An unusual dental pathology in a tooth of *Spinosaurus* (Dinosauria, Theropoda) from the mid-Cretaceous of Morocco

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ABSTRACT

A single tooth identified as cf. *Spinosaurus* sp. from the Ifezouane Formation of the Kem Kem Group of eastern Morocco is noteworthy for a series of extensive palaeopathologies. These include an enhanced lingual curvature to the crown and the development of three deep grooves extending from at least the crown root junction to the apex of the crown. An attenuated carina is present but this does not extend to the crown tip, and neither does it start at the crown base. A wear facet is also present at the tip. This is the first report of external dental pathologies in the tooth of a spinosaurine spinosaurid.

Key words: Dental palaeopathology; Dinosauria; Theropoda; Cretaceous; Morocco; Kem Kem Group

1. Introduction

Pathologies in theropod dinosaur bones occur frequently in the fossil record (e.g., Gross et al., 1993; Laws, 1995; Molnar, 2001; Tanke and Rothschild, 2002; Rothschild and Tanke, 2005) but they are reported only rarely for their teeth (Farlow et al., 1991; Erickson, 1995; Candeiro and Tanke 2008; Xing et al., 2013). The mid-Cretaceous Kem Kem Group of eastern Morocco is well known for an abundance of dinosaur teeth, especially those of the theropod *Spinosaurus* (Amiot et al., 2004; Läng et al., 2013; Richter et al., 2013; Ibrahim et al., 2020a). Until now there have been no reports of dental pathologies despite the incredible abundance of teeth. Here we report on an unusual suite of pathologies on a tooth that can be referred to cf. *Spinosaurus* sp. We believe it is the first occurrence of a dental palaeopathology for a spinosaurine spinosaurid dinosaur.

The North African theropod dinosaur *Spinosaurus* has attracted considerable attention in the last decade, in part because of its highly enigmatic nature. Even when first discovered by Ernst von Stromer in 1912 it was regarded as highly distinct from other theropods, not least in part due to its massive dorsal sail composed of highly elongate neural spines (Stromer, 1915). It was also noteworthy for having an elongate skull and teeth that were more crocodilian-like than theropod-like. The first specimen was discovered in the Bahariya Formation (mid-Cretaceous) of Egypt (Nothdurft and Smith, 2002), but its teeth were discovered more widely occurring in Algeria (Benyoucef et al., 2015), and Morocco where teeth and isolated skeletal elements are reported (Dal Sasso et al., 2005; Hendrickx et al., 2016; Ibrahim et al. 2020a; Arden et al., 2019). More recently in Morocco articulated remains have been recovered that have revealed important insights into the ecology and biomechanics of this bizarre and gigantic dinosaur (Ibrahim et al., 2014; 2020b).

Isolated teeth of *Spinosaurus* occur commonly at some horizons in the Ifezouane Formation of the Kem Kem Group, and are frequently quarried and mined by local fossils diggers (e.g., Läng et al., 2013; Ibrahim et al., 2020a). Indeed, at one locality, Tarda, the teeth of *Spinosaurus* and rostral 'teeth' of the sclerorhnchoid *Onchopristis* form a bone bed (Beevor et al., 2021). This abundance of dinosaur teeth has attracted considerable attention, with several papers describing aspects of their occurrence (e.g., Läng et al., 2013; Beevor et al., 2021), preservation and morphology (Hasegawa et al., 2010; Richter et al., 2013;

Smyth et al., 2020), their histology (Buffetaut et al., 1986; Heckeberg and Rauhut, 2020) and their isotopic composition (Amiot et al., 2010). Despite the incredible abundance of teeth, this is the first reported occurrence of a dental palaeopathology in a spinosaurine spinosaurid. The only previous dental pathology reported for a spinosaur is a split carina in a baryonychine from the Castrillo de la Reina Formation of Spain (Alonso et al., 2017, fig. 5) and a microscopic interruption in the lining of the pulp cavity of a *Spinosaurus* sp. tooth also from Morocco (Heckeberg and Rauhut, 2020 fig. 4c) that was considered as a possible pathology.

