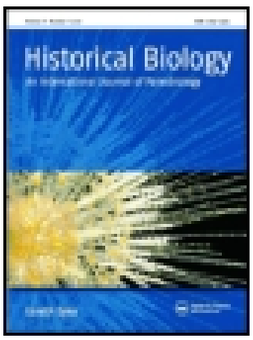

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On a cranial bony nodular protuberance on *Mourasuchus pattersoni* Cidade et al. 2017 (Crocodylia, Alligatoroidea) from the late Miocene of Venezuela

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ABSTRACT

Mourasuchus pattersoni, from the late Miocene Urumaco Formation of Venezuela, is the fourth and most recent species described for the genus. The holotype, and only known specimen, is comprised of an almost complete skull with both mandibular rami and several postcranial remains. In ventral view, the right palatine bone has a spherical, nodular bony protuberance located on the anterior portion, near the suture with the maxilla. Unfortunately, we cannot assign a specific diagnosis based only on macroscopic inspection. Its appearance, form and location are compatible with three conditions: *torus palatinus*, a common benign intraoral bone overgrowth; osteoma, a benign neoplasical overgrowth of the bone; and hamartoma, an overgrowth of normal bone tissue that can only be differed from an osteoma by histological features. While occurrences of *torus palatinus* or hamartomas are not yet known in the nonhominid vertebrate fossil record, there are previous records of osteomas in fossil vertebrates, including in crocodylians, such as a specimen assigned to '*Crocodylus* sp.' from the Eocene, aside from several records for living crocodylians. Future studies are needed to uncover an accurate diagnosis of this unusual structure and help increase our knowledge of paleopathology in fossil crocodylomorphs in general, especially in the Caimaninae clade.

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Mourasuchus; *Mourasuchus pattersoni*; Crocodylia; osteoma; *torus palatinus*; hamartoma

Introduction

Crocodylia is a well-known group of vertebrates that comprises 24 extant species and a much larger number of fossil forms (Brochu 1999, 2003; Hekkala et al. 2011; Shirley et al.2013). The anatomy and the physiology of this group has been extensively studied in both extant and extinct taxa (e.g. Kälin 1933; Iordansky 1973; Thorbjarnarson 1992; Leitch and Catania 2012; Walmsley et al. 2013). However, diagnoses of diseases in the crocodylian fossil record are relatively scarce (see Rothschild et al. 2012), particularly for the clade Alligatoroidea and its sub-group Caimaninae. Up to now, the most common pathologies proposed in the literature for crocodylian fossil taxa include joint lesions (Sawyer and Erickson 1985, 1998; Rothschild 2008), infections (Sawyer and Erickson 1985; Rothschild 2008), exostoses (Sawyer and Erickson 1998), tumors (Rothschild 2008), fractures (Sawyer and Erickson 1985, 1998; Rothschild 2008; Mackness et al. 2010) and unspecific injuries (e.g. Neill 1971), digital proliferative osteitis (Martínez-Silvestre et al. 2015), spondylitis deformans (Ruffer 1920) and necrotizing dermatitis (Wolff et al. 2007). In addition, several diseases have also been identified in non-crocodylian fossil crocodyliforms (e.g. Auer 1909; Moodie 1916, 1918, 1923; Tasnádi-Kubacska 1962; Buffetaut 1983; Hua 1995; Langston 1995; Erickson and Sawyer 1996; Georgi and Krause 2010; Cabral et al. 2011; Rothschild et al. 2012; Botfalvai et al. 2014).

Mourasuchus Price 1964 is an alligatoroid crocodylian genus belonging to the Caimaninae clade distinguished by the presence of a long, wide, dorsoventrally flattened rostrum with long, slender mandibular rami (Price 1964; Langston 1965; Bocquentin-Villanueva 1984; Gasparini 1985; Bona et al. 2013; Cidade et al. 2017). Currently, this genus consists of the species *M. amazonensis* Price 1964, *M. atopus* (Langston 1965), *M. arendsi* Bocquentin-Villanueva 1984 and *M. pattersoni*.

