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FRACTURES OF THE RADIUS AND ULNA IN A SKELETALLY IMMATURE FIN WHALE [1]

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Abstract: A naturally-occurring fracture of the distal radius and ulna in a skeletally immature fin-whale, *Balaenoptera physalus,* appeared to be failing to heal. When compared to the response to fracture in the skeletally immature human and to other terrestrial mammals, this animal did not show any endosteal and only minimal subperiosteal callus, even though the fractures appeared to be several weeks, if not months old. This suggests that the larger ceteceans may not be able to respond appropriately to skeletal injury in the major structural units of the flipper.

INTRODUCTION

Fractures in the skeletally immature human generally heal rapidly. Even within the shaft of the bone (diaphysis) these have roentgenographically evident callus within three weeks and are in the remodeling phase within six weeks.[7,9] Within the metaphysis, with its intrinsically high rate of osseous modeling and remodeling, the fracture healing rate is even faster. Accordingly, there may be very little roentgenographic evidence of a metaphyseal fracture 5 to 6 months after the injury. Very little information is available on relative rates of healing in skeletally immature terrestrial mammals.[6] Nothing is written about rates of fracture healing in cetaceans, although Cowan described "healed fractures" in *Globiocephala melaena.*[1] These apparently were rib fractures, with no mention of flipper skeletal injury (healed or unhealed). Certainly other patterns of congenital and acquired skeletal deformities, such as phalangeal reductions and osteoarthritis, do occur relatively frequently in some cetacean species.[1,10]

The unexpected opportunity to study a naturally-occurring fracture of the distal radius and ulna in a skeletally immature fin whale, *Balaenoptera physalus,* suggests that healing of fractures in major bones may be impaired, possibly because of the relatively decreased rate of remodeling in cetacean bone and the necessity for continued use of the extremity.

CASE MATERIAL

A fin whale measuring 14 m in length was found stranded beneath the Ben Franklin Bridge near Philadelphia, Pennsylvania, USA. While the exact cause of death was not determined, an injury in the caudal region may have been caused by a collision with a large vessel. The flippers were removed as part of an ongoing project of comparative chondro-osseous development in marine mammals. There was no evidence of any external injury to the flippers. The overall contour was comparable to other fin whale flippers previously studied in our laboratory (unpubl.).

During roentgenographic evaluation a complete fracture of the distal radius and ulna at the metaphyseal/diaphyseal junction was found (figure 1). This fracture appeared to show the typical failure

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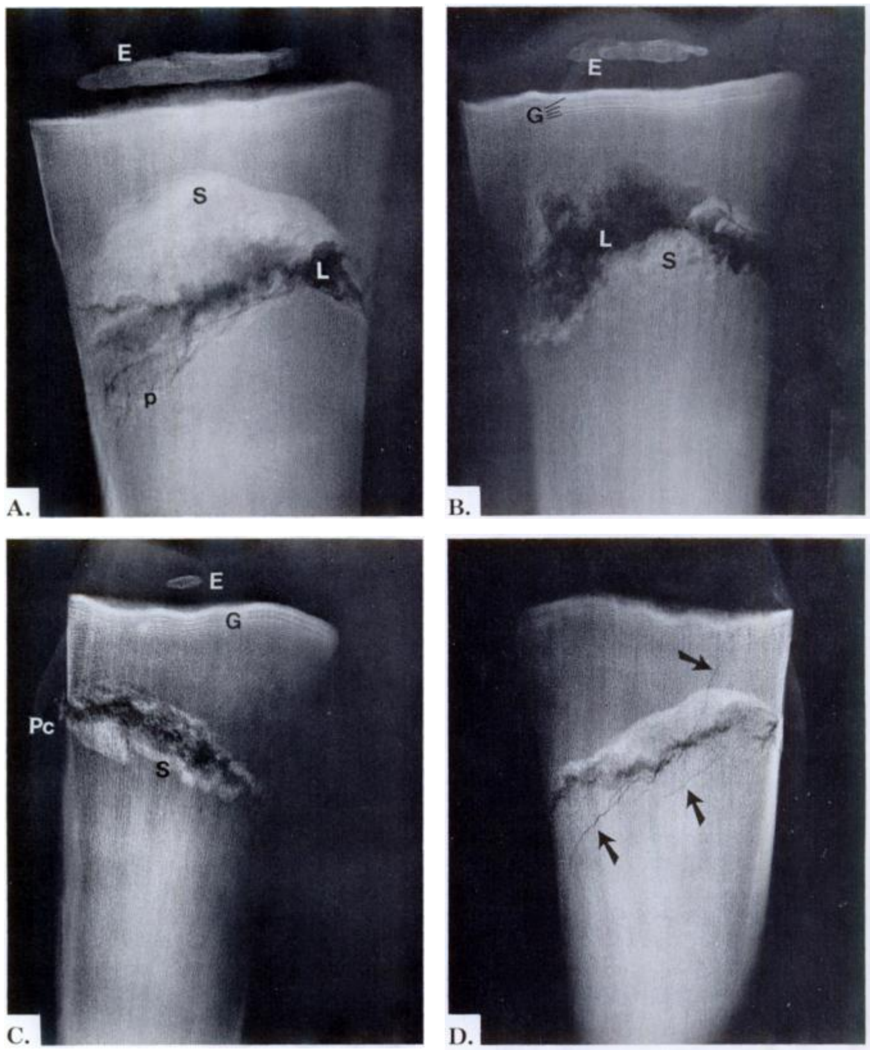