2. Material, methods and context

The tooth described here is accessioned to the collection of University King Hassan II, Ain chock, Casablanca, Morocco (prefixed FSAC-KK 7326). Photographs were taken using a Nikon D5600 DSLR camera and images processed using CombineZP and CorelDRAW Graphic Suite X8 software. The specimen was topographically scanned using a Einscan Pro+ scanner and scans processed using Geomagic Design X software. Measurements were obtained using digital callipers following Smith et al. (2005) and Hendrickx et al. (2015). The tooth was part of a mixed assemblage of teeth obtained from a commercial fossil collector in Erfoud, a Saharan town at the centre of the Moroccan fossil trade. Matrix adhering to the tip of the crown and to the base is consistent with a source from the Ifezouane Formation of the Kem Kem Group (?Albian to early Cenomanian) that crops out and is extensively collected in the region (e.g., Ibrahim et al., 2020a). The white dentine interior and golden-brown enamel exterior are consistent with northern localities such as Zrigat, Douira, Tarda and Ikhf N' Taqmout (see Ibrahim et al., 2020a,b; Martill et al., 2020; for locality details). Our Kem Kem Group spinosaur taxonomy follows Ibrahim et al. (2014) and Smyth et al. (2020). Tooth terminology follows Hendrickx et al. (2015) and orientations follow Smith and Dodson (2003).

3. Results

3.1 Systematic palaeontology

DINOSAURIA Owen, 1842

THEROPODA Marsh, 1881

MEGALOSAUROIDEA (Fitzinger, 1843) (= SPINOSAUROIDEA Stromer, 1915)

SPINOSAURIDAE Stromer, 1915

SPINOSAURINAE Sereno, et al., 1998

cf. *SPINOSAURUS* Stromer, 1915

cf. *Spinosaurus* sp.

Note: Following Ibrahim et al. (2014) and Smyth et al. (2020) we consider there to be only one spinosaurine taxon in the Kem Kem Group dinosaur assemblage.

Material: FSAC-KK 7326, isolated tooth crown and partial root.

Locality and strata: Tafilalt region, Morocco. Ifezouane Formation, Kem Kem Group, mid-Cretaceous (?Albian-Cenomanian).

3.2. Identification

The isolated tooth FSAC-KK 7326 is identified as cf. *Spinosaurus* sp. on account of the following shared morphology: crown conidont, flanks of crown fluted, mesial and distal carinae lacking denticles, enamel surface with fine anastomosing ridges (e.g., Hasegawa et al., 2010; Hendrickx et al., 2019, fig. 15[4]). In addition, the overall appearance, apart for the pathologies resembles *Spinosaurus* rather than any other tooth type from the Kem Kem Group strata. There is a very superficial resemblance to the premaxillary teeth of ornithocheirid pterosaurs such as *Coloborhynchus* and *Anhanguera*, both reported for the Kem Kem Group (Jacobs et al., 2020), but the strongly crenulate ornamentation basally of these pterosaurs is absent from the new tooth. Similarly, there is a superficial resemblance to some crocodyliform teeth, such as the mesial ‘fangs’ of *Hamadasuchus* and *Laganosuchus* (see Ibrahim et al., 2020a), however both are

quite smooth and lack the flutes typical of *Spinosaurus* teeth. The carinae on *Hamadasuchus* teeth are also serrated (Larsson and Sidor, 1999, fig. 1A) unlike the unserrated carinae of *Spinosaurus* teeth.

3.2 Description

Single crown with incomplete root and a near circular cross-section, except for three indentations where the cross-section intersects longitudinal grooves extending from the broken base (approximating to the root/crown junction) to the crown tip. The tooth is 54 mm high (crown plus root) with a crown height of 35 mm and an apical length of 37 mm. The specimen has a crown base length of 12.5 mm, a crown base width of 14.5 mm and a crown base ratio of 1.2 (Table 1, Fig. 1E-F). A small wear facet (11 mm long) is present labially on the crown apex. The outer surface of the root is smooth, but the enamel crown has a veined or anastomosed enamel surface texture with a number of faint vertical ridges and faceted reflecting ridges (flutes *sensu* Hendrickx et al., 2019), typical of spinosaurid dentitions (e.g., Martill et al., 1996; Charig and Milner, 1997; Hendrickx et al., 2019). The boundary between enamel and the outer dentine surface of the root is irregular (cervical line *sensu* Hendrickx et al., 2015) (Fig. 1B,C).