The holotype of *Mourasuchus pattersoni*, whose skull is housed at the Museo de Ciéncias Naturales de Caracas (MCNC) under the catalogue number MCNC-PAL-110-72V, has a small bone overgrowth on the right palatine bone that is not part of the regular crocodylian anatomy (Figure 1). In this work, we describe and discuss the possible nature of this bone alteration.

Material and methods

The holotype of *Mourasuchus pattersoni* was collected in late Miocene deposits of the Urumaco Formation, Venezuela. The exact collection locality has been considered by the previous authors who studied the specimen (Langston 2008; Cidade et al. 2017) as belonging to the Upper Member of the Urumaco Formation, in a stratum known informally as '*capa de huesos*' ('layer of bones') or '*capa de tortugas*' ('layer of turtles'). However,

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this stratigraphic placement cannot be confirmed due to contradictory information present in the field notes of the 1972 expedition that collected the specimen (see Langston 2008, for details).

The holotype (MCNC-PAL-110-72V) consists of a nearly almost complete skull (Figure 1) and almost complete mandibular rami. Several portions of the skull were covered by plaster as part of a restoration, which included the implantation of artificial teeth also made of plaster (Cidade et al. 2017). Postcranial material belonging to the holotype (atlas, axis, two sacral vertebrae and the first caudal vertebra, along with tentatively identified seven cervical, six thoracic, three lumbar and 13 caudal vertebrae, five cervical ribs and an unknown number of sacral and caudal ribs along with fragments of thoracic ribs, both scapulae and coracoids, a right ilium and ischium and 15 osteoderms) had been described previously by Langston (2008), who did not identify the specimen as a new species but instead assigned it tentatively to *Mourasuchus arendsi*.

In order to interpret the bone overgrowth observed, we carried out a macroscopic examination of the *Mourasuchus pattersoni* holotype (MCNC-PAL-110-72V) essentially considering its appearance and location.

Description and diagnostic perspectives

The analyzed structure is a single small bony nodular protuberance located on the anterior portion of the right palatine bone, near its border with the right maxilla, visible in ventral view of the skull of the holotype of *Mourasuchus pattersoni*. The nodule measures 23.4 mm mediolaterally and 21.7 mm craniocaudally, with a maximum dorsoventral height of 21.1 mm (Figure 2). Unlike some other portions of the skull, the protuberance is not covered by plaster.

This single nodular protuberance located on the palate is compatible with three possible conditions: *torus palatinus* (TP), a common benign intraoral bone overgrowth whose identification depends heavily on its location (Czuszak et al. 1996); osteoma, a benign, slow-growing bone-forming tumor (Greenspan 1993); and hamartoma, an abnormal overgrowth of normal bone tissue (Eshed et al. 2002).

Torus palatinus is considered a benign nodular tumor-like mass. However, it represents a natural occurrence and not a true pathological condition (Seah 1995). In some cases, it can grow quite large and compromise the feeding of the affected individual. This is likely not the case of MCN-PAL-110-72V due to the small size of the protuberance relative to the size of the skull (Figures 1 and 2).

The etiology of *torus palatinus* is still controversial and considers several different factors including genetic predisposition (Gorsky et al. 1996), environmental conditions (Haugen 1992), masticatory hyperfunction (Kerdporn and Sirirungrojying 1999) and abnormal continued growth of the bone tissue (Topazian and Mullen 1977). However, associated environmental and genetic factors (which are yet unclear) have been considered the main processes responsible for origination of this benign change (Gorsky et al. 1996; Jainkittivong and Langais 2000).

Palatal exostose – multiple bony nodules located on the palate found less often that TP (Neville et al. 1995; Antoniades et al.

