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Metacarpo-Phalangeal Anomalies in Bottlenose Dolphins (*Tursiops truncatus*)

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Abstract

Radiographs of 99 intact flippers from 60 subadult to adult bottlenose dolphins (*Tursiops truncatus*), all stranded on the Texas coast from 1990 to 1995, were examined to determine location and nature of lesions in the metacarpal and phalangeal bones. Eleven flippers from seven mature dolphins (2.35 to 2.45 m TL) had radiographically obvious lesions: three dolphins had conjoined metacarpal III – first phalanx, which appeared as a bilateral congenital developmental anomaly with incomplete separation and defective formation of the metacarpo-phalangeal joint; two dolphins had degenerative joint disease of the metacarpal III – first phalangeal joint; and two dolphins had metacarpal II – first phalanx lesions. The acquired lesions showed similarities to those seen in domestic mammals. The distinct affinity of both developmental and degenerative lesions for the metacarpal III – first phalanx in these dolphins is noteworthy.

Key Words: congenital abnormalities, degenerative joint disease, digit, flipper, radiology, bottlenose dolphin, *Tursiops truncatus*

Introduction

The flipper of extant whales, dolphins, and porpoises (Order: Cetacea) evolved from the thoracic limb of their terrestrial ancestors as an adaptation to the aquatic habitat and now functions as a hydrofoil that assists maneuvering. Cetacean skeletal architecture and its development diverged from the basic mammalian plan: the brachium, antebrachium, and manus bones are flattened dorsoventrally and topographically aligned into a single plane; joints distal to the scapulohumeral articulation have limited movement and reduced synovial features; metacarpals and phalanges are similar in shape; and the manus contains four or five digits (Family specific) within a common skin investment without claws or nails (Flower, 1885). In addition, hyperphalangealism, unique among mammals, is characteristic of cetaceans—for example, some long-finned pilot whales (*Globicephala melas*) possess a second digit with as many as 14 phalanges and a phalangeal formula of I4, II14, III11, IV3, and V2. Cetacean limb bones are distinctive from those in terrestrial, weight-bearing mammals for their lack of compact-bone cortices and single medullary cavities; instead, they consist of a lattice of trabeculated bone (de Buffrénil & Schoevaert, 1988). Furthermore, the metacarpals and phalanges each have a proximal and distal epiphyseal ossification center; and, compared with that in terrestrial mammals, the ossification of flipper bones is delayed beyond sexual maturity (Figure 1a) (Flower, 1885).

Skeletal lesions of the pentadactylous flipper in dolphins are uncommonly reported. In the bottlenose dolphin (*Tursiops truncatus*), these include congenital polydactyly (Watson et al., 1994); synovial joint disease in the scapulohumeral joint (Turnbull & Cowan, 1999); flipper osteomyelitis, particularly of the carpals, metacarpals, and adjacent phalanges (Foley, 1979); mild chronic bony proliferation of the scapula, resulting from penetration and embedment of a stingray spine (McFee et al., 1997); and, in a wild common dolphin (*Delphinus* sp.), fibrous osteodystrophy of both scapulae (Flom et al., 1978). We report here seven wild bottlenose dolphins with congenital and acquired degenerative anomalies of the metacarpo-phalangeal joint.

Specimens and Radiographic Technique

As part of an ongoing osteological investigation, left and right intact flippers (n = 99) disarticulated at the scapulohumeral joint were collected and frozen from 60 (32 male, 26 female, two of undetermined sex, 2.01 to 2.94 m TL, total body length) bottlenose dolphins from the Gulf of Mexico that were stranded on the Texas coast from 1990 to 1995. Actual age or physical maturity status was unknown, although based on tooth growth-layer-group analysis of comparable Texas dolphins longer than 2.00 m TL, all 60 dolphins in the present study are estimated to be 3 y of age or older (Fernandez & Hohn, 1998). In comparable Florida bottlenose dolphins, females complete puberty at 2.20 to 2.35 m TL (5 to 12 y of age) and males at 2.45 to 2.60 m TL (10 to 13 y of age) (Wells & Scott, 1999).

