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# FINITE ELEMENT ANALYSIS TO COMPARE THE ECOLOGY OF THE LATE JURASSIC THEROPODS *CERATOSAURUS* AND *ALLOSAURUS*. PART II: SKULLS AND FEEDING

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ABSTRACT

*Ceratosaurus* and *Allosaurus* are Late Jurassic sympatric theropods from Portugal and the USA. The presence of similar size carnivorous dinosaurs in the same ecosystem raises questions about resources partitioning. Feeding partitioning have been previously hypothesized but never systematically tested. Using Finite Element Analysis (FEA) we compared the mechanical capabilities of *Ceratosaurus* and *Allosaurus* skulls projected in 2D. Both theropods present very similar results. However, *Ceratosaurus* present greater overall stress patterns. More studies are required to test these preliminary results and to have a better understanding of the feeding strategies of these theropods.

*Keywords:* Theropoda, Feeding, FEA, Skull, Late Jurassic.

## 1. INTRODUCTION

The Late Jurassic ecosystems of the Lusitanian Basin (Portugal) and the Morrison Formation (USA) are characterized by a wide diversity of taxa in high trophic levels with the theropod dinosaurs *Ceratosaurus*, *Torvosaurus* and *Allosaurus* occurring together (Mateus, 2006). Ecosystems are limited in resources and such diversity raises questions about theropod ecology and partitioning in these ecosystems. Organisms are in competition for re-

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sources, and different partitioning processes have been observed in extant ecosystems, allowing to explain the presence of animals with similar ecology in the same ecosystem. For the Morrison Formation, separation of habitats and/or biogeographic provinces segregation has been suggested (Bakker, 1996; Farlow & Planka, 2002) as well as exploitation competition (*sensu* Park, 1962) and niche partitioning (Henderson, 1998). The exploitation competition and niche partitioning has been suggested by the study of *Allosaurus* and *Ceratosaurus* skull and tooth morphology (Henderson, 1998). However, Henderson's study has been later refuted as an improperly mounted specimen was used and the cranial morphology of *Allosaurus* and *Ceratosaurus* differs little compared to that of coexisting mammalian carnivores of very similar body size (Farlow and Planka, 2002). The significantly larger teeth of *Ceratosaurus* have been interpreted as indicative of a more specialized diet than those of *Allosaurus* which has been understood as a more generalist predator (Foster, 2003). However, this hypothesis has never been tested. Furthermore, comparative studies such as reconstructed neck muscles tend to find similar patterns between *Allosaurus* and *Ceratosaurus* (Snively & Russell, 2007). Nowadays, Finite Element Analysis (FEA) is widely used in paleontology to investigate feeding mechanisms and even niche partitioning. This tool is popular to study structural problems by modeling the mechanical properties of bones. FEA has been used on several analysis of theropods as well as in the sauropods, for example to test feeding mechanisms and niche partitioning in between sympatric species in the Morrison Formation (Button *et al.*, 2014).

## 2. OBJECTIVES

The objective of this study was to determine if *Ceratosaurus* and *Allosaurus* had different structural capabilities, through the use of FEA on plane models (2D), that could represent a niche partitioning between these sympatric theropod dinosaurs.

## 3. METHODOLOGY

Pictures of casts of reconstructed skulls of *Ceratosaurus* and *Allosaurus* housed in the Museu Nacional de História Natural e da Ciência (MUHNAC) were taken in lateral view. These pictures were imported in ANSYS to create scaled plane models by scratch. Following Fawcett *et al.* (2023), we applied the average material properties of *Alligator* mandibular cortical bone ($E = 15.00$ GPa, $\upsilon = 0.29$) and a bite force of 3500 N to *Allosaurus*. The force was scaled for *Ceratosaurus*, following the methodology described by Marcé-Nogué *et al.* (2013), using the surface and the thickness of the plane models. The nasal horn of *Ceratosaurus* increases the surface of the skull in lateral view and so, to test the impact of the horn on the 2D model, a hornless-model has also been created and analyzed. Both extrinsic and intrinsic bite scenarios were tested, the first with constraints placed on the quadrate condyle and the occipital region and the forces equally applied vertically on the three first mesial most maxillary teeth, and the latter with constraints placed on the three first mesial most maxillary teeth and the force applied vertically on the postorbital (Fig. 1).

