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1 **Wild Crocodiles Hunted to Make Mummies in Roman Egypt: Evidence from**
2 **Synchrotron Imaging**

3
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16
17 **Declarations of interest:** none

18
19 **Abstract**

20 An ancient Egyptian crocodile mummy (MHNL 90001591, Musée des Confluences, Lyon,
21 France) dating to the Roman period and discovered at Kom-Ombo (Upper Egypt) was
22 analysed through synchrotron multiscale microtomography. Using this advanced technology,
23 the virtual autopsy of the animal was carried out without affecting **the bones, flesh, balms and**
24 **linen bandages**. The technique allows for the precise analysis of the specimen’s bones and
25 tissue, enabling us to establish the cause of death and the last meal(s) of the animal. From
26 these data, we can conclude that this crocodile was hunted while living in the wild. This is the
27 first evidence for this mode of obtaining animals to produce mummies. With this case study,
28 it is apparent that the praxis related to the mummification of animals in ancient Egypt are
29 more diverse than the current Egyptological reconstruction of that phenomenon.

30
31 **Keywords :** Ancient Egypt, Crocodile, Animal mummy, Hunting, Roman Period,
32 Environment, Synchrotron tomography

33

34 **Highlights:**

- 35 - Hunting as a source of animals to produce mummies
36 - Highlight to the cause of death and the last meal(s) of a crocodile
37 - Virtual autopsy of a crocodile mummy through 3D Synchrotron Imaging
38 - Diversity of the praxis related to the mummification of animals in ancient Egypt

39

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43 Montpellier, France.

44

45

46 *Why, into the entrails, the entrails of the crocodile... So to speak, for exploration, for*
47 *investigation of the facts on the spot. I would, of course, be a novelty, but that is progressive*
48 *and would at the same time show zeal for enlightenment. (Dostoevsky, 1865)* If epigraphs are
49 accepted

50

51

52 **1. Introduction**

53

54 From the 1st Millennium BC until the 4th Century AD (Roman period), the ancient
55 Egyptians mummified millions of animals, most of the mummies having been classified as
56 ‘votive offerings’ to gods and goddesses by Egyptologists (Ikram, 2017; Richardin et al.,
57 2017). Such large numbers of this type of mummy raises the question of how the animals
58 required for their manufacture were obtained. Egyptologists have proposed several means for
59 supplying such large number of dead bodies. (1) Textual and archaeological evidences
60 indicate that already dead (and sometimes decaying) animals, domestic or wild, were gathered
61 for embalming (Spiegelberg, 1928; Preisigke and Spiegelberg, 1914; Ray, 2011), what tends
62 to prove in particular the large proportion of fragmentary individuals in many mummy
63 packages, as well as the presence of necrophagous insects (Boessneck and von den Driesch,
64 1987). (2) Another source of supplying would have been the gathering of the bodies of pets as
65 mentioned by Herodotus, the Greek historian (Hérodote, II.66-67; Boessneck and von den
66 Driesch, 1987). (3) Breeding or keeping animals is the most efficient way, as well as the best
67 documented, for procuring large numbers of animals for mummification (Nicholson, 1994;

68 [Davies and Smith, 2005](#); [Ikram, 2017](#)). For example, mummified ibises at all stages of
69 development, from egg to juvenile to adult, as well as dog or cat mummies of neonates to old
70 animals, have been found ([Ikram, 2017](#); [Ikram et al., 2013](#)). Moreover, textual references to
71 « birth chapels » of ibises ([Ray, 1976](#)), have raised the question of artificial incubation of eggs
72 for breeding purposes ([Martin, 1981](#); [Meeks, 1997](#)). In the case of crocodiles, it has been
73 shown that incubation of eggs and breeding of juveniles and adults were practised to obtain
74 animals to mummify for the god Sobek ([Molcho, 2014](#)). The most telling example is the
75 temple of Medinet Madi (Fayum) where two structures have been identified as egg-incubation
76 areas, and crocodile nurseries ([Bresciani and Giammarusti, 2006](#)). To this category must be
77 added the animals trapped in their natural environment, fed into structures provided for this
78 purpose, and then sometimes allowed to breed in captivity; as birds of prey for example
79 ([Meeks, 2012](#); [Ikram et al., 2015](#)). (4) At last, only a very few Egyptologists have suggested
80 hunting as a mode of procuring animals for mummification, as there was insufficient evidence
81 to support this hypothesis ([Preisigke and Spiegelberg, 1914](#); [Nicholson, 1994](#)), except in the
82 case of fish that are caught in their natural habitat ([Van Neer, 2004](#)).