Standard plain-film ventrodorsal radiographs were taken and then examined by the naked eye on a standard radiographic illuminator. Lesions were further evaluated with an 8× handheld magnifier and a "bright light," and skeletal anomalies of the metacarpals and their first phalanges were detected in seven dolphins (11.7%). Three other large male dolphins (2.62, 2.70, and 2.94 m TL, respectively) had limited, chronic osteolysis-osteosclerotic lesions involving two or three distal phalanges and their narrowed interphalangeal joints of digit II.

Case Descriptions and Radiographic Findings

In these dolphins, the normal cetacean pattern of separate proximal and distal epiphyseal ossification centers for both the metacarpals and the phalanges was evident in various stages of maturation (Figure 1a).

Case No. 1

Case No. 1 was a mature 2.40 m TL male. The right and left flippers had bilaterally symmetrical and virtually identical malformations. The third metacarpal bone and its first phalanx were smoothly united as a composite bone over their cranial one-half to two-thirds, obliterating the intervening metacarpo-phalangeal joint (Figure 1b). Caudally, there was a broad, U-shaped transverse cleft, interpreted as the remains of the joint. The union was regular with a smooth periosteal border cranially and continuous trabeculation internally. In the cranial half of the bone, the trabeculae were aligned longitudinally parallel, but near the cleft, they formed a radial arrangement converging to a focus of mild sclerosis at the apex of the cleft. The cleft margin was regular, smooth, and sharply defined along its entire border and blended caudally with the periosteal surfaces of the adjacent shafts. The margin itself was bordered by a thin line of sclerosis, deep to which lay a thin, radiolucent band, and deep to that was a second, thin contour-line of sclerosis similar to a metaphyseal scar. Faintly visible trabeculae were present between the two sclerotic lines. Additionally, a short, cone-shaped, relatively radiolucent zone extended craniad from the apex of the cleft to the radial sclerotic center, consisting of low opacity trabeculae. The inner sclerotic margin of the cleft extended into the cancellous bone to surround and define the borders of this cone-shaped radiolucency. Within the apex of the cleft lay a poorly mineralized nidus of cancellous bone, comparable to a bony epiphyseal remnant. In addition, the first phalanx portion was foreshortened by approximately 50% and its distal end was malformed, with a marked concave contour; a sclerotic and slightly irregular margin over the full width of the distal end; and a reduced, eccentrically placed, distal epiphyseal ossification center.

Case No. 2

Case No. 2 was a mature female estimated to be 2.35 to 2.40 m TL. (The carcass, which was missing its head, measured 2.10 m. The estimate is based on carcass + skull measurements as well as its comparable flipper development observed among other females in the 2.30 to 2.45 m range.) In the right flipper, metacarpal III and its first phalanx were united by 80% of their transverse width axially with a broad V-shaped cleft caudally, and the cranial common periosteal border was smooth (Figure 1c). In the left flipper, metacarpal III and its first phalanx were united by 60% of their transverse width axially with a 20% broad V-shaped cleft cranially and caudally (Figure 1d). In both flippers, the cleft borders were smooth without a sclerotic margin, and on the left, a very faint osseous band incompletely spanned the cleft caudally. Centrally, there was increased radiopacity compared to adjacent metacarpals and phalanges, owing to an increased number of uniform trabeculae, with four transverse bands of alternating opacity, indicative of periodic growth. The zone of union consisted of somewhat disorganized, but still longitudinally oriented, trabecular bone, with slight sclerosis at the cleft border proximo-caudally. Metaphyseal scars were not apparent on the right, although on the left, a faint scar was present proximally on metacarpal III and distally on the first phalanx.