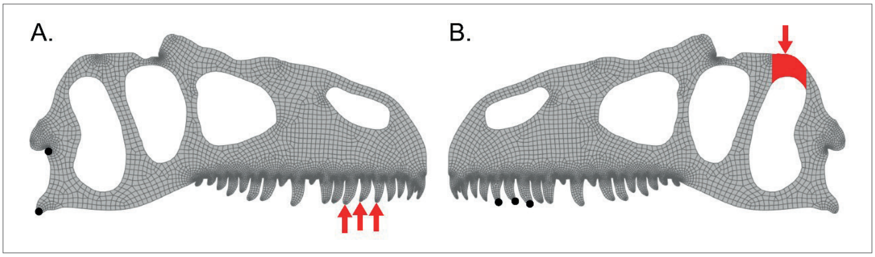


Figure 1: Free body diagram of intrinsic (A) and extrinsic (B) bite scenario on *Allosaurus* skull. Red: forces; black dots: constraints.

## 4. RESULTS AND DISCUSSION

The results of the FEA show some close results between *Ceratosaurus* and *Allosaurus* for both the extrinsic and intrinsic scenarios (Fig. 2). The regions presenting high von Mises stress, corresponding to the warm colors, exhibit either tensile or compressive stress.

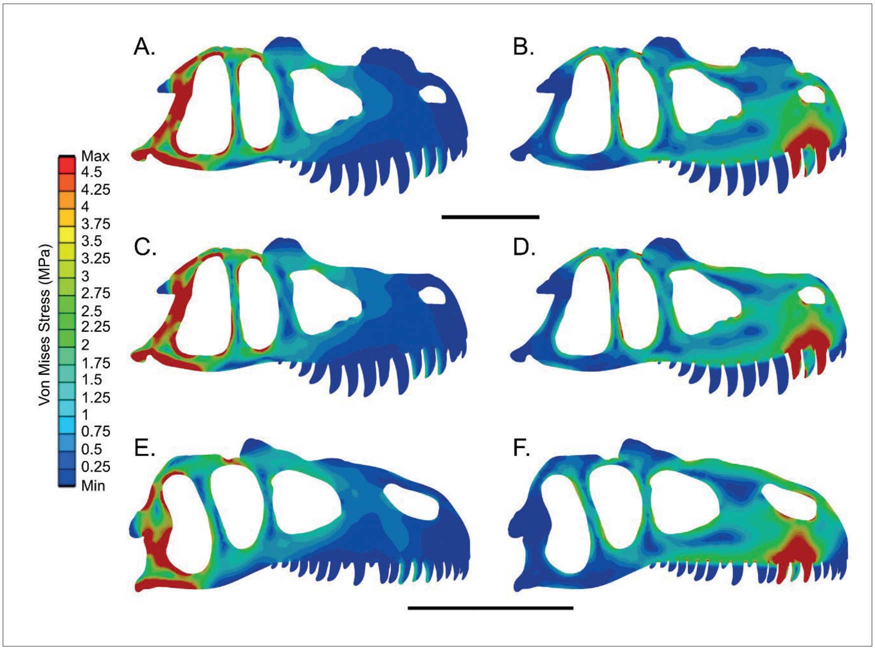


Figure 2: Von Mises stress in the 2D FE models of the skulls of *Ceratosaurus* (A-D) with (A-B) and without horn (C-D) and *Allosaurus* (E-F) in intrinsic (A; C; E) and extrinsic (B; D; F) scenario. scale bar:10cm.

Since the forces have been scaled to the surface of the model, the stress pattern differences are only dependent of the skull shape. The results for the extrinsic scenario are close to the overall results previously found for Megalosauroidea and Carcharodontosauridae (Rayfield, 2011) with high stress values in the posterior skull roof, the squamosal, the quadrate, the squamosal as well as the jugal and the quadratojugal (Fig. 2). However, it is interesting to notice that *Ceratosaurus* displays some high stress values on the anterior part of the lateral fenestra and around the posterior and ventral margins of the orbit whereas this is not the case in *Allosaurus*. The intrinsic scenario for both models displays stress from the postorbital and jugal to the premaxilla with the highest values occurring on the maxilla and, in *Ceratosaurus*, the highest values are on the ventral ramus of the postorbital and the postorbital process of the jugal. The horn-less *Ceratosaurus* mesh displays greater stress patterns on the nasal. The difference noticed here is not significant enough to infer any feeding partitioning.

## 5. CONCLUSION

The analysis performed in this study, applying FEA on plane models of skulls of *Ceratosaurus* and *Allosaurus*, displays very similar results for these two taxa. *Ceratosaurus* displays slightly greater stress patterns in both extrinsic and intrinsic models. However, this difference is not significant enough to infer any feeding partitioning and further studies, some of them in process, such as FEA on solid models (3D) could allow to characterize these differences and correlate them with possible diverse feeding mechanics in these two sympatric theropod taxa.

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