MR imaging of crocodilians can help for brain volume estimation of some extinct vertebrates

Daniel Jirak[1], Jiri Janacek[2], and Martin Kundrat[2,3]

[1]*IKEM, Prague, Czech Republic,* [2]*Institute of Physiology, Academy of Sciences of the Czech Republic, Prague, Czech Republic,* [3]*Evolutionary Biology Centre, Uppsala University, Uppsala, Sweden*

Target Audience:

This information could be useful for scientists in the field of brain development and neuropaleontology.

Introduction

The brain is entirely composed of soft tissue and as such it rarely fossilizes. Brain proportions and morphology of some extinct vertebrates have usually been only inferred from the their endocasts[1]. Here we provide a new approach for assessment of encephalic volume of these animals. We use modern crocodilians to gauge how the endoneurocranial cavity and brain can change their configuration during ontogeny and how much the configuration differs in adults of two genera that are of different size classes.

Methods

Ex vivo magnetic resonance imaging (MRI) was performed using a clinical 3-T (larger specimens) or an experimental 4.7-T scanner (the smallest specimen). The used coils were selected according to the size of specimen and MR sequence was chosen and its parameters optimized to achieve high resolution as well as high contrast between the brain structures. Specimens were fixed in the formalin. For volume analysis based on manual segmentation, the following MR sequences were selected with the optimized parameters:

Crocodylus niloticus and *Caiman crocodilus* - adult: 3D gradient echo sequence: Repetition time (TR) = 20ms, Echo time (TE) = 7ms, Flip angle = 25º, Resolution = 0.75x0.75x1mm^3;

Caiman crocodilus - late juvenile: 3D gradient echo sequence: TR = 20ms, TE = 8.9ms, Flip angle = 25º, Resolution = 0.3x0.3x0.3mm^3;

Caiman crocodilus – early juvenile: 3D turbo spin echo sequence: TR = 500ms, TE = 20ms, Resolution = 0.2x0.2x0.2mm^3.

We quantified the ratio of brain+interstitium and brain volume (BIBV) and the partial/total volume indices (PTV) by dividing the endocasts into four major sectors (olfactory (Olf), prosencephalic (Pros), mesencephalic (Mes) and metencephalic (Met)).

Results

In *Caiman crocodilus* (Fig. 1a-c), we found a significant elaboration of the overall configuration in both the endocast and brain when comparing an early juvenile, late juvenile, and adult suggesting that the endocast elongated and expanded interstitially, and the brain became more linearly organized during ontogeny. The more linear adult configuration is evident in the much larger species *Crocodylus niloticus* (Fig. 1d). The total volumes and results of BIBV and PTV calculation are summarized in Table 1 and 2.

Stadium / Volume	Early juvenile	Late juvenile	Adult	Large adult
Brain [mm^3]	1713	2365	5991	8958
Brain+interstitium [mm^3]	2006	4474	12278	29532
BIBV	1.17	1.89	2.05	3.30

Table 1: Total volume of the brain and brain + interstitium and its ratio (BIBV) of *Caiman crocodilus* and *Crocodylus niloticus* (large adult)

Sectors	Olf	Pros	Mes	Met
Caiman/early juvenile	0.05	0.56	0.13	0.25
Caiman/adult	0.17	0.37	0.16	0.30

Table 2: Calculated partial/total volume of the brain of early juvenile and adult *Caiman crocodilus*

Discussion

Although the more linear adult configuration is an ontogenetically related phenomenon, it provides the only available analogue that might explain similar evolutionary transformation of the endocast in extinct vertebrates. Moreover, it shows that in adults the linear-shaped endoneurocranium encases a similarly linearly-arranged brain enveloped by a thicker interstitium. While the volume of the brain in Caiman increased 3.5 fold, the endoneurocranial volume enlarged 6.1 fold. Thus the bigger (ontogenetically more mature) endoneurocranium becomes less informative with regards to the shape of the brain. Our results might support hypothesis that similar transformation of the evolutionary patterns of endocast occurred also in extinct vertebrates and explain why in evolutionary younger gigantic tyrannosaurs, the linear-type endocast is observed in comparison to small and much older tyrannosaurids[2]. Therefore the encephalic volume of large extinct vertebrates will be likely much smaller compared to their endocast. The first clue, how much smaller brain could be, might provide BIBV calculated in modern crocodilians.

Conclusions

We conclude that the endocast is elongated and expanded, and the brain became more linearly organized in larger and more mature modern crocodilians. Our result could make more precise phylogenetic interpretations of neuroanatomic characters of extinct vertebrates and could explain the development of the central nervous system during the evolution of gigantism in tyrannosaurs.

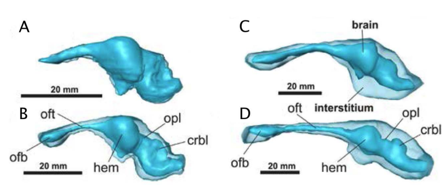

Figure 1: Brain and interstitium of juvenile (A – early, B- late) and adult Caiman (C) and adult Crocodile (D)

References

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