Case No. 3

Case No. 3 was a mature female estimated to be 2.35 to 2.40 m TL. (This was a mature dolphin with a suspect field-recorded measurement of 1.77 m. This estimate is based on comparable flipper development to other females in the 2.30 to 2.45 m range.) In the right flipper, metacarpal III was conjoined with its first phalanx over their

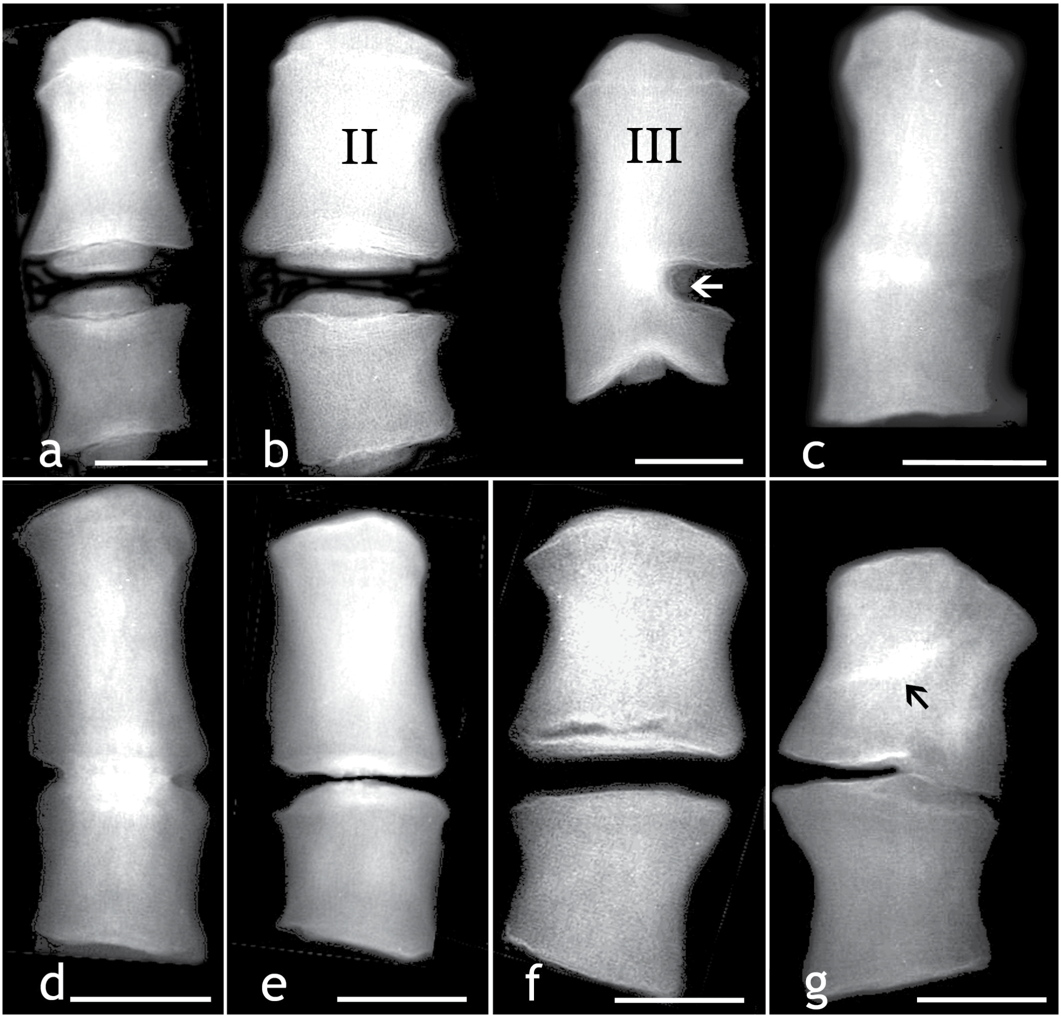

Figure 1. (a) Ventrodorsal radiograph of right metacarpal III and first phalanx from a bottlenose dolphin; normal skeletally immature male (2.19 m TL) that had separate proximal and distal epiphyseal ossification centers for both the metacarpal and phalanx. Bar = 1 cm. **(b)** Ventrodorsal radiograph of right metacarpal II and III and their first phalanges from bottlenose dolphin No. 1, a mature male (2.40 m TL); notice normal metacarpal II (II) and its first phalanx, and conjoined metacarpal III – first phalanx (III) with cleft caudally that contains an epiphyseal remnant (arrow) and central radial sclerosis. The distal end of the conjoined phalanx is misshapened. Bar = 1 cm. **(c)** Ventrodorsal radiograph of right metacarpal III – first phalanx from bottlenose dolphin No. 2; notice that metacarpal III is conjoined with the first phalanx and has transverse sclerotic bands at union site and a cleft caudally. Bar = 1 cm. **(d)** Ventrodorsal radiograph of left metacarpal III – first phalanx from bottlenose dolphin No. 2; the metacarpal III is conjoined with the first phalanx and has transverse sclerotic bands at union site and clefts cranially and caudally. Bar = 1 cm. **(e)** Ventrodorsal radiograph of left metacarpal III – first phalanx from bottlenose dolphin No. 4; there is a narrowing of metacarpal III – first phalangeal joint and an irregular subchondral margin and sclerosis axially. Bar = 1 cm. **(f)** Ventrodorsal radiograph of left metacarpal II – first phalanx from bottlenose dolphin No. 6; notice the transverse radiolucency in distal metacarpal II. Bar = 1 cm. **(g)** Ventrodorsal radiograph of right metacarpal II – first phalanx from bottlenose dolphin No. 6; the metacarpal II has an oblique, healed malunion fracture (arrow) and the caudal half of the joint is collapsed. Bar = 1 cm.

cranial 70% with a broad V-shaped cleft caudally. The cranial common periosteal border of this composite bone was smooth. The cleft margin was slightly sclerotic, with a second radiopaque line deep to this—the intervening lucency being more distinct along the distal edge. A poorly defined cancellous nodule occupied 85% of the cleft. Over the union site, there was increased radiopacity resulting from four transversely oriented foci of increased radiopacity; each focus was poorly defined and irregular in shape with an irregular and poorly defined margin. The whole composite bone had an axial opacity approximately 50% denser than its neighboring metacarpal II. The left flipper was not available.