83 In the course of work of the MAHES (Momies Animales et Humaines EgyptienneS)
84 international research program, we analysed a crocodile mummy through synchrotron
85 multiscale microtomography. The resulting data shows that the animal was killed while living
86 in the wild and then was rapidly mummified. This allows us to propose hunting as a mode of
87 obtaining crocodile for mummification. This praxis, which had never been documented by
88 Egyptology, is the first concrete evidence of hunting being used to source animals for
89 mummification.

90

91 **2. Material and methods**

92

93 *2.1 The crocodile mummy MHNL 90001591*

94

95 The crocodile mummy (inventory number MHNL 90001591 ([Fig. 1](#))) under study -
96 which has been dated to the Roman period (1935 ± 30 BP; 1-130 cal. AD) using ^{14}C
97 accelerator mass spectrometry ([Richardin et al., 2017](#)) - is from the Musée des Confluences in
98 Lyon (France), which houses the largest collection of animal mummies in the world outside
99 Egypt with more than 2500 mummified specimens (cats, dogs, foxes, gazelles, rams, shrews,
100 baboons, ibis, crocodiles, fish, etc.). It brought back from Upper Egypt in the early 20th
101 century, more precisely from Kom Ombo ancient city of a great temple of Sobek. The exact

102 find-spot is undocumented in the museum register but the mummy was presumably
103 discovered in the el-Shatb necropolis during the excavations carried out by Dr Louis Lortet in
104 February 1909 for the Museum d'histoire naturelle of Lyon (Lortet and Gaillard, 1909;
105 Rabolt, 2013).

