thickness of 20 μm (resulting in 2622 slices and a data volume of 5.12 gigabytes). To avoid damage to the object, the temperature was controlled during the scan; it was measured to be between 30 and 35 degrees Celsius. Scan time was approximately 4 h.

2.3. Segmentation and 3D printing

From the micro-CT data, the skeleton was segmented (D2P, DICOM to PRINT; 1.0, 3D Systems Corporation, Littleton, USA). The produced 3D model was edited by means of mesh-repair, noise reduction, and merge (Geomagic Studio 12.1; Geomagic Inc., Morrisville, USA), and was surface rendered for visualisation (Fusion 360 2.0; Autodesk Inc., San Rafael, USA).

In order to obtain a realistic representation of the shrew, a 3-D model was printed by first preparing the image files using the slicing-software Simplify3D (4.1.2, Cincinnati, US). 3-D printing was performed on a Raise3D N2 Plus (Raise3D Technologies, Pasadena, US) printer with

TitanX (Formfutura BV, Nijmegen, NL) as printing material. Only the isolated skull was printed in 16-fold magnification. Printing of the remaining skeleton seemed not feasible with the available technique due to the thin structure of the ribs, the tail, and the distal limbs.

3. Results

3.1. Evidence of a shrew

The micro-CT examination revealed the mummy of a complete shrew with preservation of the skeleton and soft tissues including various inner organs.

The skeleton was clearly identified as that of a shrew (Fig. 3). Typical features are the shape of the pelvis, and the slender and tapering skull with 28 teeth including the large first incisors (Fig. 4).

A comparison with measurements of 7 species of shrews known to have been embalmed in ancient Egypt revealed that the shrew under investigation belonged to *Crocidura religiosa*, a small species known only from Upper Egypt. Typical features are the small skull (total length 16.2 mm) and the short toothrow (Hutterer, 1994; Woodman et al., 2017). The epiphyses of the long bones were closed but still apparent, indicating an adolescent individual.

The soft tissue of the pointed-shaped snout of the shrew was clearly identifiable (Fig. 4). The soft tissues of the flattened ears were preserved. The heart was preserved as a homogeneous structure measuring 4.0 (cranio-caudal) × 1.4 (antero-posterior) × 1.9 mm (medio-lateral). It was located in the anterior chest on the left side with contact to the chest wall (Fig. 5a). The right lung was preserved as a whole measuring 5.8 (cranio-caudal) × 1.8 (medio-lateral) x. 1.1 mm (antero-posterior). It was located in the anterior part of the right chest. From the left lung, the upper and lower lobe were preserved separately (Fig. 5b). The preserved liver measured 8.2 (cranio-caudal) × 4.3 (antero-posterior) × 5.2 mm (medio-lateral), and was found in its typical location (Fig. 5b). Bilaterally, parts of the diaphragm were discernible. Multiple intestinal loops were present in the abdomen, partially filled with small hyperdense structures (Fig. 5b).

(a)

(b)

Fig. 3. a, b 3D model showing the completely preserved skeleton of the shrew. The animal was mummified with bent upper and lower extremities, the lower extremities were slightly crossed and the tail was curled around the back. The interactive 3D model is provided in supplement 1.

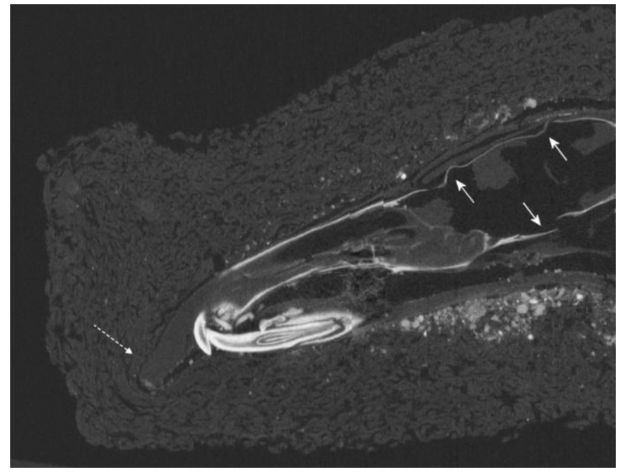


Fig. 4. Sagittal multiplanar reconstruction of the anterior part of the shrew illustrates the preserved soft tissues of the trunk-like snout (dotted arrow) and the detailed anatomy of the first lower incisor with distinguishable dentin forming the main body of the tooth and the chamber that is filled with pulp consisting of soft, vascularized and innervated tissue. Note fractures of the skull cap and skull base (arrows) and the preservation of brain structures inside the braincase.