FIGURE 1. A. Roentgenogram of distal radius showing a lytic central area (L) and sclerosis (S) within the distal fragment. Additional fracture propagations (P) are evident in the proximal fragment. E — epiphyseal ossification center of distal radius. B. Ventral half of distal radius showing more extensive lytic (L) area, and sclerosis (S) in proximal side of fracture. Transversely oriented growth "arrest" lines (G) are evident across the distal metaphysis. These are thin except for the one closest to the physis. This particular band is thick and sclerotic and probably represents altered growth since the fracture. C, D. Dorsal and ventral halves of the distal ulna, showing variably lytic and sclerotic fracture, with some propagation (arrows) into proximal and distal fragments. Comparable growth arrest lines are also evident. A small region of subperiosteal callus (Pc) is evident.

pattern found in skeletally immature humans. Tension failure with widening on the dorsal side and compression failure with some cortical fragmentation on the volar side was evident. Minimal subperiosteal new bone formation could be seen along a small region of the ulnar border, but no evidence of callus bone was seen elsewhere within the subperiosteal space of the radius and ulna. There was no evidence of irregular ossification or calcification compatible with a healing endosteal callus.

Figures 1A and 1B show, respectively, the intact and volar half of the distal radius. In the complete bone dense sclerosis was evident in the distal metaphysis adjacent to the fracture. Additional small fracture propagations were seen in the proximal fragment. In the volar half sclerotic bone was observed along the proximal side of the fracture. Figures 1C and 1D show, respectively, the dorsal and ventral halves of the distal ulna. Sclerotic bone was present along both sides of the fracture. Again, additional fracture propagation lines were noted in both the proximal and distal fragments.

In both the radial and ulnar metaphyses there was increased density directly adjacent to the physis in what represents the primary spongiosa (figures 1B, 1C). These represent thickened trabecular bone growth probably occurring after the fracture, a situation commonly seen near the physis in humans after distal radial fractures.[7,9]

Examination of the intact bones showed that a definite failure to heal with false motion was present, allowing approximately 15 to 20 degrees of angular malunion. Angular deformity was possible only by volar-oriented force on the distal fragment. In contrast, anterior, posterior and dorsal displacement motions were not evident.

Dissection of the flipper did not reveal hemorrhage in the interosseous musculature of either the dorsal or ventral interosseous region between the radius and ulna, which certainly would have been anticipated in an acute fracture. The periosteum was not disrupted, but did show areas of hyperemia and proliferation of small blood vessels, as might be expected from a more chronic injury subjected to continued motion. Each of the bones was sagittally sectioned to reveal the fracture (figure 2). The sectioned bones could be deformed easily, corroborating the findings on the intact bones that this was an unhealed and unstable injury.

The fracture site contained a firm, whitish tissue and some congealed hemorrhage. Histologic examination revealed this tissue to be resolving hematoma and inflammatory tissue with no evidence of callus formation. There was no evidence of any subperiosteal callus formation except in the very limited aforementioned area of the ulna. Endosteal bone on both sides of the fracture appeared quite viable macroscopically as well as microscopically. Trabeculae directly at the fracture margins showed minimal necrosis and fragmentation. The sclerotic bone showed new bone on the original trabeculae.

DISCUSSION

Gross and microscopic examination indicated these fractures probably were several weeks to months old, and certainly did not represent acute injuries sustained at the time of the animal's death. There was virtually no evidence of the pattern of fracture healing one might expect from extrapolation of the rapid rates of healing in a skeletally immature human and other terrestrial mammals.[6,7,9]

Absence of the anticipated fracture healing response is not totally unexpected, inasmuch as cetaceans do not have a great deal of osseous remodeling. Essentially, they maintain the trabeculae of the primary spongiosa, whether it is formed by endochondral or membranous bone formation.[3,4,10] Some

