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BRAINTEASERS: EVOLUTION AND VARIATION IN CYNODONT ENDOCRANIAL ANATOMY

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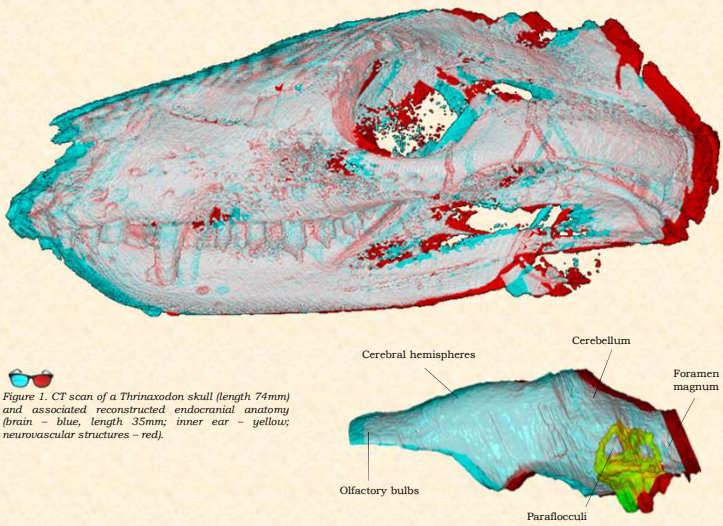

Figure 1. CT scan of a Thrinaxodon skull (length 74mm) and associated reconstructed endocranial anatomy (brain – blue, length 35mm; inner ear – yellow; neurovascular structures – red).

Using 3D reconstruction techniques to investigate intraspecific and ontogenetic variation within endocranial structures, quantifying relative cognition, sensory capabilities and anatomical evolution along the cynodont-mammal lineage.

ONCE UPON A TIME...

Fossils had to be destroyed to make a model of the brain, but thankfully virtual palaeontology has come to the rescue, utilising non-destructive modeling techniques to restore soft tissues lost to time. Such methods are of particular interest for the understudied Cynodontia, a group of therapsids that survived the end-Permian extinction event to radiate during the Triassic, with later Mammalian origination.

Cynodont brains are yet to be comprehensively studied for morphological evolution and as such, no known attempts have been made to identify intraspecific (between members of a species), ontogenetic (life cycle) and sexually dimorphic variation. With *Thrinaxodon liorhinus* exhibiting the most abundant cynodont fossil record, it thus facilitates study of brain, inner ear and neurovascular anatomy (figure 1) to identify these changes and permits further understanding of the evolution of sensory capabilities and subsequent behavioural patterns.

Moreover, the methodology provides opportunity to discover biases in digital reconstruction techniques resulting from the software used and the subjectivity of the model maker.

PAINTING THE PAST

High resolution CT scans of cynodont skulls facilitate 3D endocranial reconstruction within Avizo (and comparative software, including SPIERS, VG Studio and Mimics). Linear and volumetric analyses within Avizo and CloudCompare assess size and shape changes for individual parts of the brain and inner ear, with calculation of encephalisation quotients (a measure of relative cognitive ability) and best hearing frequencies possible for comparison with more recent cynodont genera and the modern *Monodelphis domestica* (figure 2).

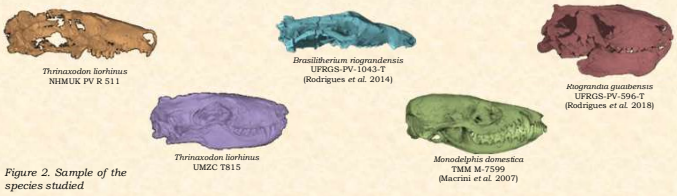

Figure 2. Sample of the species studied

PEERING INSIDE THE SKULL

New anatomical descriptions of the *Thrinaxodon* brain and inner ear highlight structurally similar endocranial anatomy across all cynodonts studied, with a foramen magnum, cerebellum, paraflocculi, cerebral hemispheres and olfactory bulbs (figure 1).

Cloud Compare analyses of the *Thrinaxodon* models (figure 3) shows millimeter scale size variations amongst the reconstructed elements, alongside slight shape changes in the olfactory region (figure 4). With the three *Thrinaxodon* specimens all being at various stages of adulthood, this indicates the potential for identifying intraspecific variation. However, the variation is not significant enough to make a definitive conclusion as to whether the changes result from subjectivity during the model making process or are natural variations. It is thus necessary to produce further models for this species for a plethora of skull sizes to assess the presence of ontogenetic variation.

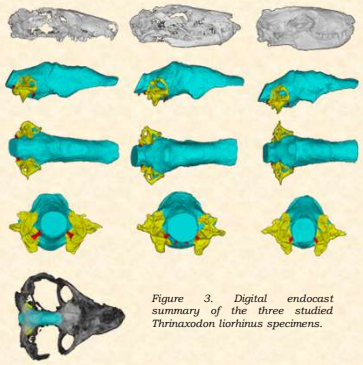

Figure 3. Digital endocast summary of the three studied Thrinaxodon liorhinus specimens.

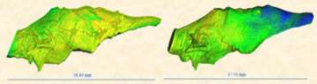

Figure 4. CloudCompare analyses reveal intraspecific differences in the olfactory bulbs (blue) for specimens UMZC T815 and NHM 511 respectively.

Calculated encephalisation quotients for *Thrinaxodon* vary between 0.15 and 0.2, consistent with other, more derived cynodonts (figure 5). However, a cognitive change accompanies the origination of Mammaliaformes, with EQ values between 0.5 and 1.09 for *Monodelphis*, suggesting a more primitive cognitive ability for *Thrinaxodon*, despite a similar body size.

Regarding inner ear anatomy, *Thrinaxodon* possessed larger semi-circular canals than later cynodonts (for example, *Brasilitherium*). With these canals being responsible for coordination and agility (by detecting angular accelerations and decelerations in the head), it may be that inner ear anatomy was a strong influence upon *Thrinaxodon* being able to hunt successfully.

Moreover, calculation of a best hearing frequency between 1.87 and 2.41 kHz for *Thrinaxodon* is considerably more restricted than in *Monodelphis domestica* (8 to 64 kHz; Frost and Masterton 1994). Consequently, *Thrinaxodon*'s poor auditory acuity may have been compensated for by larger olfactory bulbs than in later cynodont genera, thus supporting a burrowing life mode and nocturnal hunting style.

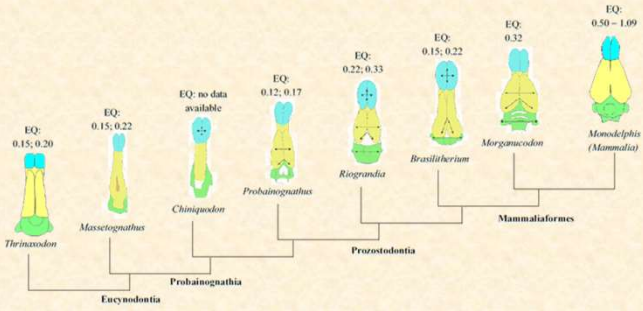

Figure 5. The evolutionary development of mammalian brain morphology, highlighting cognitive compartmentalisation from the late Permian onwards.

CONCLUSIONS

The lack of basicranial bones in the braincase and subjectivity during the modelling process pose some of the greatest challenges to studying cynodont endocranial anatomy. Yet analysing a larger dataset of skulls over a plethora of size ranges and temporal distributions will provide new insights into the evolution of the mammalian brain from its ancestral forebears.

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