Fossorial adaptations of the functional morphology and internal structure of the forelimb of the Early Triassic cynodont *Thrinaxodon liorhinus*.

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Introduction

The Early Triassic represents an age of deep transformation as it follows the Permian-Triassic mass extinction event (Sues and Fraser 2010). One of the few lineages that persisted were the cynodonts, a group that includes the ancestor of living mammals (Ruta *et al*. 2013). One of the main behavioural responses that aided in the survival of cynodonts (Damiani *et al*. 2003) by escaping the harsh climates that followed the extinction event was fossorialism.

Cynodonts first appeared in the Late Permian and were dominantly represented by *Thrinaxodon liorhinus* (Rubidge and Sidor 2001). Among the *Thrinaxodon* skeletons, several specimens were preserved in a curled-up position which inferred death in a burrow, while others were found in fossilised burrow casts (Fernandez *et al*. 2013). Combining the evidence, Damiani *et al*. (2003) formalized the idea that this taxon was a fossorial species. However, the findings of *Thrinaxodon* in a burrow only proves occupancy and not actual capability for digging the burrow itself.

Figure 1: *Thrinaxodon* fossils found in a burrow and in a curled-up position

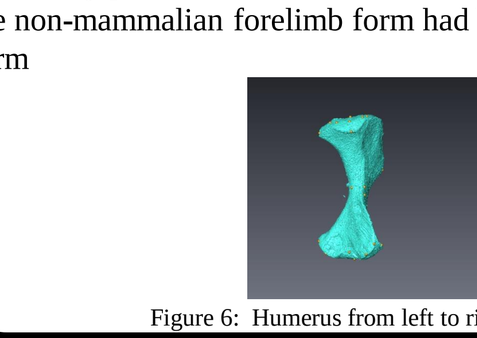
Problem, Hypothesis and Aims

Problem:

Research documenting posture and behaviour in the cynodont, *Thrinaxodon*, has not fully documented functional morphology of the forelimb as reflecting adaptation to fossorialism or response to the semi-sprawling posture, nor have geometric morphometric analyses been applied in addressing this issue.

Hypothesis:

The morphology of the forelimb of the mammal-like cynodont *Thrinaxodon* is adapted for burrowing. Alternatively, forelimb musculoskeletal structure may be more a consequence of semi-sprawled posture and gait..



Methods & Materials

Species:

- The burrowers - *Cistecephalus , Varanus niloticus, Vombatus ursinus* and *Lasiorhinus krefftii., Gerrhosaurus validus, Cordylus giganteus*
- The non-burrowers – *Cynognathus, Cordylus warreni, Platysaurus imperator, Pseudocordylus melanotus, Anolis equestris*
- The test - *Thrinaxodon liorhinus*.

Method:

- Forelimb bones were microCT-scanned
- Segmentation was performed and landmarks were placed on homologous structures using Avizo 7.1.1 and/or VG Studio Max 2.1 computer programs.
- Procrustes and Principal Component Analyses.

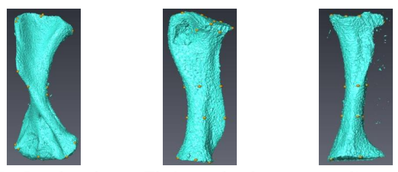


Figure 2: Landmarks on *Thrinaxodon* humerus, radius and ulna

Results

Geometric morphometric landmark-based analyses

Principal component analyses (PCAs) of landmark configurations were performed on the standardized forelimb. For the humeri, PC1 (52.0%), PC2 (21.4%) and PC 3 (8.7%) explain most of the variation in the sample where PC1 corresponds to shape and PC2 corresponds to width size (Figure 3). The correspondence of PC1 to shape and PC2 to size is evident in the warp factor when the slider is moved along respective PC axes and the wireframes/renderings are deformed accordingly. PC1 (37.9%) and PC2 (23.7%) explain the most variation in radial configurations while PC3 accounts for 13.1% (Figure 4). PC1 (48.4%), PC2 (23.5%) and PC 3 (9.3%) accounts for the variation in the ulnae (Figure 5).