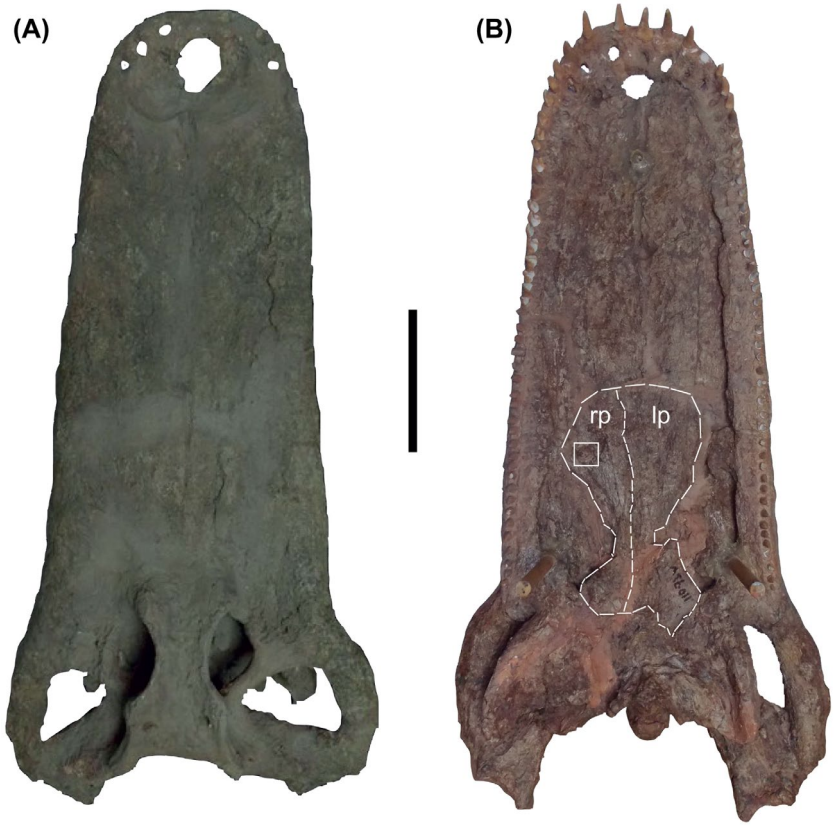

Figure 1. Skull of the holotype of *Mourasuchus pattersoni* (MCNC-PAL-110-72V) in dorsal (A) and ventral (B) views. In ventral view, the right (rp) and left (lp) palatine bones are highlighted, and a white square points to the location of the protuberance. Figure modified from Cidade et al. (2017), Figure 2.
Scale = 20 cm.