106



107

108

Fig. 1. The crocodile mummy MHNL 90001591. *(color: in print and online)*

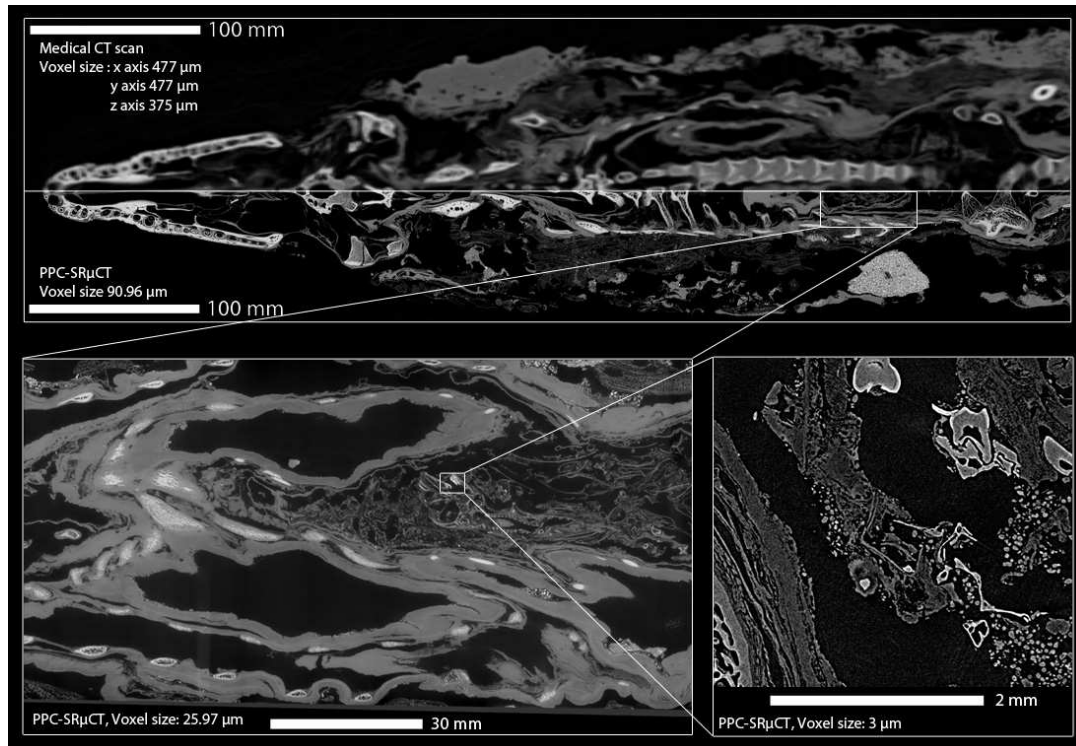
109

110 2.2 Comparison medical CT scan and synchrotron microtomography

111

112 In the field of Egyptology, a variety of imaging techniques have been used to study
113 mummies. These include radiography (Falke, 1997; Morgan and McGovern□Hoffman,
114 2008; McKnight, 2010; Atherton-Woolham and Mcknight, 2014), CT scan (Jackowski et al.,
115 2008; Morgan et al., 2011; Cornelius et al., 2012; Wade et al., 2012; Atherton-Woolham and
116 Mcknight, 2014; McKnight et al., 2015a; Anderson and Antoine, 2019), sometimes MRI, and
117 more less frequently Micro-Computed Tomography (Du Plessis et al., 2015; Ikram et al.,
118 2015). These imaging techniques have revolutionized the study of mummies. Nevertheless,
119 the resolution of these images is often insufficient for archaeological studies where seeing
120 details is crucial. Propagation phase-contrast synchrotron microtomography (PPC-SRμCT)
121 uses a specific technology: the synchrotron light. Thanks to the properties of this particular
122 beam (e.g. coherence, flux, divergence and source size) it is possible to use propagation phase
123 contrast and to create virtual images with a much smaller voxel (3D pixels) size that
124 considerably increases the resolution (Fig. 2). The phase contrast effect also dramatically
125 improves the sensitivity to small details compared with classical absorption contrast
126 (Tafforeau et al., 2006). Despite the fact that this synchrotron-based approach is increasingly
127 used for palaeontological samples, its application on archaeological samples remains very
128 limited, especially regarding investigations of mummies. It has to be noticed that propagation

129 phase contrast is, to a limited extend, accessible with specific laboratory X-ray sources based
130 systems, as demonstrated on the recent study of a human mummified hand, but these
131 applications remain currently at the proof of concept level due to the extremely long
132 acquisition time it implies (Romell et al., 2018), and the limitations of size of the object
133 studied.