3.2. Pathology of the shrew

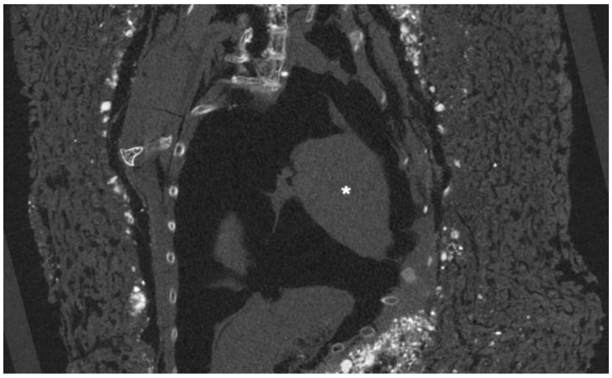
Skull fractures and a dislocated cervicothoracic spine were found as indicators of fatal violence, causing the death of the shrew. The skull revealed bilateral impression fractures on the skullcap indicating most obviously one hit on each side (Fig. 6a). The galea adjacent to the fractures was detached and the space between bone and soft tissues was filled with air. Additionally, the skull base was fractured in its middle parts including ethmoid cells. The left petrous bone broke out and was dislocated (Fig. 6b). The cranio-cervical junction was intact. The alignment of the spine was interrupted between the first and second thoracic vertebra whereby the first thoracic vertebra was dislocated dorsally up to 0.6 mm resulting in a complete obstruction of the spinal canal. In the same point, the preserved spinal cord (diameter of 0.6 mm) was disconnected. The adjacent dorsal soft tissues of the shrew were markedly thickened and contained an irregularly bordered area measuring approximately 3.6 (cranio-caudal) × 1.5 (antero-posterior) × 1.5 mm (medio-lateral) that was filled with air (Fig. 6c). In connection with the injury of the spine and spinal cord, we strongly hypothesize this area as a residual cavity where haemorrhage had occurred that was then replaced by air during the desiccation within the mummification process.

Additionally, fractures of the left 4th and 8th rib, the left proximal humerus, and the 8th caudal vertebra were present, all without relevant dislocations. We considered them as peri- or postmortem fractures. A slight dislocation occurred between the 11th and 12th thoracic spine with intact articulation of the facet joints and without conspicuous changes of the adjacent soft tissues that was then assumed as a postmortem change.

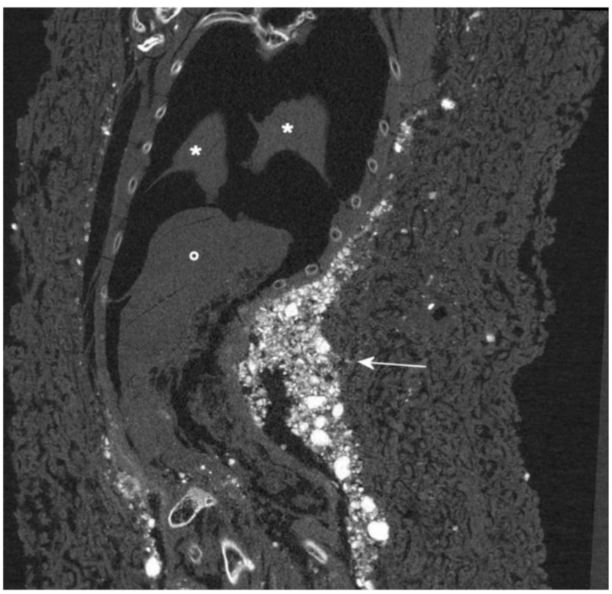
The soft tissues including the parenchyma of the lungs and liver revealed thin linear fractures that are attributed to cracks of the desiccated and therefore rigid structures during or after the mummification procedure (Fig. 5b).

