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SHORT COMMUNICATION

EVIDENCE OF PACHYOSTOSIS IN THE CRYPTOCLEIDOID PLESIOSAUR *TATENECTES LARAMIENSIS* FROM THE SUNDANCE FORMATION OF WYOMING

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INTRODUCTION

In this paper we present evidence for pachyostosis in the cryptocleidoid plesiosaur *Tatenectes laramiensis* Knight, 1900 (O'Keefe and Wahl, 2003a). Pachyostosis is not common in plesiosaurs and is particularly rare in non-pliosaurian plesiosaurs, although enlarged gastralia were first recognized in *Tatenectes* by Wahl (1999). This study aims to investigate the nature of the disproportionately large gastralia of *Tatenectes* in greater depth, based on new material. A recently discovered partial skeleton consisting of a dorsal vertebral series, ribs, gastralia, and a complete pelvic girdle was collected from the Jurassic-aged Sundance Formation of the Bighorn Basin in Wyoming during the summer of 2006. The gastralia of this specimen are disproportionately large considering the small size of the taxon (about 3 meters total length), and we therefore investigated the size of these elements quantitatively. Polished cross-sections were also prepared to explore the histology of the ribs and gastralia. The ribs of *Tatenectes* are not pachyostotic, whereas the gastralia exhibit a novel condition of pachyostosis while lacking osteosclerosis.

Skeletal tissue modification is common among secondarily marine tetrapods. These modifications can follow one of two major trends: toward a lighter skeleton or toward a heavier skeleton. The skeleton can be made lighter by reduction in number or size of skeletal elements. Bones themselves can also be reduced in density (de Buffrénil et al., 1990; de Ricqlès and de Buffrénil, 2001). This condition, known as osteoporosis, occurs when the cortical bone layer, usually the most compact and dense region of a bone, is reduced, and the marrow cavity or regions of cancellous bone are increased (de Ricqlès and de Buffrénil, 2001). Osteoporosis is a common pathology in humans, but in secondarily marine tetrapods the osteoporosis is adaptive, having occurred in several lineages including ichthyosaurs, pliosaurs, and cetaceans (de Buffrénil et al., 1990; de Ricqlès and de Buffrénil, 2001).

At the other end of the spectrum, the skeleton of secondarily marine tetrapods can become heavier. Bones can become enlarged via pachyostosis. Pachyostosis is another adaptive condition through which the periosteal cortex of the bone undergoes hyperplasy (Francillon-Viellot et al., 1990). In such cases hyperplasy indicates that the cortical bone layer grows to a greater thickness, either through increased amount of time in the growth stage, or accelerated growth rate. The periosteal cortex of the bone is therefore thicker, thus enlarging the entire bone (de Ricqlès and de Buffrénil, 2001). The total weight of the skeleton can also be multiplied through increased bone density. Osseous tissue may also become more dense via a condition termed osteosclerosis. This condition involves disruption of endochondral ossification, resulting in less resorption of endochondral tissue and a lack of endosteal development. Therefore, cancellous bone tissue or marrow cavities do not form and the bones are instead filled with dense calcified cartilage. Pachyostosis and osteosclerosis can occur concurrently, and this combined condition is known as pachyosteoslcerosis (Taylor, 2000; de Ricqlès and de Buffrénil, 2001). Varying degrees of these conditions are seen in basal sauropterygians, primitive cetaceans, and sirenians, among others (de Buffrénil et al., 1990; Domning and de Buffrénil, 1991; Taylor, 2000; de Ricqlès and de Buffrénil, 2001).

Pachyostosis is uncommon among plesiosaurs. The extant literature contains no mention of possible pachyostosis in other cryptocleidoid plesiosaurs other than that of Wahl (1999), although detailed descriptions of ribs and gastralia are rare in the literature (Andrews, 1910; Brown, 1981). Currently, *Pachycostasaurus dawni* Cruickshank et al., 1996, is one of the few plesiosaurs described as exhibiting some degree of pachyostosis. This small pliosauromorph (~3 m long) displays marked pachyostosis of the dorsal vertebrae, ribs, and gastralia. The pachyostosis of these skeletal elements is accompanied by an increase in tissue density as well, resulting in a pachyosteosclerotic state (Cruickshank et al., 1996). It has also been hypothesized by Wiffen et al. (1995) that the condition of plesiosaurian bone tissue changes throughout ontogeny. Their research on Late Cretaceous elasmosaurs and pliosaurs indicates a possible trend from osteosclerosis in immature individuals to an osteoporotic state in adults (Wiffen et al., 1995). It should be noted that the specimen under consideration in this study, USNM 536076, is a fully mature adult. All known *Tatenectes* specimens, including the relatively common juvenile specimens, exhibit pachyostosis of the gastralia (Wahl, 1999, 2006).

In marine tetrapod taxa displaying pachyostosis that is not pervasive throughout the entire skeleton, the enlargement of bones is often concentrated within the thoracic region (de Ricqlès and de Buffrénil, 2001). This is expected if the increase in bone mass serves as ballast. For maximal maneuverability and stability, the most buoyant region of an aquatic tetrapod, the lungs, and the densest region, skeletal pachyostosis, should both be near the anteroposterior midpoint of the organism (Domning and de Buffrénil, 1991). The new partial skeleton of *Tatenectes* does appear to have this pattern and we describe it here. Unlike what is seen in *Pachycostasaurus*, the only bones in the new skeleton that exhibit pachyostosis are the gastralia, as mentioned briefly in O'Keefe and Street (2009) and Wahl (1999). In comparison to the dorsal ribs, the gastralia of *Tatenectes* appear to be disproportionately robust. The gastralia are also noticeably thicker than those of *Pantosaurus*, another, larger Sundance cryptocleidoid. It is the goal of this research to determine if the gastralia of *Tatenectes laramiensis* do indeed exhibit pachyostosis, and if so whether the histologic condition is pachyostotic or pachyosteosclerotic.

MATERIALS AND METHODS

This study focuses on the axial morphology and histology of the cryptocleidoid plesiosaur *Tatenectes laramiensis*. We also present comparative material from three related taxa: *Pantosaurus striatus* Marsh, 1891, *Cryptoclidus eurymerus* Phillips, 1871, and *Muraenosaurus leedsii* Seeley, 1874. Specimens were examined from the Natural History Museum, London (NHM), the National

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