The following features are considered pathologies: three longitudinal grooves extending from the crown tip to the base of the specimen (i.e., passing across the crown/root junction). A single groove is present on the midline of the labial surface (Fig. 1C,C') while two grooves are more closely spaced on the lingual surface (Fig. 1D,D'). A faint carina is seen on the mesial face that extends neither to the tip of the crown or as far as the crown/root junction. There is no ?distal carina. There is also an enhanced lingual curvature to the crown. The specimen is three-dimensionally preserved, uncrushed, excluding some minor crack of the enamel, and one crack that follows the line of longitudinal groove three (lg3 on Fig 1C), and unabraded. Consequently, none of the features described here are regarded as taphonomic artifacts.

3.3. Comparisons

The overall morphology of the tooth as imparted by the pathologies renders it highly distinct and unlike any other tooth, normal or pathological seen in the Dinosauria. Grooves as pathologies have not previously been reported for Theropoda, but grooves on tooth crowns have been described for other archosauriforms including Dinosauria (Hendrickx et al., 2019, fig. 9), but these differ significantly from the grooves descried here.

Hendrickx et al., (2019, fig. 6) reports longitudinal grooves of non-pathological origin in the teeth of Metriacanthosauridae, Tyrannosauridae (e.g. *Alioramus altai*), Abelisauridae, Allosauridae and Paraves and faint longitudinal grooves in the alvarezsauroid *Mononykus*. These grooves are all weakly developed and do not show the deep morphology seen in FSAC-KK 7326.

There is a superficial resemblance to the grooves on the labial and lingual surfaces of the crowns of *Uatchitodon kroehleri* Sues, 1991, a likely venomous archosauriform from the Triassic Turkey Branch Formation of Virginia, USA (Sues, 1991).

4. Discussion

Dental pathologies in theropods (see Table 2), although rare include split or diverging carinae (Bohlin, 1953; Erickson, 1995; Maisch and Matzke, 2003; Lanser and Heimhofer, 2013; Hendrickx et al., 2019), double cusped crowns (Anon, 1991); crowns with multiple rows of supernumerary serrations/denticles (Abler, 1997) and grotesque distortions of root and crown (Brochu, 2003 fig. 11C,D). By far the most frequently reported of these dental pathologies are diverging carinae where they occur frequently in tyrannosauroids (Erickson, 1995, Lanser and Heimhofer, 2013; Hendrickx et al., 2019) including *Tyrannosaurus rex* (Smith, 2005). In this pathology a single serrated mesial carina diverges basally. This reported pathology occurs in up to 29% of collected tyrannosaurid teeth in some Cretaceous formations (Erickson 1995). Note that split or diverging carinae in the therizinosaur *Segnosaurus galbinensis*, although resembling the pathological condition seen in other theropod taxa, might be the norm for this taxon, as they are present uniformly in the tooth row (Zanno et al., 2016). However, Hendrickx et al. (2019) considers the sporadic variation of

denticle size, bilobate denticles and extracarinal denticles exhibited by *Segnosaurus galbinensis* teeth to be the result of trauma.

Enhanced lingual curvature of the crown of an indeterminate theropod was considered by Wings et al. (2007, fig. 1., A1, A2; 2015) to be pathological and Kellner (1996, fig 9A,B) similarly considered a sigmoidal curvature of the carina of an indeterminate theropod as a possible pathology. Teeth of the enigmatic *Paronychodon*, Cope, 1876 a theropod taxon known only from its dentition, frequently display anomalies in crown morphology that have been regarded as pathologies (Baszio, 1997; Sankey et al., 2002; Hwang, 2005; Williamson and Brusatte, 2014), but has also been considered a tooth morphotype of *Richarchoestesia* (Longrich, 2008).

The occurrence of deep grooves on the crown of theropod teeth has not, to the best of our knowledge, been reported previously. A basal, shallow groove is seen on the labial surface of an indeterminate bird tooth from the Late Cretaceous Judith River Group of Alberta, Canada (Sankey et al., 2002, fig. 5, #37). This tooth groove (specimen RTMP 87.4.19) does not extend the full height of the crown, but has a superficial resemblance to the grooves seen in FSAC-KK 7326, however the authors do not state if they consider it a palaeopathology.

