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Digital proliferative osteitis due to stress fracture in an Eocene crocodilian

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A pathological phalanx of an Eocene crocodile is described, macroscopically and microscopically examined, and compared with contralateral phalanx of the same individual and other specimens of extant *Crocodylus niloticus*. Both manual examination and computed tomography scan analysis on the specimen reveal a significant bone abnormality in shape which translates into a moderate bone growth, producing a bone callus that covers part of the medial third of the distal diaphysis. Near the affected area, a pathological *sulcus* was found in comparison with the other healthy phalanges. This set of features fits to a stress fracture with a proliferative osteitis around the primary lesion. These data are not only according to described bone pathologies of living reptiles but also with other described bone lesions in extinct reptiles. This is the first description of a pathological lesion in an Iberian Eocene crocodile.

Keywords: paleopathology; Crocodylia; proliferative osteitis; abcess; Eocene

Introduction

Crocodilians are among the best-known vertebrates in the world with a number of data on their biology, distribution and ecology. The anatomy of the group is well constrained thanks to the study of extant species that allows for the assessment of many biological aspects including multiple pathologies and diseases (e.g. Webb and Messel 1977; Webb and Manolis 1983; Yoon-Seok et al. 2011). In the fossil record, pathologies and diseases have been recognised, including articular gout, post-traumatic infectious diseases or tumours, fibrous osteodystrophy, stress fractures, periosteopathy/osteopathy, osteomyelitis, spondyloarthropathy, exostoses and congenital malformations (Sawyer and Erickson 1985, 1998; Rothschild and Martin 2006; Santiago et al. 2006; Rothschild 2010; Cabral et al. 2012).

The fossils described in the present study come from La Boixedat, a locality found south of Roda de Isàbena town (Aragón, NE Spain) near the road A-1605, on the left margin of the Isàbena river. The site is located at the Isàbena basin, in the South-Pyrenean Central Unit, and has a lower Eocene age (Lower Lutecian; Golpe 1971, 1972). It falls in the outcrops of the continental Castissent Formation that is represented by mudstones and sandstones of fluvial influence. The site, which is currently exhausted, was reported after the research conducted by the team of the Catalan paleontologist Miquel Crusafont at early fifties of the twentieth century (Crusafont et al. 1956). It yielded mammals including placental creodonts and perissodactyls, some prosimians and artiodactyls, as well as a high abundance of chelonians and crocodilians (Crusafont et al. 1966 and updated faunal list in Crusafont and Golpe 1968 and Checa and Casanovas 1989–1990). Berg and Crusafont (1970) briefly reported on a partial mandible of an undetermined, small crocodilian from the site. Among the material collected in the La Boixedat locality, the reptilian elements have remained unstudied due to its fragmentary or isolated nature. They include postcranial elements of crocodilians (disarticulated limb bones and undetermined fragments) and turtles (plate fragments). The present study aims to contrast pathological hypothesis on the basis of the study of an isolated crocodilian phalanx.

Material and methods

The present study concentrates on the fossil specimen IPS-4459 (Figure 1(A)) housed in the Institut Català de Paleontologia Miquel Crusafont (Barcelona, Catalonia). We compared this material with the counterpart phalanx IPS-4489 (Figure 1(B)) and a phalanx (MZB 2003-1423) of the extant *Crocodylus niloticus* housed in the Museu de Ciències Naturals de Barcelona (Barcelona, Catalonia). All the specimens were analysed macroscopically and microscopically and were photographed using a camera Panasonic DMC-FZ18 and measured with manual calliper (all measurements in millimetres). The abnormalities detected in the IPS-4459 specimen were measured and described on the basis of its location, extent and texture. Both anatomical and pathological terms used in the description are based on terminology applied to the description of diseases in reptiles pathology (Jacobson 2007). IPS-4459 and IPS-4489 were scanned with an industrial computed tomography (CT) scanner (YXLON

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Figure 1. (Colour online) Pathology in the pedal phalanx of an Eocene crocodile. (A) Specimen IPS-4459 (pathologic), left pedal I phalanx in dorsolateral view. Arrows indicate abnormalities. (B) Specimen IPS-4489, right pedal I phalanx (reversed) in dorsolateral view. Scale bar: 5 cm.

Y.TU450.D09) at the Institut Català de Paleontologia at 200 kV and 3.5 mA and obtaining 0.267 mm of pixel size and an output of 1024 × 1024 pixels per slice, with an interslice of 0.5 mm. The slices for all the phalanges were obtained using the CT software Avizo 7.0 (Visualitzation Sciences Group).