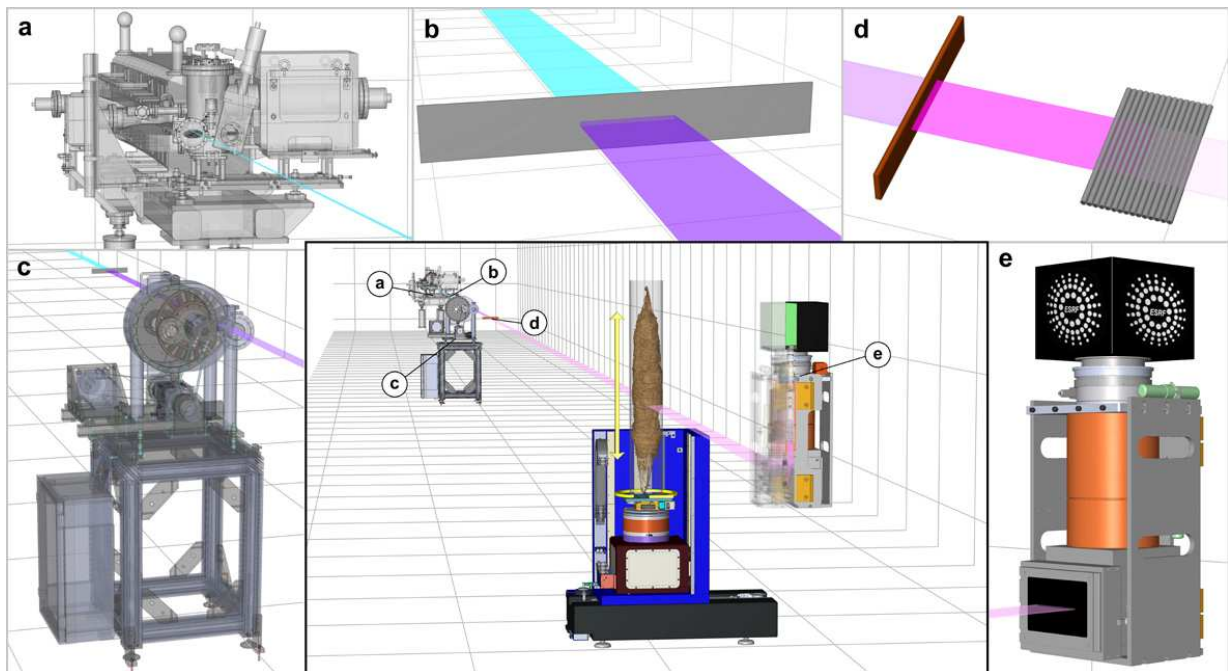


134
135 **Fig. 2.** Comparison between PPC-SR μ CT (voxel size 90 μ m) and medical CT scan (voxel size: x axis: 477 μ m,
136 y axis: 477 μ m, z axis: 375 μ m; directed by Samuel Mérigeaud, Tridilogy). It illustrates the multi-resolution
137 synchrotron X-ray imaging used in this study: from 90,96 μ m for imaging the complete mummy, 25,97 μ m for
138 the stomach content, to 3 μ m for the teeth of the rodent inside the stomach of the crocodile. The images were
139 taken through different angles for 90,96 μ m, 25,97 μ m and 3 μ m in order to see relevant structures for the
140 different scans.

141 142 2.3 Synchrotron imaging protocol

143
144 To investigate this specimen, we used the non-destructive hierarchical imaging approach
145 based on the propagation phase-contrast synchrotron microtomography (PPC-SR μ CT) with
146 voxel sizes ranging from 90.96 down to 3 μ m. The different scans of the mummy MHNL
147 90001591 were performed at the beamline BM05 of the ESRF. Four different configurations
148 were used to image respectively the complete specimen (voxel size: 90,96 μ m; **setup**
149 **presented on Fig. 3 and Video 1**), the stomach content (voxel size: 25,97 μ m), the humerus
150 structure, (voxel size: 12,99 μ m), and the teeth of the rodent in the stomach (voxel size: 3

151 μm). The reconstruction was performed using the single distance phase retrieval algorithm
152 (Paganin et al., 2002) and filtered back projection as implemented in the PyHST2 software
153 (Mirone et al., 2014). All the 3D renderings and segmentations were performed using the
154 software VGStudioMax 3.0 (Volume Graphics, Heidelberg, Germany). All the acquisition
155 parameters are summarized in the Supplementary Material (Table SM1).
156



157
158 **Fig. 3.** Schematic diagram of the experimental setup on the BM05 beamline. Perspective rendering is used as the
159 total distance between the X-ray source and the detector is 55m. In addition to the sample stage with the
160 crocodile mummy installed vertically, different elements are depicted with more details. (a) bending magnet in
161 the storage ring, *i.e.* the X-ray source of BM05. (b) 0.4mm thick molybdenum filter to cut out the low energies
162 from the white beam. (c) chopper used to reduce beam power without changing its spectrum. (d) 3mm thick
163 copper filter followed by 15 aluminum bars of 5mm diameter to reach high energies and compensate natural
164 beam vertical profile. (e) Indirect detector based on a large crystal scintillator that produces visible light from X-
165 ray, projected onto a CCD camera through optics. *(color: in print and online)*
166

167 3. Results

168
169 Mummy MHNL 90001591 is wrapped in several layers of linen impregnated with
170 resins, except for the head and the tip of the tail (Fig. 4a, b, Video 2). The 3D segmentation of
171 the 90,96 μm voxel size data made it possible to separate the mummy from its linen layers
172 (Fig. 4c, Video 2), and then to virtually remove its skin and osteoderms in order to isolate its
173 skeleton and its internal organs (Fig. 4d, e, f, Video 2). The virtual autopsy revealed a juvenile
174 male (Appendices A, Video 3), measuring 112 cm in length (the end of the tail is missing). A