The seemingly regular nature of the extended grooves and their distribution on the crown of FSAC-KK 7326 gives the appearance of a natural feature (Fig. 1), akin perhaps to the plicidentine venom delivery canals of some snakes and lizards (e.g., Fry et al., 2009; Palci et al., 2021). However, any pathological disruptions in the development of a complete circle of enamel around a tooth would result in the formation of a groove as the new tooth developed if the pathology, perhaps an infection, persisted. Thus, this similarity is likely to be circumstantial, as the teeth of *Spinosaurus* have been collected in immense quantities from the Moroccan Kem Kem Group, and no such specimen with tooth grooves has been noted previously.

5. Conclusions

A series of grooves extending the length of the crown and part way into the root of a tooth attributable to the theropod dinosaur cf. *Spinosaurus* are regarded as palaeopathologies. The presence of three deeply incised grooves appears to be a pathology not previously described for any dinosaur. We speculate that the tooth persisted for some time in the jaw due to the presence of a small terminal wear facet.

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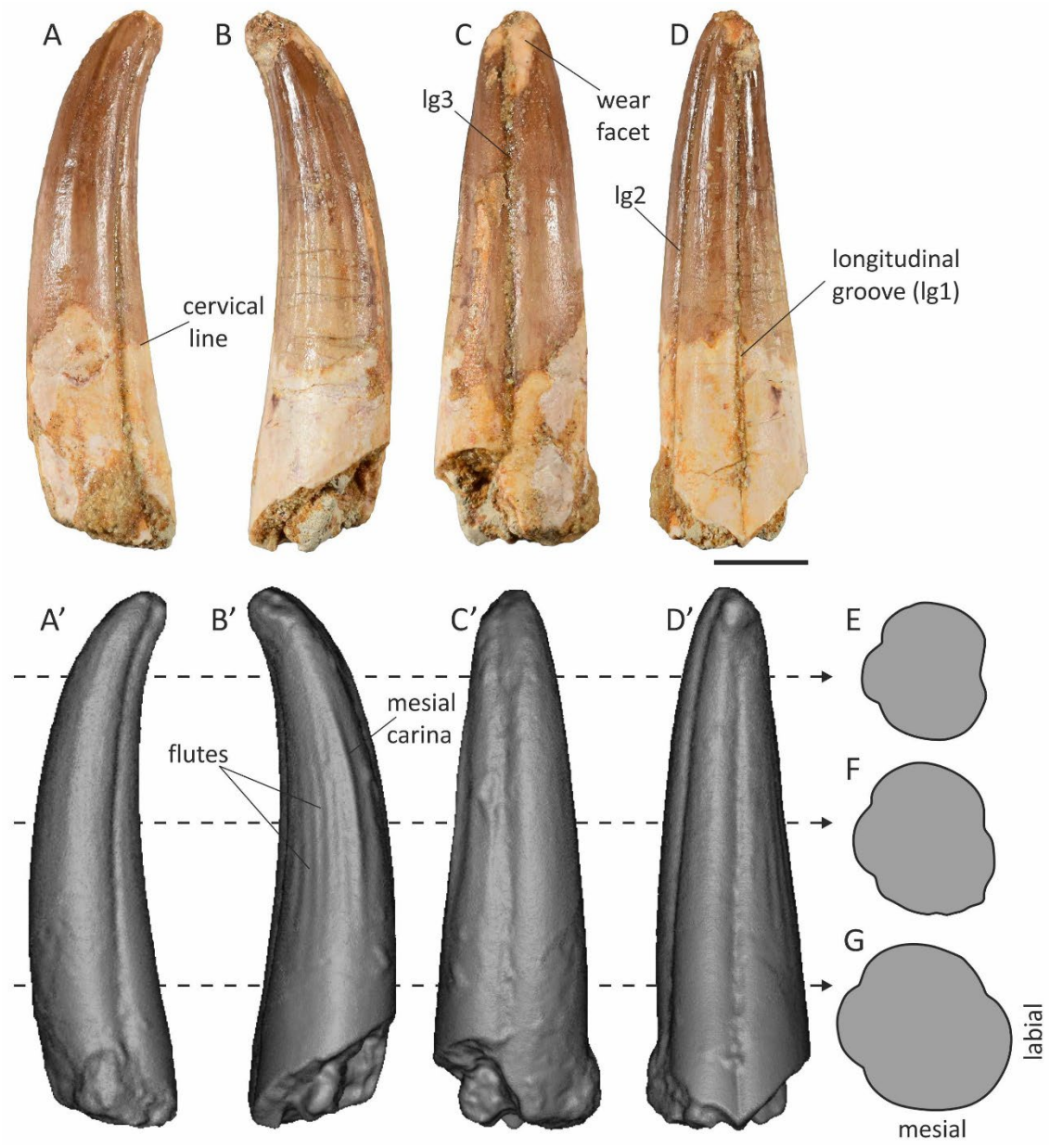
345 **Figures and tables**



