Reconstructing an unusual specimen of *Haplocanthosaurus* using a blend of physical and digital techniques

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Abstract

A partial skeleton of a sauropod dinosaur, Museum of Western Colorado 8028, was recovered from the Upper Jurassic Morrison Formation near Snowmass, Colorado, USA, and in 2014 it was referred to *Haplocanthosaurus* sp. The material includes four proximal caudal vertebrae, which are unique in having strongly amphicoelous vertebral bodies, in which the centrum is reduced to a thin vertical plate of bone between the concave articular surfaces, and neural canals that are laterally and ventrally expanded and strongly sloped relative to the centrum. To reconstruct the soft tissues that left these traces on the skeleton, we rebuilt these vertebrae using both physical and digital techniques. We CT scanned the specimens, generated digital models, 3D-printed the vertebrae, physically sculpted missing material onto the printed models, optically scanned the sculpted vertebrae to create second-generation digital models, and finally, retro-deformed and articulated those digital versions of the vertebrae. The spaces between the deeply amphicoelous caudal centra were likely filled by large, ellipsoidal intervertebral discs, as in the amphicoelous vertebrae of *Sphenodon* and gekkotan lizards. The expanded neural canals remain enigmatic. In ostriches, the lumbosacral spinal cord is expanded laterally and ventrally in each vertebra, lending the spinal cord a shape that roughly resembles beads on a string. Similar spinal cord morphology might explain the expanded neural canals in the Snowmass

Haplocanthosaurus, but it is not clear why a relatively small-bodied, small-tailed sauropod would need such a spinal expansion, given that similar expansions have not been reported in larger-bodied and larger-tailed taxa.