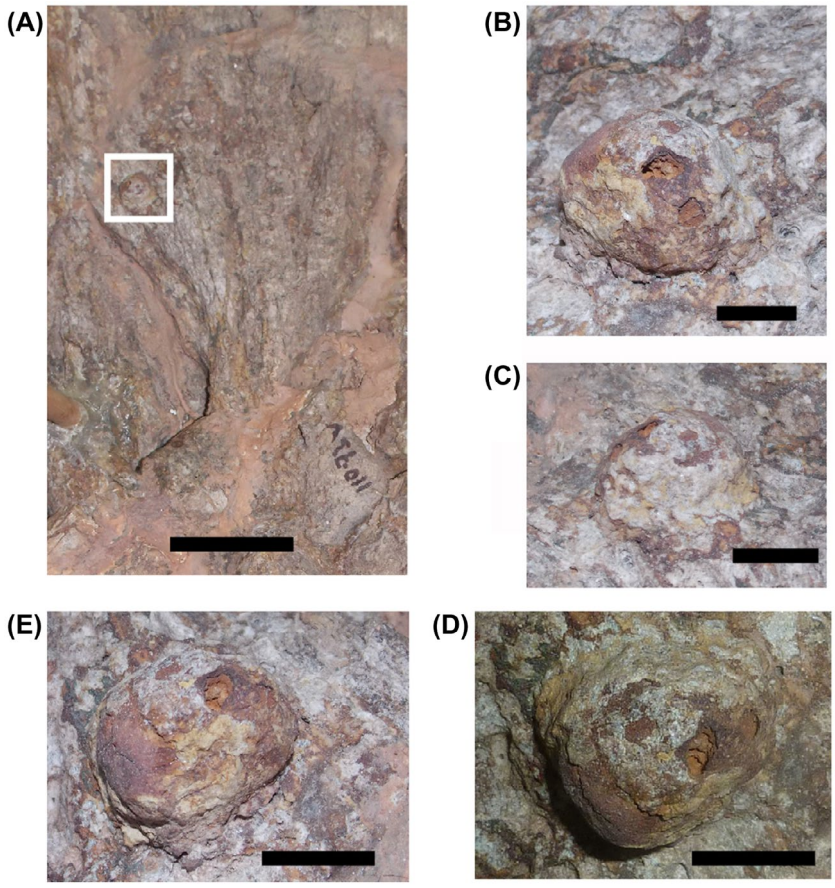

Figure 2. Details of the cranial nodular protuberance present on the right palatine of the holotype of *Mourasuchus pattersoni*: a view of the location of the protuberance in the palatines (A), and detailed pictures of the protuberance in anterolateral (B), posterior (C), dorsal (D) and anteromedial (E) views.
Scales = 10 cm (A) and 1 cm (B, C, D and E).

1998) – can be excluded as a possible diagnosis of the protuberance observed in MCN-PAL-110-72V because the specimen has only a single alteration.

Torus palatinus have been sporadically recognised by archeologists and paleoanthropologists in extinct hominids. There are documented cases for Pleistocene Neandertals (Hrdlička 1940; Sergi et al. 1972; Lebel and Trinkaus 2002) and *Homo heidelbergensis* Schoetensack 1908 (Hrdlička 1940; Sergi et al. 1972). Nevertheless, *torus palatinus* is unknown in the nonhominid vertebrate fossil record.

Another possible diagnosis is osteoma, a benign neoplasm characterized by a button-like shape (Greenspan 1993). Unlike TP, osteoma has been relatively well documented in both fossil and extant crocodylians. Osteomas have been described in an Eocene *Crocodylus* sp. specimen (Rothschild 2008), although the author does not provide information about its anatomical location, and in two phalanges of *Borealosuchus formidabilis* (Erickson 1976) from the Paleocene of the United States (Sawyer and Erickson 1998). However, this last case was questioned by Rothschild et al. (2012), who considered the possibility that those growths could actually be other kinds of exostoses. In extant crocodylians, osteomas have been identified between the last lumbar and the first caudal vertebrae in *Crocodylus porosus* Schneider 1801 by Rothschild et al. 2012, on a reevaluation of an original report by Kälin (1937) and in the ventral portion of the right angular of an *Alligator mississippiensis* (Daudin 1802) specimen deposited at the University of Kansas (KU 19538, photographed in Rothschild et al. 2012). Rothschild et al. (2012) also interpreted a pathological report by Kälin (1937) for *Caiman latirostris* (Daudin 1802) as an osteoma, but did not specify the anatomical location, and interpret pathological occurrences in the vertebrae of crocodylians reported by Kälin (1934) as osteomas, but did not specify the taxa that were affected.

Hamartoma is the third possible diagnosis. Unfortunately, it is visually indistinguishable from osteoma, being differentiated only by histological features (Eshed et al. 2001, 2002). Hamartoma is unknown for the vertebrate fossil record and for non-human extant animals (see Rothschild et al. 2012).

Discussion

The accurate diagnosis of the protuberance observed in the holotype of *Mourasuchus pattersoni* (MACN-PAL-110-72V) requires further analyses. However, it is important to remark that in the case of the protuberance being a *torus palatinus*, this would be the first instance of such phenomenon in the nonhominid vertebrate fossil record. On the other hand, if the nodular protuberance represents a hamartoma, this would be the first document occurrence in the fossil record. Finally, if this lesion represents an osteoma, this would be the first occurrence of an osteoma on the palatine bones to both extinct and extant crocodylians, with

osteomas having already been reported to phalanges, vertebrae and the angular, as detailed above.