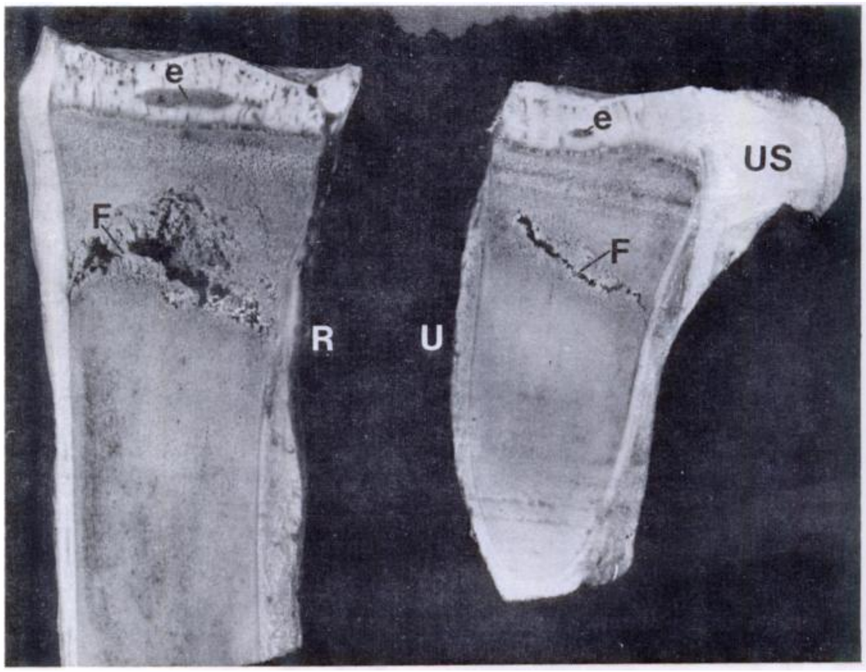

FIGURE 2. Separated sagittal sections of distal radius (R) and ulna (U) showing fracture (F) with minimal subperiosteal change. The lytic region was filled with semiliquid tissue and minimal amounts of blood, but no reparative bone. The epiphyseal ossification centers (e) are evident within well formed epiphyses. The radial epiphyseal cartilage is extremely well-vascularized (small black areas within cartilage). The extensive cartilaginous distal ulnar styloid process (US) is evident.

remodeling and formation of denser cortical bone is usually evident peripherally. The fluid dynamics of the aquatic environment may be such that the pattern of bone formation and remodeling necessity for a marrow cavity as well as formation of extensive secondary and tertiary osteons within cortical bone. Decreased activity in these systems may be a major factor in the failure to form significant amounts of proliferative callus in response to the injury.

Probably this injury predisposed the animal to the subsequent total injury. Our dissections in other fin-whale flippers, as well as other large whales indicates that a large neurovascular plexus goes into the flipper (unpubl.). The periosteum presumably is well innervated, such that the animal would perceive pain comparable to the pain felt by a human with a mobile, ununited fracture. Pain potentially limits the animal's use of the flipper for stabilization, this the main function of the flippers during swimming. Lack of ability to stabilize in the water and maneuver effectively may therefore have been a factor in the inability to avoid subsequent collision with a large vessel.

The necessity for continued use of the injured flipper, the constant external water pressure, and the drag on the dorsal surface would also predispose to continued motion at the fracture site, and set the conditions for non-union, similar to a human walking on an inadequately immobilized tibial fracture.

In ongoing studies of prenatal and postnatal flipper development in several odontocete species, we have observed a significant number of healing and healed phalangeal fractures, but no fractures of the humerus, radius and ulna.[10] In these species the flipper is small, generally less than 1 m in length. However, in the fin whale, the greater length of the flipper may allow fracture along the radius and ulna. The radius and ulna of smaller odontocetes tends to be broad and flat (rectangular), whereas that of the fin whale tends to be circular or elliptical, depending upon the level sectioned. These differences in cross-sectional morphology may be a factor in differing fracture patterns.

Transversely oriented lines of "growth arrest" are characteristically found in the metaphysis of skeletally immature humans following systemic diseases and localized injury.[7,8,9] These gradually "migrate" with resumption of normal endochondral growth and eventually disappear with medullary remodeling. In figure 1B several thin "growth arrest" lines were present and might indicate cyclical growth of the flipper, with phases of slow and rapid endochondral bone formation (possibly related to feeding and migratory habits). However, the zone directly adjacent to the metaphysis was a widened zone of sclerosis, very comparable to the appearance in children after trauma. Therefore, this may represent longitudinal growth (endochondral ossification) occurring after the fracture, further supporting the contention that this fracture was a chronic, rather than acute injury.

Artificial diets as well as the presumably naturally duplicated diets of captive animals in zoo populations often lead to problems in skeletal physiology, making animals more susceptible to osteoporosis, osteomalacia and rickets, depending on the state of skeletal maturity.[2,5,11,12] Such disruption of normal architecture also predisposes to pathologic fractures. Certainly similar diets in captive cetaceans might lead to similar problems in bone development as well as susceptibility to injury, although such problems have not been described. If such a fracture occurs during transport or in the aquarium, there may be a considerable delay in healing, if not a complete malunion. It would not be unreasonable to consider internal fixation of such a bone in a captive specimen.

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