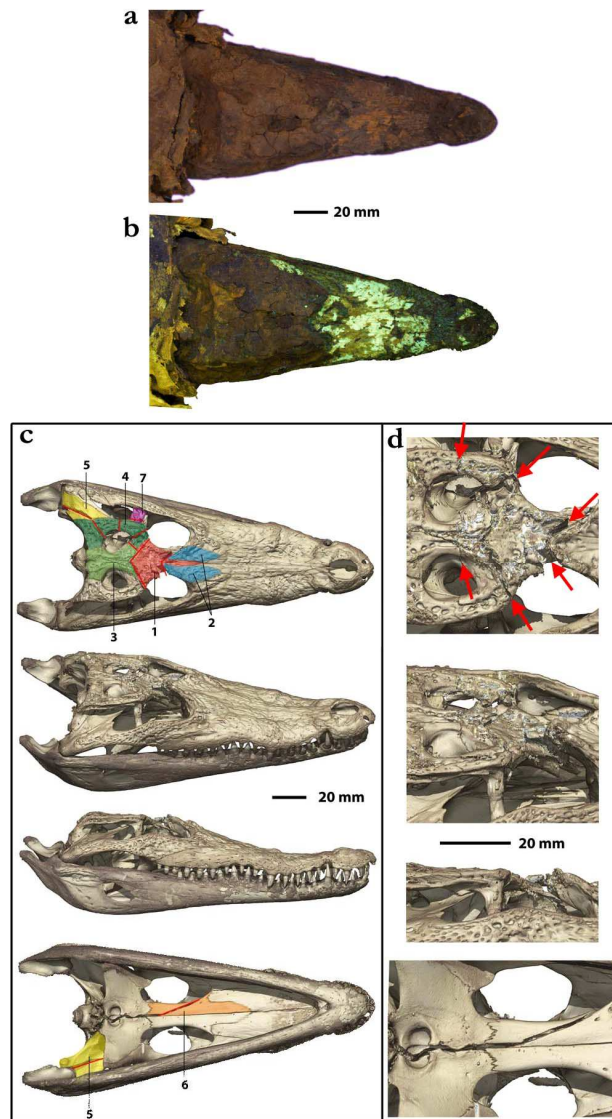
175 skeletochronological study carried out using virtual histology on the 12,99 μm voxel size
176 data, on the humerus diaphysis, indicates an age at death between 3 and 4 years (Appendices
177 B). The body is very well preserved, without any trace of decomposition, and was not
178 eviscerated during the course of mummification (Fig. 4e).



179
180 **Fig. 4.** Photo and 3D rendering of the crocodile mummy (Inv. MHNL 90001591). Photograph in
181 dorsal view (a); 3D rendering showing the same view with the wrapping (b), the skin of the crocodile
182 (without the wrapping) in dorsal view (c), the muscles and the skeleton in dorsal view (d), some
183 internal organs and skeleton in ventral view (e) and the skeleton in dorsal view (f). (color: in print and
184 online)

185
186 The crocodile's cranium is fractured in different areas, as visible on medical CT scan
187 and PPC-SR μ CT, indicating that the animal received a violent blow (Fig. 5, Video 4). The
188 fracture is located on the top of the skull and affects the frontal, the left squamosal, the left
189 part of the parietal, the left prefrontal, the right quadratum and the right palatine process of
190 palatine and the left postorbital (Shaker and el-Bably, 2015).

191



192
 193 **Fig. 5.** Photo of the head and 3D rendering showing the lethal skull fracture. From top to bottom:
 194 Visible light photography (a), Ultra Violet fluorescence photography shows the balm and cranium
 195 reconstruction area (b), 3d rendering viewed from four different angles and the associated zooms
 196 focusing on the fracture itself (c-d). The different bones affected by the fracture (red lines and red
 197 arrows) are coloured on the dorsal and the ventral views 1. Frontal 2. Prefrontal 3. Parietal
 198 4. Squamosal 5. Quadratum 6. Palatine process of palatine 7. Postorbital. *(color: in print and online)*

199
 200 Imaging obtained by PPC-SR μ CT has enabled the virtual examination of the
 201 crocodile's internal organs, which remain inside the body. The stomach, imaged with a voxel
 202 size of 25.97 μ m, contains different elements in various proportions (Fig. 6, Video 5). As our
 203 aim was only to define the diversity level of the stomach contents, only superficial
 204 determination of the various organisms present was performed in most of the cases. First of
 205 all, the preliminary survey indicates that stomach content is well preserved and is dominated

