

Deep-diving dinosaurs

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Abstract Dysbaric bone necrosis demonstrated in ichthyosaurs may be the result of prolonged deep diving rather than rapid ascent to escape predators. The bone lesions show structural and anatomical similarity to those that may occur in human divers and in the deep diving sperm whale, *Physeter macrocephalus*.

Keywords Ichthyosaurus · Deep diving · Dysbaric bone necrosis · Decompression illness

I commend the article on the decompression syndrome in dinosaurs (Rothschild et al. 2012). The illustrations in their article of dysbaric osteonecrosis (DON) in *Ichthyosaurus* correspond closely to the appearances of these lesions in the human (Hasan and Romeo 2002), and the presence of the lesions in the heads of the humerus is also analogous to the human situation (Davidson 1972). They accurately describe the bone lesions present in these reptiles but the presence of these deformities may have a different explanation for the one that they offer.

In human medicine, the term decompression *illness* covers two different entities. One is *arterial gas embolism*, a circumstance that occurs in divers breathing compressed air or gas mixture. It is this condition that happens after an uncontrolled ascent and may occur after dives in relatively

shallow water (Vann et al. 2011). An untrained diver surfacing from 10 m without exhaling reaches the surface with two atmospheres pressure in his lungs. This leads to alveolar rupture; air enters pulmonary veins, passes through the left ventricle with embolisation of cerebral, coronary and other arteries. Symptoms may develop within seconds with fitting and loss of consciousnesses.

The second entity is that of decompression *sickness*, with nitrogen coming out of solution, forming extravascular tissue and intravenous gas bubbles. This condition occurs after prolonged dives at depth (deeper than 30 m) with inadequate staging during the ascent. At depth, air is supplied through a regulator that increases the pressure of the inspired air to equal that of the ambient water pressure; the partial pressure of nitrogen is increased and this enters solution in accordance with Henry's law (Battino and Clever 1966) and passes into fatty tissue. On ascent with falling partial pressure the dissolved nitrogen comes out of solution and is excreted in expired air. Bubble formation occurs if this process is too rapid and it is this condition that produces 'the bends', pain due to gas distortion of soft tissue (Vann et al. 2011). This process may take hours, even days to develop, unlike arterial gas embolism.

DON is believed to be the sequel of inadequate bone perfusion as a result of venous obstruction from actual bubbles or from gas damage to endothelial cells. DON may occur in divers who have not experienced other symptoms of decompression sickness.

Ichthyosarians would not develop decompression sickness from sudden rapid ascent but might well do so if herded into and confined for some time in shallow water by predators. An alternative explanation for the presence of DON in the more recent fossils is that the reptiles evolved the ability to dive deeper and to remain at depth for longer periods. Air inhaled at atmospheric pressure on the surface would be pressurised due to compression of the rib cage at depth, resulting in increased nitrogen absorption. When resting at the surface after deep

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diving, intra-alveolar pressure would again be near atmospheric and the excess nitrogen would come out of solution with possible intravenous bubble formation.

The question of why deep, prolonged diving ability would evolve without a physiological mechanism to excrete increased dissolved nitrogen is not answered. A facile explanation could be that success in diving provides immediate survival advantage while dysbaric osteonecrosis is a late event. It may occur unassociated with muscle and joint pain (Hutter 2000) and remain without symptoms until there is collapse of the articular surface and secondary arthritis. The lesions depicted appear to without secondary changes and would not have affected the reptiles mobility or caused any significant morbidity. Ichthyosaurian hunting ability and reproductive success would be unaffected.

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