Case Nos. 4 & 5

Case No. 4 was a mature 2.37 m TL female, and Case No. 5 was a mature 2.45 m TL female. In both right and left flippers of Case No. 4 and in the left flipper of Case No. 5 (right flipper was not available), the joint space between metacarpal III and its first phalanx was narrowed, particularly axially, by 50 to 60% compared with the neighboring metacarpal II – first phalangeal joint (Figure 1e). The adjacent surfaces of subchondral bone were moderately irregular at the center of the apposing surfaces, with small, narrow projections of radiolucency extending deeper into the sclerotic subchondral plate on both sides of the joint space, especially on the distal end of metacarpal III. Within the gray "smudged" area of the joint space there was a slightly increased opacity that bridged the joint space at its axial one-third. Additionally, in the right flipper of Case No. 4, the second and third phalanges of digit III were axially conjoined across an irregular zone of sclerosis.

Case Nos. 6 & 7

Case No. 6 was a mature 2.41 m TL female, and Case No. 7 was a 2.48 m TL female. In the left flipper of Case No. 6, within the distal metaphysis of metacarpal II, there was a transverse radiolucency almost devoid of mineralized structures, which was irregular in shape and in its proximodistal width, with a sharply defined and sclerotic margin (Figure 1f). There was also an undulating radiolucency without a sclerotic margin across the width of the distal metaphysis of metacarpal II in the one flipper available from Case No. 7. Additionally, in Case No. 6, at the distocaudal corner of metacarpal II bordering the caudal limit of the lucency, there was a sclerotic rim, and the underlying cancellous bone was less opaque than other areas of the metacarpal. In the right flipper, the second metacarpal bone was shorter than its left contralateral pair; had an oblique sclerotic lesion across the mid-part of the bone, comparable to a healing scar; and presented an overall impression of a compressive malunion fracture (Figure 1g). The metacarpal II – first phalangeal joint was partially collapsed obliquely, with marked narrowing caudally and without apparent osseous fusion. The subchondral bone adjacent to this narrowing was more lucent than normal; in contrast, in the remainder of the joint, the subchondral bony plate was of normal opacity. In addition, the intermediate carpal bone had heterogeneous mineral content in its central three-fourths with alternating areas of radiopacity and radiolucency—a finding compatible with prior trauma and/or infection.