Within the perspective that osteomas have not been recorded on the palatine bones of either fossil or extant crocodylians, an anatomical positional criterium alone would favor the diagnosis of *torus palatinus*. However, TP can be distinguished from osteomas and hamartomas only by histological analyses, and the same holds true for distinguishing between osteomas and hamartomas. Therefore, while the definitive diagnosis as to the nature of the protuberance requires further analyses, occurrence of such a formation in a fossil caimanine crocodylian still warrants discussion.

In comparison with the record of bone lesions in fossil crocodylomorphs, the pathological records of fossil alligatoroids, and particularly of caimanines, are scarce. Diseases have been reported in two species of the Late Cretaceous alligatoroid genus *Brachychampsa*: *B. montana* Gilmore 1911 has been reported as exhibiting a strong lateral compression of the 9th, 10th and 11th teeth with pathological causes (Carpenter and Lindsey 1980; Rothschild et al. 2012), whereas *Brachychampsa sealeyi* Williamson 1996 is reported as having pits associated with wounds in its mandible (Williamson 1996; Rothschild 2008). Wolff et al. (2007) described a possible case of necrotizing dermatites in *Diplocynodon hantoniensis* (Wood 1846) from the Oligocene of the United Kingdom. Finally, Neill (1971) reported a healed lateral snout injury in *Alligator mcgrewi* Schmidt 1941 from the Miocene of the United States.

For Caimaninae, the only pathological report in a fossil specimen was carried out by Patterson (1936), who suggested that the symphyseal area of a fragmented right dentary of *Purussaurus* (AMNH-3855, part of the holotype of *Brachygnatusuchus braziliensis* Mook 1921) could be pathologically deformed. His interpretation was accepted by Langston (1965), but a proper analysis of the specimen has not been performed. Ferigolo (1993) reported a case of osteomyelitis in a femur assigned to be from a 'crocodylian' from the Neogene of the Acre state of Brazil. The author, however, did not illustrate the specimen nor give a lower taxonomic assignment or disclose a catalogue number. In any case, femora are not very diagnostic for lower taxonomic levels within Crocodylia. The only systematically important feature of the bone (the presence of one or two heads in the *M. caudofemoralis* and the respective scars that result from the insertion of the heads in the femur) allows only a distinction between the clades Gavialoidea and Brevirostres (the latter of which includes Caimaninae) (see Brochu 2011). However, no known crocodylian fossil taxa preserve *M. caudofemoralis* and the insertion scars themselves are very difficult to detect in fossils (Brochu 1997). The fact that the specimen is from the 'Neogene of the Acre state' suggests it is likely from the Solimões Formation, a late Miocene unit with a diverse crocodyliform fossil record, especially of Caimaninae (see Riff et al. 2010; Souza et al. 2016). However, as this femur could not be reassessed, this pathological record is considered to be from a 'Crocodyliformes indet' specimen. Thus, this paper can be considered a pioneer record of a pathological condition in fossil Caimaninae, with further description of occurrences being needed for a deeper understating of the bone lesions that affected this group throughout its evolutive history.

Conclusions

This contribution describes a small bony nodular protuberance on the right palatine bone of the holotype of *Mourasuchus pattersoni*, a fossil caimanine crocodylian from the late Miocene of Venezuela. The protuberance is spherical and is located in the anterior portion of the bone. Due to its small size, it is unlikely that it would cause any difficulty to the feeding habits of the animal. Three different diagnostic perspectives are proposed for the protuberance: *torus palatinus*, osteoma or hamartoma. Further analyses, particularly a histological one, are required to establish a definitive diagnosis. Nevertheless, this feature may still be considered as one of the first records of a pathological alteration in a fossil caimanine crocodylian, which indicates the necessity of new studies of these phenomena in the Caimaninae clade to achieve a better understanding of the paleopathology, paleophysiology and paleoecology of this group in the environments that it inhabited.

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Disclosure statement

The authors declare to have no conflicts of interest in the publication of paper.

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