3.3. Anthropogenic mummification of the shrew

Apart from the externally visible textile wrapping, micro-CT imaging indicated prior anthropogenic mummification of the shrew's body. The mummy bundle had a maximum diameter of 16 mm. The textile was wrapped tightly around the body of the shrew and had a thickness of up



(a)



(b)

Fig. 5. Organ preservation. a Paracoronal multiplanar reconstruction of the chest illustrating the preserved heart (asterisk). b Paracoronal reconstruction of the body demonstrating both lungs (asterisks), the liver (circle), and the intestine. Note thin cracks of the parenchyma of lungs and liver as well as of the soft tissues surrounding the body. Multiple foreign bodies are discernible between the mummified shrew and the textile (arrow).

to 5 mm. Up to 10 layers of textile were discernible. Generally, the distance between the body and the inner textile was less than 0.5 mm, and this space was filled with air. Close proximity of textile and body indicated that the body was already desiccated and shrunken to a great extent at the time of wrapping. The shift of the heart and right lung to the anterior parts of the chest also indicated that at least the beginning of the mummification process was performed in prone position. Multiple spherical small foreign bodies were detectable on the surface of the body and in the deep layers of the textile (Figs. 4, 5, 6). They had a maximum diameter of 0.9 mm and a varying density predominantly higher than that of bone with Hounsfield Units (HUs) up to 1760.

3.4. 3D printing of the shrew's head

The 3D print of the head of the shrew is approximately 24 cm long (16-fold magnification) and relatively robust (Fig. 7). It will be used for guided tours for school classes and for the blind in the exhibition. Thereby, "grasping" the object helps to understand it and is particularly possible due to the magnification of the shrew's head. 3D printing of archeaological remains have been reported as a useful tool for museum pedagogics (Bastir et al., 2019; Fiorenza et al., 2018; Shelmerdine et al., 2018).

4. Discussion

In this study we examined an ancient Egyptian mummy bundle using micro-CT imaging. The micro-CT images allowed for a detailed assessment of the contents of the bundle and revealed a complete shrew with well-preserved skeleton and soft tissues. Severe premortem spinal injury was observed as well as an obviously fatal head injury.

4.1. Species identification of the shrew

Quantitative measurements enabled the determination of the species as *Crocidura religiosa*. A comparison with measurements of 7 species of shrews known to have been embalmed in ancient Egypt (Hutterer, 1994; Woodman et al., 2017) revealed that the shrew under study belongs to *Crocidura religiosa*, a small species known only from Upper Egypt. Typical features are the small skull (total length 16.2 mm) and the short toothrow. Woodman et al. (2017) measured 14.4–16.1 mm in 13 skulls of *Crocidura religiosa*, and 17.1–18.7 mm in 2 skulls of *Crocidura floweri* Dollman, 1915, another but larger species endemic to Upper Egypt.

4.2. Anthropogenic mummification

Micro-CT indicated anthropogenic mummification of the shrew's body that must have been desiccated before final wrapping, e.g. by natron and/or sun exposure. Due to the relatively high HUs, the small foreign bodies on the surface of the body and in the deep layers of the textile most probably represented small stones and sand, rather than natron (Gostner et al., 2013; Panzer et al., 2013).

Armitage and Clutton-Brock (1981) reported that for mummification of cats the body cavities of some of the corpses had been filled with earth or sand to absorb moisture, a practice that is known from examination of other animal or human mummies. This earthy material was visible on the radiographs as opaque granules. The authors described two methods of mummification of the investigated cats, one using natron-soaked bandages and the other using resin applied directly to the corpse.

In their study on a collection of shrews, Woodman et al. (2017) reported that none of these animals was individually wrapped, but each was covered in a "croûte bitumineuse" (bituminous crust), which was presumed to have been a preservative used in the embalming process. Micro-CT showed a fairly homogenous crust of resin, covered on the surface by a thin layer of small globular particles with densities similar to that of bone. These particles were rounded and had diameters of 0.5–3.0 mm. The authors assumed that they represented limestone, natron, or some other mineral.

4.3. Cause of skeletal trauma in mummified animals

The discussion on the cause of skeletal trauma in mummified animals from ancient Egypt is controversial as shown by the examples below.

Fitzenreiter and Roeder (2013) summarized several references that have reported on violent deaths of ibises, cats, canines, crocodiles, and snakes prior to mummification. The author commented these findings as strange. However, he stated that violent death seemed to be the general practice in the ancient Egyptian animal cult.