206 by soft shell eggs (Fig. 6e) and fragments of insects. Eggs are present in all the stomach with
207 a slightly higher density on the posterior part. We counted 28 different specimens that
208 measure 13.4 mm by 10 mm in average (Fig SM2, table SM3). All the eggs are quite similar
209 in their general aspect, and homogeneous in term of size and eggshell thickness and structure.
210 Considering that they all present a similar level of digestion, one can assume that they were
211 swallowed in a much limited time period. The most probable explanation is that these eggs
212 originate from a single nest belonging to small lizards or snakes, which were eaten by the
213 crocodile. The second most frequent component in the stomach is insects. They include a sub-
214 complete large hemipteran (51.6 mm long) that shows evidence of bite marks. We tentatively
215 identified as a giant water bug *L. cordofanus* (= anc. *L. niloticum*) (Perez Goodwyn, 2006)
216 (Fig. 6a, Fig SM4), the only species of this genus know in Egypt. Other remains of insects,
217 represented by fragments only, (Fig. 6b) belong to coleopterans. We distinguished two groups
218 based on the shape, size, and pattern of these elytra. Several elytra present bite marks too (Fig
219 SM5). All the insects, except the *L. cordofanus*, present only the cuticle, the soft parts having
220 been already digested. In addition to reptiles' eggs and insects, several other remains have
221 been identified in the stomach: three fish vertebrae, only the vertebral bodies are partially
222 preserved due to digestion (Fig. 6c, Fig SM6), fragments of feathers (Fig. 6d), some
223 unidentified plants (Fig. 6f) and a nearly complete rodent (Fig. 6g). The rodent is relatively
224 well preserved, except the head and the lumbar region that are smashed. The flesh and the fur
225 are conserved, though the bones of the forefeet (carpals, metacarpals, phalanges), the distal
226 part of the hind feet (i.e. phalanges) and the last caudal vertebrae are missing, probably
227 destroyed by digestive process. The rodent was identified as a member of the Muridae family
228 based on the 3 µm voxel size data of its teeth. The dental wear, indicates an old individual,
229 and makes it impossible to directly identify it to species level. However considering that there
230 is only one species of *Mus* known in Egypt (Hoath, 2009), we can be tentatively attributed to
231 the species *Mus musculus* (Osborn and Helmy, 1980) whose size and dental morphology are
232 compatible with our observations.
233



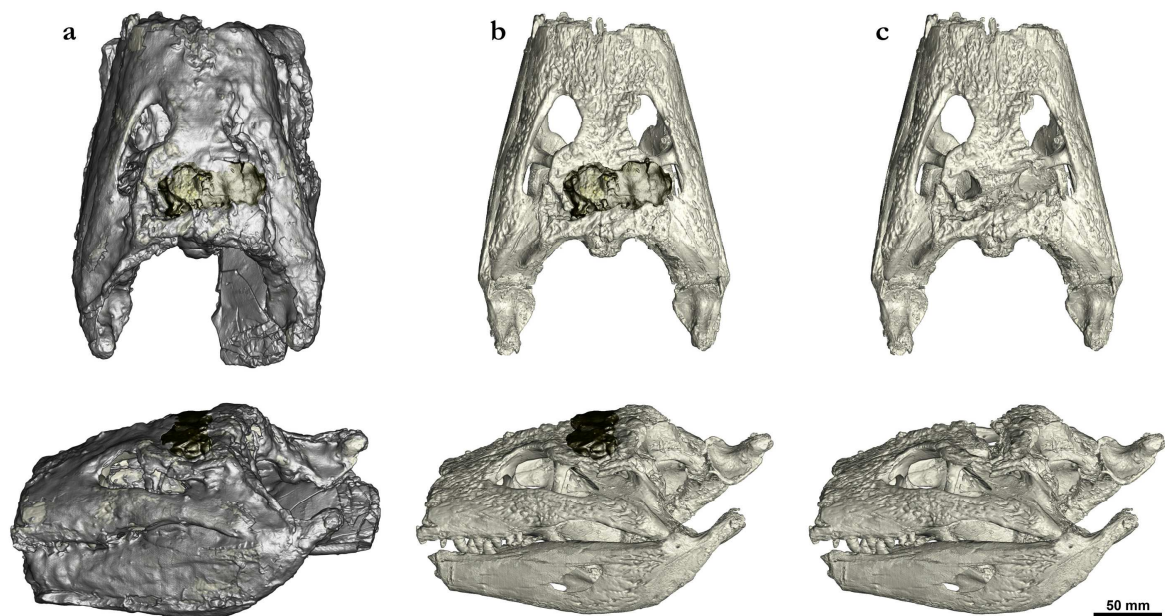
234
 235 **Fig. 6.** 3D rendering showing a part of the contents of the crocodile stomach. Stomach (black box) of
 236 the crocodile and a representation of the diversity of the stomach content. A nearly complete large
 237 *Lethocerus cordofanus* (a), a coleopteran elytra (b), a fish vertebrae (c), a feather (d), some soft shell
 238 eggs (e), a plant (f) and a complete rodent from genus *Mus* (g). (color: in print and online)