Discussion

The most striking finding from this review of manus lesions was the marked predilection for the metacarpal III – first phalangeal joint. Eight flippers radiographed from five affected dolphins (of the 60 examined) had lesions at this particular anatomic site and were bilaterally symmetrical in the three pairs of flippers available. In three flippers from two other dolphins, the metacarpal II – first phalangeal joint was affected. Topographically, the metacarpal III – first phalangeal joint is located at the center of the proximal manus, and whether this area is subject to unusual physical stresses in postnatal life or translational developmental stressors prenatally must await further investigation. What impingement these localized lesions may have had on flipper function is unknown and was probably limited. The manus assists swimming as a semi-rigid plate, and thus any loss of function (i.e., joint flexibility) in any one of the many inter-phalangeal or metacarpo-phalangeal joints would likely be minimal. Moreover, some dolphins with massive structural deformations have been observed in the wild to swim normally and apparently to have good physical health for many years (Berghan & Visser, 2000).

The pronounced concordance of the conjoined metacarpal III – first phalanx lesion in three dolphins (Case Nos. 1 to 3, Figure 1b to 1d), its remarkable bilateral symmetry in Case No. 1, and near symmetry in Case No. 2 is highly suggestive that these three dolphins share a common anomaly and causative mechanism—that it was the result of a developmental error, most likely congenital in nature. Furthermore, these three dolphins stranded on neighboring counties of Texas, and it is possible that they were from the same population. Although a genetic basis for this developmental lesion might be considered, the genetic identity and boundaries of different bottlenose dolphin populations in the northern Gulf of Mexico are poorly known. The authors do suggest, however, that the congenital developmental error is most likely faulty synovial joint formation and thus defective separation of the metacarpal and phalangeal skeletal primordia. During early development of the embryonic flipper bud in dolphins, the metacarpals and phalanges are laid down in a strict proximodistal sequence as a longitudinal series of chondrogenic mesenchymal condensations under induction from the thickened overlying apical ectodermal ridge (Richardson & Oelschläger, 2002). In these three dolphins, the error would have been localized at the primordial metacarpal-phalangeal joint in the third digital ray and affective briefly at the critical stage of synovial joint induction. The secondary remodeling of a non-cartilaginous region, the interzone, that normally develops between the cartilaginous skeletal elements at the presumptive joint region, is under a complex and continuous interplay of induction and maintenance by regulatory genes, their signaling proteins, and other factors (Archer et al., 2003)—specifically, disruption of the Wnt/β-catenin signaling pathway (Guo et al., 2004) will interfere with this early inductive process and result in skeletal fusion. A defective apical ectodermal ridge – mesenchymal interaction is likewise considered fundamental to the malformation of digits in ectrodactylous flippers of manatees (Watson & Bonde, 1986).

The joint narrowing and subchondral sclerosis at the metacarpal III – first phalangeal joint in two other dolphins (Case Nos. 4 & 5; Figure 1e) is similar to the early stages of degenerative joint disease in terrestrial mammals (Thrall, 2002). Moreover, that lesions in these dolphins had a predilection for a particular anatomic site is similarly seen in degenerative joint disease of the tarsus in horses, for example. The limited extent and mildness of the degenerative joint disease lesions in these dolphins is in contrast to the severity of the disease in the fully synovial scapulohumeral joint in other bottlenose dolphins (Turnbull & Cowan, 1999). In Case No. 6 (Figures 1f & 1g), the three lesions could be related to an initial trauma to the right flipper, a bite wound maybe (possibly with sepsis), which fractured metacarpal II and damaged the intermediate carpal bone and the cartilage of the metacarpal II – first phalangeal joint. The authors posit that the metacarpal bone healed and, subsequently, a lytic/sclerotic lesion developed in the carpal bone, asymmetrical loss of cartilage with degenerative joint disease developed in the metacarpal II – first phalangeal joint, and sepsis spread hematologically to the left flipper affecting metacarpal II. Similarly, the chronic osteomyelitic lesions at the leading edge of the flipper (digit II) in the three large male dolphins are likely sequela to trauma. The classification of skeletal anomalies in these dolphin flippers, although not critically dissimilar from recognized skeletal pathologies in terrestrial mammals, should be taken with caution since comparable lesions have not been previously reported and histopathological study is lacking.

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