Armitage and Clutton-Brock (1981) described a severe dislocation of one or more of the cervical vertebrae on radiographs of cats and assumed that they were deliberately killed by having their neck broken. The authors also stated that the age distribution of the mummified cats was very unlikely to reflect natural mortality and believed that the cats were slaughtered at two optimum ages for mummification. The first, at about four months, when the cats had reached a suitable body size for

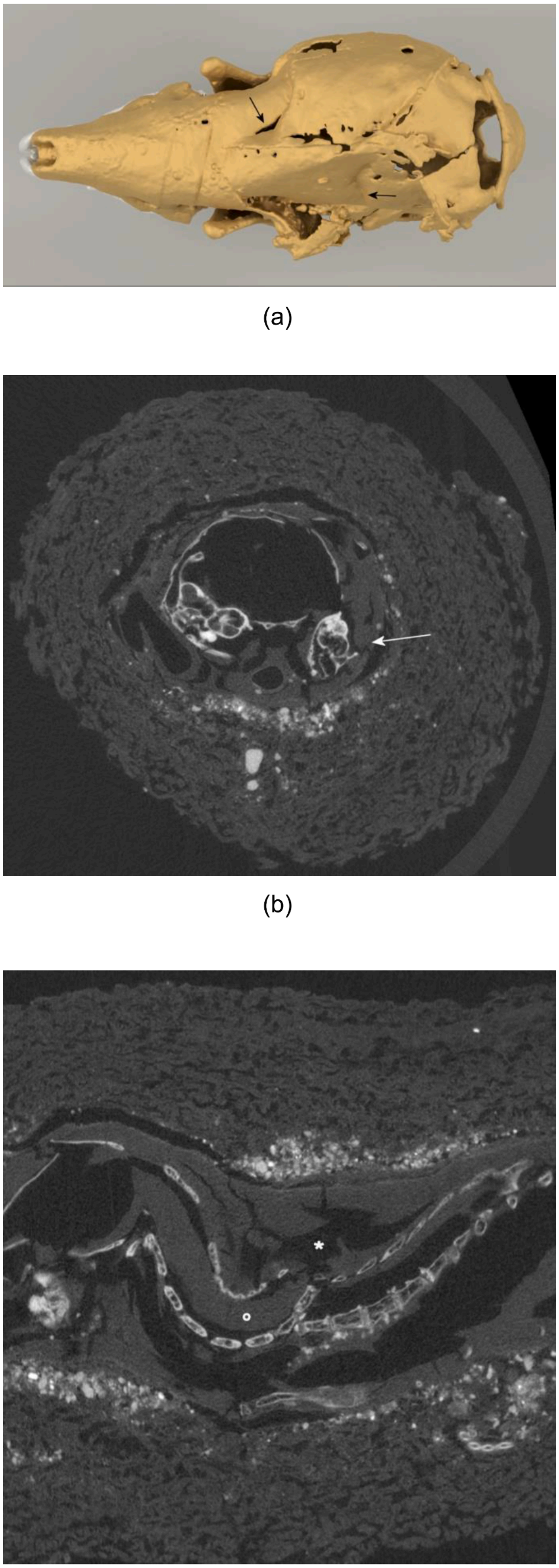


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Fig. 6. Posttraumatic changes. a 3D model of the skull illustrating bilateral impression fractures of the skullcap (arrows) indicating probably one hit on each side. b Axial multiplanar reconstruction of the skull demonstrating the broken out and dislocated left petrous bone (arrow). Note the thick circular textile wrapping. c Sagittal multiplanar reconstruction of the cervical and thoracic spine showing the dislocated fracture of the upper thoracic spine. The cervical spinal cord is preserved (circle) and cut at the level of the fracture. The adjacent dorsal soft tissues are thickened and surround a cavity filled with air (asterisk).

mummification, and the second, between nine and twelve months, when all those cats not required for the purpose of breeding were culled.

In contrast, McKnight et al. (2015) considered the presence of previously identified fatal trauma, such as unhealed cervical fractures, as results of the compression of the skeleton during the application of constrictive wrappings, along with the force of excavation, transportation, handling, and storage. The authors believed that it is speculative to identify fatal trauma by using imaging alone.

4.4. Reconstruction of the perimortem injuries of the shrew

The publication by Woodman et al. (2017) enabled a direct comparison with our findings. The authors examined 19 shrews using high resolution x-ray and in 6 of them additionally micro-CT. From the intact 16 shrews, 8 were reported to have a broken vertebral column (especially in the cervical and thoracic section) and/or a broken braincase. Four of them had a combination of broken spine and braincase. These skeletal alterations were interpreted as probable results from drying or processing, or caused by predators such as cats. However, no canine punctures as a result of predation were visible.