239
 240 **4. Discussion**

241
 242 *4.1 The cause of the death*

243
 244 The most probable cause of death is a serious skull fracture on the top of skull that
 245 caused a direct trauma to the brain. The size of the fracture as well as its direction and shape
 246 suggest that it was made by a single blow presumably with a 2cm thick wooden club, aimed
 247 at the posterior right side of the crocodile, probably when it was resting on the ground. During

248 the course of mummification, the depression in the cranium was filled with resinous material,
249 probably to restore the original appearance of the skull so that the animal seemed intact. A
250 similar fracture was noticed on a mummified crocodile kept at Manchester Museum (MM9,
251 1772; provenance unknown) (McKnight et al., 2015b) and on at least two crocodile heads
252 also from Kom Ombo (Musée des Confluences MNHL 90001839 to 90001841, unpublished,
253 Fig. 1). The latter are not complete, only the back of the skulls are preserved. Dr. Louis Lortet
254 and Dr. Claude Gaillard examined the skulls more than a century ago and concluded that the
255 animals had undergone amputation of the muzzle caused by a violent blow of an axe that
256 had severed the maxilla and the mandible (Lortet and Gaillard, 1909). According to them, this
257 amputation was intended to prevent the crocodiles from biting anyone before they were killed.
258 Following analysis of radiographic images and CT-scan images carried out as part of the
259 MAHES project, it is not possible to confirm the hypothesis that these animals were mutilated
260 while living. The depression in the cranium of MNHL 90001839 and 90001841 (Fig. 7a),
261 were filled with resinous material during the course of mummification as crocodile MNHL
262 90001591 (Fig. 4b-c).
263



264
265
266 **Fig. 7.** 3D rendering of a fragment of crocodile skull from Kom Ombo (MNHL 90001841). 3D
267 rendering showing the crocodile's head covered with balm in dorsal and lateral views (a), the skull
268 and mandibles with cranium reconstruction area (b), the skull and mandibles, without cranium
269 reconstruction area, illustrating cranial fracture at the level of the braincase (c) (initial CT from scan
270 Samuel Merigeaud, Tridilogy). (color: in print and online)

271 *4.2 The stomach content*

272

273 The examination of the stomach content clearly shows that it had a diverse diet,
274 corresponding to that of wild crocodiles of a similar age. In the wild, the diet of young
275 crocodiles consists primarily of insects and arachnids (Wallace and Leslie, 2008). Sub-adult
276 crocodiles have a more diverse diet, feeding on small mammals, birds, reptiles, amphibians,
277 crustaceans, fish, and gastropods. They feed on insects and arachnids too, but in a lower
278 proportion than younger animals (Wallace and Leslie, 2008; Tucker et al., 1996; Diefenbach,
279 1975). When fish are eaten, only the vertebrae remain relatively undigested (Wallace and
280 Leslie, 2008). Unlike other reptiles, complete digestion by crocodiles is relatively quick, and
281 in general takes 72 hours (Pooley and Gans, 1976), although it can be slower, taking up to 8
282 days if the ambient temperature is around 20°C (Diefenbach, 1975).