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347 **Fig. 1.** Pathologically deformed tooth crown referred to the aquatic theropod dinosaur *Spinosaurus* sp.,
348 specimen number FSAC-KK 7326. For convenience it is assumed that the tooth is from the left dentary. A,
349 distal; B, mesial; C, labial; and D, lingual views. A'-D' 3D scanned images of the same as A-D better showing
350 surface textures and relief. E, F, G cross-section shapes at points indicated. Scale bar = 10 mm. Cross-
351 sections not to scale.

352 **Table 1.** A selection of measurements of pathological tooth of *Spinosaurus* sp. (FSAC-KK 7326) from the

353 Kem Kem Group of Morocco. Measurements follow Smith et al. (2005) and Hendrickx et al. (2015).

Parameter	**Measurement**
Crown height	35 mm
Apical length	37 mm
Crown base length	12.5 mm
Crown base width	14.5 mm
Crown base ratio	1.2
Maximum height (crown + root)	54 mm

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356 **Table 2.** Records of dental pathologies in Theropoda.

Pathology	**Taxon**	**Age**	**Place/Notes**	**Reference**
Enhanced crown curvature	cf. *Sinraptor*	Late Jurassic	China	Wings et al., 2007, 2015
Distorted crown	*Tyrannosaurus rex*	Late Cretaceous	USA	Brochu, 2003
Multiple crowns	*Tyrannosaurus rex*	Late Cretaceous	USA, not figured	Anon, 1991
Sigmoidal carinae	Theropoda indet.	Late Cretaceous	Brazil	Kellner, 1996
Split/diverging carinae	Theropoda indet.	Late Cretaceous	Mongolia	Bohlin, 1953
	Theropoda indet.	Late Cretaceous	Brazil	Kellner, 1996
	Tyrannosaurus rex, *Daspletosaurus* sp., *Albertosaurus* sp. *Alectrosaurus olsoni*	Late Cretaceous	USA	Erickson, 1995
	Tyrannosauroidea indet.	Early Cretaceous	Germany	Lanser and Heimhofer, 2013
	Tyrannosaurus rex	Late Cretaceous	USA: cites in jaw occurrences (not figured)	Smith, 2005
	Dromaeosaurus albertensis	Late Cretaceous	Canada	Fiorillo and Ganloff, 2000
	Segnosaurus albinensis	Late Cretaceous	Mongolia	Zanno et al., 2016

Pathology	Taxon	Age	Place/Notes	Reference
	Dromaeosaurinae indet.	Early Cretaceous	Spain	Rauhut, 2002
	Carcharodontosauridae indet.	Late Cretaceous	Brazil	Candeiro and Tanke, 2008
	Carcharodontosauridae indet.	Early Cretaceous	Niger	Sereno and Brusatte, 2008
	Baryonychinae indet.	Early Cretaceous	Spain	Alonso et al., 2017
	Allosaurus fragilis	Late Jurassic	USA	Erickson, 1995
	?Dromaeosauridae indet.	Middle-Late Jurassic	China	Han et al., 2011
	Small Theropoda indet.	Mid Jurassic	China	Maisch and Matzke, 2003
Multiple carinae	Tyrannosauridae indet.	Late Cretaceous	Canada	Abler, 1997
	Segnosaurus albinensis	Late Cretaceous	Mongolia: may not be pathological	Zanno et al., 2016 Hendrickx et al., 2019
Denticles abnormalities: bilobate denticles, extra-carinal denticles, sporadic variation in denticle size	*Segnosaurus albinensis*	Late Cretaceous	Mongolia	Zanno et al., 2016 Hendrickx et al., 2019
Longitudinal grooves	cf. *Spinosaurus* sp.	Mid Cretaceous	Morocco	This paper
	Indeterminate avian	Late Cretaceous	Canada: may not be pathological	Sankey et al. 2002
Ridges and flat crown sides	*Paronychodon*	Late Cretaceous	USA	Cope 1876; Currie et al., 1990; Baszio, 1997; Sankey et al., 2002; Hwang, 2005; Williamson and Brusatte, 2014

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