Description

The specimen IPS-4459 is a well-preserved left pedal I phalanx (proximodistal length: 69 mm) characterised by a robust appearance (Figure 1(A)). It only lacks part of the medial edge of the distal articular end. In proximal view, the articular end has a triangular shape and the articular surface being represented by a sub-rectangular, lateromedially elongated socket (maximum lateromedial length of the articular surface: 29 mm). The flexor tubercle is prominent. The phalanx is more robust in its proximal end (dorsoventral length: 31 mm) and thins to the midshaft (minimum lateromedial length at midshaft: 18 mm). In lateral and medial views, the phalanx shows curved profile with prominent striations for tendon attachments in its proximal edge that run oblique to the proximodistal length of the bone. There are also similar marks in the lateral margin of the distal articular end. In ventral view and near its proximal margin, IPS-4459 exhibits a small and elongated fossa, as well as a prominent bone growth in the midshaft. Both anomalies face towards the lateral margin of the bone. The fossa measures 9 mm × 6 mm and exhibits a granular texture. The bone growth occupies a 15 mm × 8.5 mm surface (Figures 1(A) and 2(A),(B)). Macroscopic examination reveals that the bone is destroyed in the fossa and remodelled in the roughened surface with bone growth. The CT scan analysis indicates that the core shows a homogeneous aspect and no pathologic mineralisation was observed inside the bone (Figure 2(C)). All these results indicate a *premortem* lesion compatible with stress fracture and secondary osteitis described in living and extinct reptiles (Antinoff 1997; Kramer 2006; Rothschild and Martin 2006).

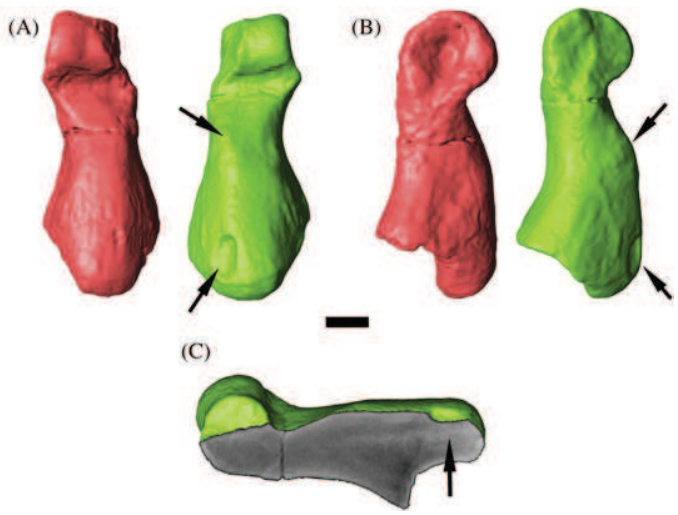

Figure 2. (Colour online) CT analysis of the pedal phalanges. (A) Dorsal view of IPS-4489 and IPS-4459, respectively. (B) Lateral view of IPS-4489 and IPS-4459, respectively. Arrows indicate abnormalities. (C) Proximo-distal cross section of specimen IPS-4459 showing the absence of pathological abnormalities inside the bone. Scale: 1 cm.

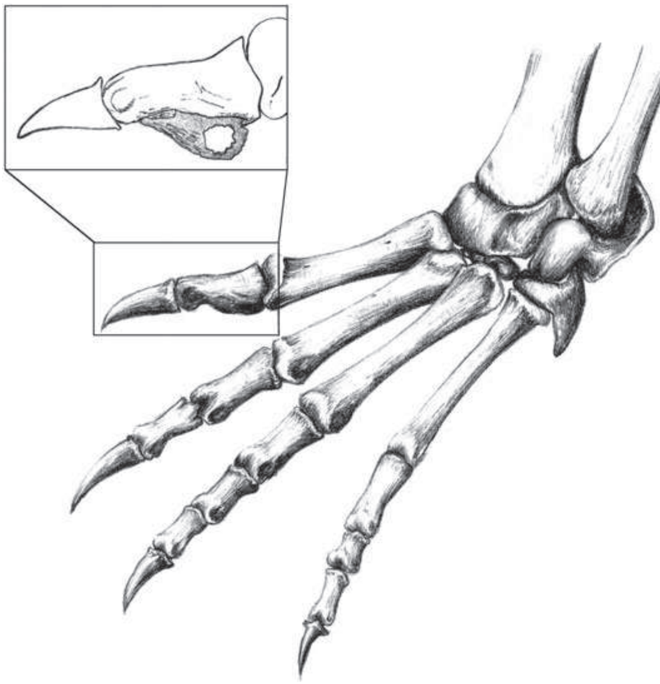

Figure 3. Drawing of the left pes of a crocodylian with indication of the pathology in phalanx I. Note that the pathologic phalanx is slightly bevelled medially to illustrate the pathologies on its ventral surface. Restoration by Agnès Amblàs.