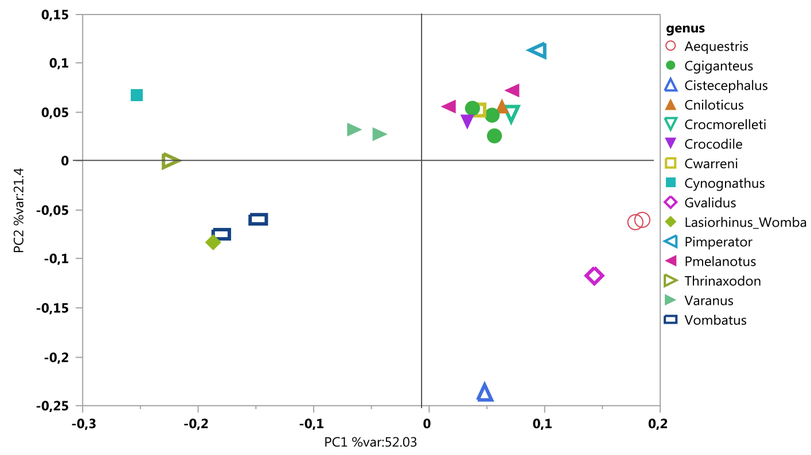


Figure 3: Plot of PC1 (x-axis) vs. PC2 (y-axis) for humeri

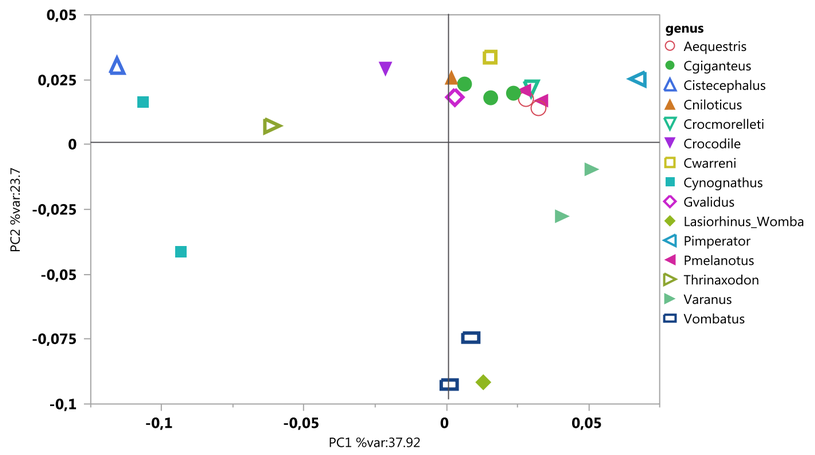


Figure 4: Plot of PC1 (x-axis) vs. PC2 (y-axis) for radii

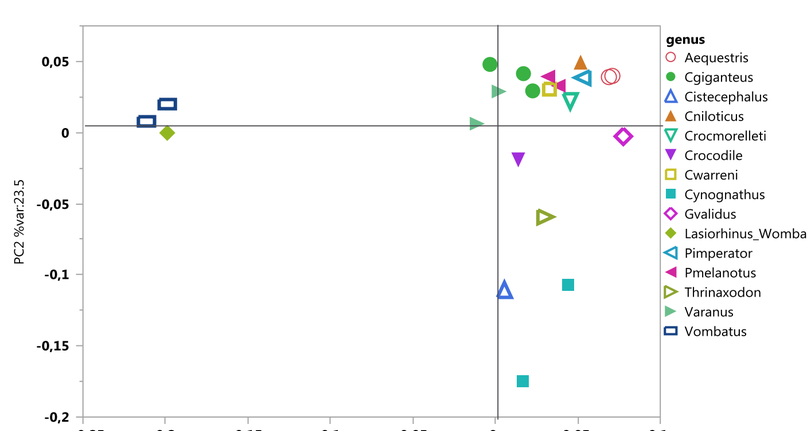


Figure 5: Plot of PC1 (x-axis) vs. PC2 (y-axis) for ulnae

Conclusions

The research commenced to investigate the extent of *Thrinaxodon* forelimb being similar to fossorial morphology or to the reptilian gait demonstrated that *Thrinaxodon* is closest to fossorial mammals. However, due to the semi-sprawled limb posture, *Thrinaxodon* does share minimal forelimb modifications with reptiles in order to keep its trunk (body) from dragging on the ground. *Thrinaxodon* musculoskeletal anatomy displays clear adaptations to a fossorial lifestyle and as being the transitional species from a reptilian phase to a parasagittal gait as seen in extant fossorial mammals. The goal of this study was to enhance insight into the functional morphology of *Thrinaxodon* forelimb through comparisons with species of different locomotor behaviour, which was investigated by analyses of the indices, the PCA, and the internal and external examination. This study provided direct evidence that the limb configuration of *Thrinaxodon* indicates the non-mammalian forelimb form had begun to show similarities within the mammalian form

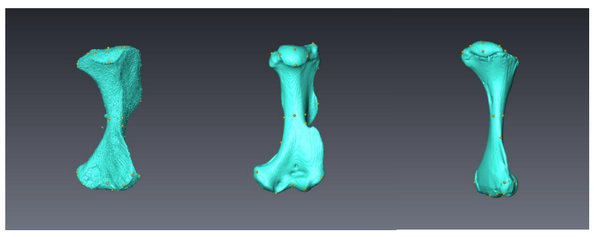


Figure 6: Humerus from left to right, *Thrinaxodon*, *Vombatus* and *Varanus*

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