The skeletal findings described by Woodman et al. (2017) are similar to the bony spinal and head alterations of the investigated shrew in our study. However, in our study, adjacent soft tissues were assessed along with the skeleton, allowing the spinal and skull trauma to be categorized as an intravital injury due to the accompanying haemorrhages that could be clearly diagnosed considering the postmortem changes during the mummification process. These haemorrhages would not have occurred in a dead specimen without blood circulation. Perimortal soft tissue hematoma was also described in the 5300-year-old glacier mummy of the Tyrolean Iceman, resulting from a laceration of the left subclavian artery after an arrowhead injury. As this mummy is still frozen, the CT appearance of the hematoma differed from that in our study (Pernter et al., 2007).

4.5. The speculated tools for gaining and killing of the shrew

The question remained, what caused the described injuries in the mummified shrew? For the spinal trauma, the obvious answer seemed to be the mousetrap. The spinal injury of the shrew in our study showed the same pattern as the figures of two shrews in the study of Woodman et al. (2017) with dislocation of the posterior part of the spine at the level of the fracture towards the abdomen. This fact indicated a similar trauma mechanism that can be best explained by a systematic method such as the mousetrap in these cases. It has been reported that the ancient Egyptians protected their houses and granaries with magic spells against the ubiquitous mice and rats, and, more prosaically, with mousetraps (Ikram, 2009). Mousetraps can basically be divided into life traps and lethal traps. In ancient Egypt, life traps were reported for mice and rats (Drummond et al., 1990), and lethal traps in the form of clap-bow traps were reported especially for small birds (Dagg, 2011; Schäfer, 1918), but have also been recognized as traps for catching small rodents such as mice (Drummond, 2005) (Fig. 8). The spinal injury caused by clap-bow traps was not supposed to be acutely fatal in all cases. Therefore, additional fatal hits on the skull might have ended the suffering and the life of the shrew in this study.

Captive maintenance of shrews was known at least by the time of

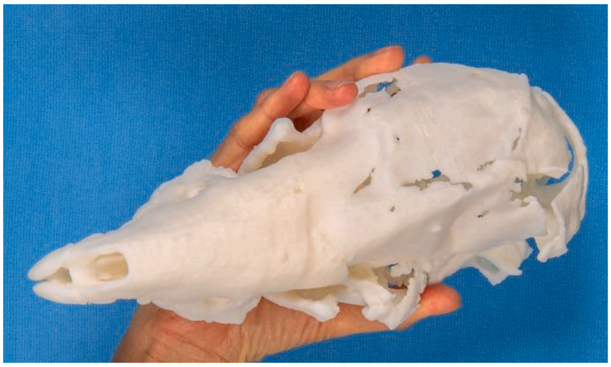

Fig. 7. 3D print of the head of the shrew in 16-fold magnification.

Fig. 8. The ancient Egyptian clap bow trap in action (©Shawn Wood) (The video is available under: https://www.youtube.com/watch?v=S3rrdMKhUoI).

Pliny (Plinius Secundus, 1942; Woodman et al., 2017). A breeding colony of shrews would be expected to produce a large number of individuals of a single species. However, the diversity among the embalmed shrews was reported to be higher than previously realized (Woodman et al., 2017). This fact makes it more likely that the shrews for mummification were obtained locally.

4.6. Strengths and weaknesses of the study

The strength of this study was the application of modern high-resolution imaging by means of micro-CT to the ancient Egyptian mummy bundle in the framework of a multidisciplinary study. Long-standing experience in paleoradiology with a focus on the current topic of soft tissues combined with the transfer of clinical radiological knowledge enabled the diagnosis and interpretation of the premortal injuries of the examined shrew. The weakness of the study was that we investigated only one shrew using only one method.

5. Conclusions

In conclusion, micro-CT examination was able to detect different aspects of the investigated little ancient Egyptian mummy bundle. The well-preserved adolescent shrew of the species *Crocidura religiosa* — the Sacred Shrew — revealed premortem severe spinal trauma that was most probably caused by a mousetrap. The fatal head injury was presumably caused subsequently by two hits. After death, the shrew's body must have been effectively desiccated before wrapping with multiple textile layers. The procedure of capturing and killing of a shrew prior to the production of a votive mummy as described in this study represents a tessera in the knowledge of ritual practices within the ancient Egyptian animal cult.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2020.102679.

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