Discussion

The observed characters in the IPS-4459 specimen indicate an anomaly in the bone tissue that results in bone remodelling and a loss of bone tissue at its proximal end, forming an osteolysis pit near the proximal condyle as well as a proliferation of the ipsilateral cortex in the medial diaphyseal area (Figure 3). This set of features fits with the symptomathology of a stress fracture and a periosteal local reactive osteitis (Sawyer and Erickson 1985). In extant wild reptiles, abscess near the skeleton sometimes results in reactive bone formation with distortion of the affected bone (Stacy and Pessier 2007). The bone reorganisation in living reptiles can be related with bacterial infections (e.g. abcess and tuberculosis) or with chronic fungal infections, the fact that should be considered in extinct reptiles (Kramer 2006; Rothschild and Martin 2006). A similar symptomathology in the diaphyseal area should be produced by a fibrous dysplasia, or osteomalacia, commonly observed in reptiles with the non-infectious metabolic bone disease (MBD) (Frye 1991), although this does not usually cause the absence of tissue but rather spongy and osteoporosis (Jacobson 2007). The MBD also produces a delay in the normal growth of the affected bone. However, the comparison of the IPS-4459 specimen with the counter-lateral phalanx IPS-4489 from the same individual shows that there is not a differential bone development between them. Therefore, we state that the lesion occurred during a bone phase without growth, that is, in its adulthood.

In our case, the examination of the bone surface in IPS-4459 and in the non-pathologic *C. niloticus* phalanx (MZB 2003-1423) rules out a taphonomic process and indicates that the lesion occurred when the animal was still alive. Thus, the bone reacted to the infection producing new cortical bone with granulomous tissue around it; more externally, it produced sclerotic bone tissue that revealed the persistence of the inflammatory reaction probably due to a tendon/ligament avulsion injury. Internal fracture lines or remodelling were not observed in the CT analysis (Figure 2(C)) and the described lesion could be considered as a local stress fracture. The periostic reaction secondary to an osteoitis can be done also in neoplastic diseases as osteosarcoma (Rothschild and Martin 2006). However, and while these lesions could be related with any kind of osteoma, the surface of this bone reaction is less proliferative in comparison with what it would be expected for a neoplastic disease. This evidence allows us to rule out a neoplastic disease in the affected phalanx, together with the fact that it is not the most common area for the occurrence of tumours in extant reptiles (Jacobson 2007).

In extant reptiles, this sort of periosteopathy is related with a local inflammation of the tissue near the bone. This reaction is non-specific, that is, it can be observed with any inflammatory disease. This is because in reptiles, this sort of degenerative and/or proliferative disease around the bone is not specific, for instance, of a tuberculosis disease. In extinct crocodiles, similar reactive osteopathies have been described in *Leidyosuchus formidabilis* from the Paleocene (Sawyer and Erickson 1998) with a phalanx spondyloarthropathy resulting in erosion of the proximal articular surface and a mild amount of neighbouring reactive bone. Another similar description is done in a Brazilian crocodile with a femur fracture and a secondary osteomielytis (Ferigolo 1993).

Finally, the association between peripheral bone osteomielytis and secondary neoplasia is described in extant reptiles. It has been reported in a turtle bitten by a dog, resulting in an osteomielytis in the affected shell with consequent chronic fibriscess. In this same lesion, a surrounding neoplastic tissue consisting of neurilemmal bone sarcome was surgically removed (Frye 1991). Accordingly, the actual origin of the pathology in the studied crocodile phalanx remains unknown, although it may be due to biting during territorial fights, a fact commonly reported in both extant and extinct crocodiles (Webb and Messel 1977; Buffetaut 1983; Heard et al. 1988; Ferigolo 1993; Katsura 2004).

In summary, the described pathological features are consistent with a chronic periostial stress fracture with a proliferative growth around the primary lesion. A noteworthy fact is that this is the first occurrence of a pathological lesion in an Eocene crocodile in the Iberian Peninsula.

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Notes

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