283 Recently, the stomach content of another mummified crocodile (British Museum EA 38562)
284 also coming from Kom Ombo and dated, using ¹⁴C accelerator mass spectrometry, to the
285 Saite Period (2518 ± 27 BP; 653-542 cal. BC), was CT-scanned (Anderson and Antoine,
286 2019). The adult animal measured 3.84 m. It was fed with choice cuts of meat: the right
287 foreleg of a cow/ox (scapula, proximal and distal ends of the humerus) and several long bone
288 shaft fragments have been identified. This supports the hypothesis that the animal was kept in
289 captivity and fed a special diet. These observations can be compared with the writings of the
290 Greco-Roman authors who reported that the Egyptians kept crocodiles in captivity within
291 consecrated enclosures, and that their attendants fed them with sumptuous foods, which
292 consisted of prime meat and poultry (Herodotus II, 69; Diodorus Siculus, I, 84; Strabo XVII,
293 1, 38; see also Aelianus, X, 21).

294 In our case, the diverse foodstuffs found in the stomach as well as the bite marks
295 observed on many organisms are clearly the result of a natural diet in the wild, rather than one
296 provided by doting humans. The state of preservation of the bones of the rodent, as well as the
297 general state of the large water bug, demonstrates that they were consumed only a few hours
298 before the crocodile's death. Indeed, studies demonstrate that mice are completely decalcified
299 24 hours after ingestion (Fisher, 1981). This indicates that the crocodile was not captured
300 alive and kept until it was killed.

301

302 *4.3 The mummification process*

303

304 As there is no evidence for insects or fly larvae linked to cadaver decay, it is obvious

305 that the mummification process was started very rapidly after the death. In this case,
306 mummification consisted of no evisceration - which is common among the animal mummies -
307 , desiccation of the body using natron salts, filling of the hole in the head, anointing the body
308 with resins and oils, and finally wrapping it in linen bandages (Bondetti et al., 2019).

309

310

311 **5. Conclusion**

312 All facts ultimately point towards the hypothesis that crocodile MHNL 90001591 was
313 intentionally killed while it was living in its natural environment for the purpose of making
314 mummy. As such, hunting appears as the most likely context, although neither ancient textual
315 sources nor archaeological remains give other evidence that animals were hunted to obtain
316 specimens for mummification. However, this can be compared *mutatis mutandis* to the case
317 of fishing and fowling migratory birds to obtain animals for mummification (van Neer, 2004;
318 Nicholson, 1994). It cannot be ascertained absolutely whether crocodile MHNL 90001591
319 was strictly a wild animal, or if it lived in relative captivity in its natural environment, in an
320 area bordering the Nile or on the banks of a canal where human action was limited (Molcho,
321 2014).

322 With this single example from Roman Egypt, it is impossible to establish if the
323 mummification of a hunted crocodile is an exceptional case resulting from a contingent event,
324 or if hunting might be considered as a common mode of obtaining animals for mummification
325 at a time when the production of 'votive mummies' seems to have increased, and thus the
326 particular modes of production are possibly a consequence (mainly young crocodiles and
327 simply manufactured mummies) (Craston, 2017). Additionally, we cannot exclude the
328 hypothesis that the mummification of a hunted crocodile was a prescription for a particular
329 (but still unidentified) ritual practice, possibly for a specific divine form of Sobek
330 (Quaegebeur, 1984). If analyses of other crocodile mummies show similar results, one would
331 have to reconsider - on both diachrony and synchrony - the current scholarly ideas about the
332 process for sourcing animals for mummification, the process for manufacturing animal
333 mummies, and the related ritual praxis.

334 Our results demonstrate once again the relevance of such an interdisciplinary study
335 in the field of Archaeology, that ensues from a fruitful dialogue between the traditional 'two
336 cultures' (i.e. Science and Humanities) with a common interpretative framework of the
337 material facts brought here by state-of-the-art imaging technologies (Kristiansen, 2017;

338 **Anheim et al., 2015; Bertrand et al., 2013**). In this context, Egyptology translates the science-
339 based evidence at anthropological and historical levels.

340

341

342 **Conflicts of interest and funding**

343 The authors declare that they have no conflict of interest. This research was carried out within
344 the framework of the MAHES Project (Momies Animales et Humaines EgyptienneS)
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347

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357 the MAHES project, especially in the radiography and CT-scan of this specimen.

358

359 **Appendices and Supplementary Material**

360 **Appendices and Supplementary Material related to this article can be found at XXX (to be**
361 **completed by the Editor)**

362

363

364 **Additional information**

365 **All the tomographic data used for the study, as well as several other details scans not**
366 **presented in the present paper, are available on the open access tomographic database of the**
367 **ESRF: <http://paleo.esrf.eu>**

368

369

370

371

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