Appendicular Joint Reconstruction in Sauropod Dinosaurs
Based on Computed Tomography of a Mammal, a Bird, and a Crocodilian
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ABSTRACT

Recently, in juvenile (Canus familiaris), adult and juvenile chicken (Gallus gallus), and a sub-adult and adult alligator (Alligator mississippiensis) were scanned at high resolution using computed tomography. Three-dimensional models of the in situ joint surfaces were rendered to examine the differences between the osseous portions of the appendicular joint surfaces. The relative distance between osseous joint surfaces was used to generate possible appendicular joint configurations for the North American Upper Jurassic sauropod, Diplodocus. Canus familiaris was used to show a “best case” scenario for joint articulation as the joints of mammals have limited articular cartilage over an ossified epiphysis. The adult chicken analysis yielded similar results to the mammalian articular, with limited space for cartilage between the closest joint surfaces allowing for a good approximation of the range of motion of the appendicular joints. Conversely, the crocodilian models and juvenile chicken resulted in a large space between the osseous joint surfaces and, therefore, greater uncertainty regarding the range of motion in the limbs. Both sub-adult and adult alligator specimens also showed a similar large space between osseous joint surfaces. The vast differences in appendicular joint reconstructions based on these extant taxa shows the importance of choosing the best extant analog when reconstructing fossil archosaurs appendicular joints.

RESULTS

Reconstructed elbow joints based on the dog and adult chicken forelimbs produced the tightest fit between the humerus and the antebachrum (Fig. 2 A, B, E and F). Reconstructed elbow joints based on the adult alligator and juvenile chicken forelimbs produced the widest joint spacing between the humerus and the antebachrum (Fig. 2 C, D, G and H). The wider joint space seen between the in situ bony elements is due to the relatively large cartilaginous epiphyses found on both the alligator and juvenile chicken articular surfaces (Fig. 3).

DISCUSSION

One of the most interesting observations made from this data is that sauropod humeri have similar osseous articulating surfaces to both the adult alligator and juvenile chicken humeri (Fig. 4). Also of note is the examined and measured articular surfaces of the adult chicken humerus which differ significantly from the preserved surfaces seen on the ends of sauropod humeri.

In not surprising that when the canine forelimb is used as a model, a very tight joint is produced in the sauropod. However, the similarity between the adult chicken and the adult canine elbow with regard to the completeness of the osseous joint surfaces is noteworthy and indicates that limb joints of non-avian theropods closely related to birds may possess joint surfaces which would allow them to be reconstructed with a confidence approaching that of fossil mammals.

MATERIALS AND METHODS

A juvenile chicken (~6 weeks old), a adult chicken, a sub-adult alligator (~1 meter), a adult alligator (~2.5 meters), and an adult dog were scanned using a Siemens Definition 164 slice dual energy CT scanner. Slice intervals for scans ranged between 0.3 millimeters and 0.6 millimeters. Dicom images were edited in Materialise Mimics 13.1 and three-dimensional stereolithography (STL) models of articulated limbs were exported for further analysis. Autodesk 3DS Max was used to compare exported STL models with a virtual 3D model of a forelimb previously described (Whitehouse, 2003).

The elbow joints of the scanned forelimbs were left in the position in which they were scanned in the articulated limb. The forelimbs were scaled to the same relative humerus length and then rendered in 3DS Max. The minimum distance between the ulna and the distal humerus was used to reconstruct the elbow joint in the Diplodocus forelimb. When reconstructing the Diplodocus elbow it was assumed that the radius and ulna were fixed relative to one another based on anatomy noted in Whitehouse, 2005. It was also assumed that the limb was oriented in an upright neutral stance.

After both adult and juvenile alligator forelimbs were rendered and the humerus scaled to the same relative size, it became apparent that relative cartilage thickness at the elbow joint was similar for both the adult and juvenile alligator specimen (Fig. 1) and the adult specimen is used for the joint reconstructions that follow.

INTRODUCTION

Several recent studies have focused on the significance of cartilaginous epiphyses in archosaurian limb joints as it relates to reconstruction of joints in extinct archosaur taxa (see Holiday et al. 2010, Fujimura et al. 2013 and Bonnan et al. in press). These studies provided detailed information on the architecture of archosaur limb joints, most significantly those of cursorial birds and crocodilians. However, they primarily focused on disarticulated limb elements. Here we present data from CT scanned in situ archosaurous joints and use that data to present hypothetical elbow joint reconstructions for the Upper Jurassic sauropod Diplodocus.

REFERENCES


Figure 1. Comparison of in situ CT data from an adult (A) and juvenile (B) right alligator forelimbs scaled to the same humeral length (medial view).

Figure 2. Reconstructions of the right elbow joint in Diplodocus (B, D, F, H) based on in situ CT data from an adult dog (A), adult alligator (C), adult chicken (E) and juvenile (~6 week old) chicken (G). All figures are scaled to the same humerus length and are illustrated in medial view.

Figure 3. Comparison of the right forelimbs of a juvenile (~6 week old) chicken (A) and an adult alligator (B) showing extent of cartilaginous epiphyses (light green). Humeri are scaled to approximately the same relative size and shown in medial view. 3D data generated from laser scans of individual bones before and after maceration of epiphyseal cartilage.

Figure 4. Comparison of the right humerus of an adult alligator (A), Diplodocus (B), juvenile (~4 week old) chicken and an adult chicken. Humeri have been scaled to the same relative length and are shown in cranial view.

Figure 5. Comparison of right elbow joint reconstructions in Diplodocus based on an adult alligator (A), an adult chicken (B) and a juvenile (~6 week old) chicken. Humeri have been scaled to the same length and limbs are shown in medial view.

CONCLUSION

The results presented here based on in situ data from multiple archosaurous specimens supports the work done by Fujimura et al. (2010) and Holiday et al. (2010) on the nature and differences of cartilaginous epiphyses between birds and crocodilians. We further demonstrate that juvenile cursorial birds and alligators may be better analogues for reconstructing missing epiphyseal cartilage in sauropod dinosaurs than adult cursorial birds or mammals. Finally, we present the first reconstructions of the elbow joint in Diplodocus based exclusively on in situ joint data from extant taxa.