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Short Note

Osseous Anomalies in a Risso's Dolphin (*Grampus griseus*)

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Osseous lesions, such as age-related degenerative changes, chronic joint infections, and old traumatic injuries, have long been recognized in the wild (Fox, 1939). Among terrestrial mammals, they have been reported mainly in large ungulates such as white-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces*) (Wobeser & Runge, 1975; Peterson, 1988). Notwithstanding major differences in type of locomotion and in weight bearing compared to terrestrial mammals, osseous lesions have also been described in several species of odontocetes and, less often, in mysticetes (Kompanje, 1999). Causes proposed to explain these lesions have included, among others, low genetic diversity, infection, traumatic injury, age-related degeneration, environmental pollution, and dysbaric stress (Kompanje, 1999; Moore & Early, 2004; Groch et al., 2019; Robinson et al., 2020). These lesions are often identified in the chronic stage or in decomposed animals by which time the original insult is no longer obvious, leaving only the morphological appearance and distribution of lesions to help determine their origin. Because life history, feeding strategy, and preferred habitat can differ greatly among cetaceans, observations of osseous lesions in animals of different species may provide further clues to their potential origins. Herein, we report anomalies in the axial skeleton of a Risso's dolphin (*Grampus griseus*), a species of odontocete that occurs in temperate and tropical seas worldwide. The sole member of its genus, the species typically inhabits upper continental slope waters of 200 to 1,000 m depth where it feeds mainly on deep-water cephalopods (Hartman, 2018).

The carcass of an adult male Risso's dolphin (length, 3.1 m) was found ashore in southwestern Nova Scotia, Canada, on 5 March 2009, only the second stranding record of this species in Atlantic Canadian waters. It was frozen until transported to the Atlantic Veterinary College, University of Prince Edward Island, and necropsied on 29 March. Based on dentinal layer counts in a mandibular tooth, the animal was determined to be 21 y old (J. Lawson, pers. comm., 21 May 2020). This is approximately midway between sexual maturity (10 to 12 y) and advanced age (up to 45 to 50 y) for this species (Hartman, 2018). This animal was in good nutritional condition based on the convex appearance of its epaxial muscle mass. The head could not be separated with a knife from the vertebral column at the atlanto-occipital (A-O) joint as is normally possible. The cause of death could not be determined by gross, microscopic, or bacteriological examination of the carcass. The complete skeleton was examined following removal of all flesh by dermestid beetles (*Dermestes maculatus*) and deposited in the New Brunswick Museum in Saint John, New Brunswick, Canada (NBM Mammal Collection #10302).

Osseous lesions involved the skull and cranial region of the vertebral column to the fifth thoracic (T5) vertebra; no other part of the skeleton was affected. The most striking lesion was a complete fusion of the atlas (C1) to the occipital condyles of the skull. This fusion was misaligned such that the block formed by C1 to C6, normally fused in this species (Cozzi et al., 2016), was deviated approximately 1.5 cm to the right of the occipital foramen (Figure 1). An asymmetry of the occipital foramen and occipital condyles could also be identified, with the dorsal border of the right condyle being approximately 1 cm lower than that of the left (Figure 2). Neither visual inspection nor computed tomography (CT) scan (Toshiba Aquilion TSX 101A; Toshiba Medical Systems Corporation, Tochigi, Japan) revealed evidence of irregularities that could suggest osseous

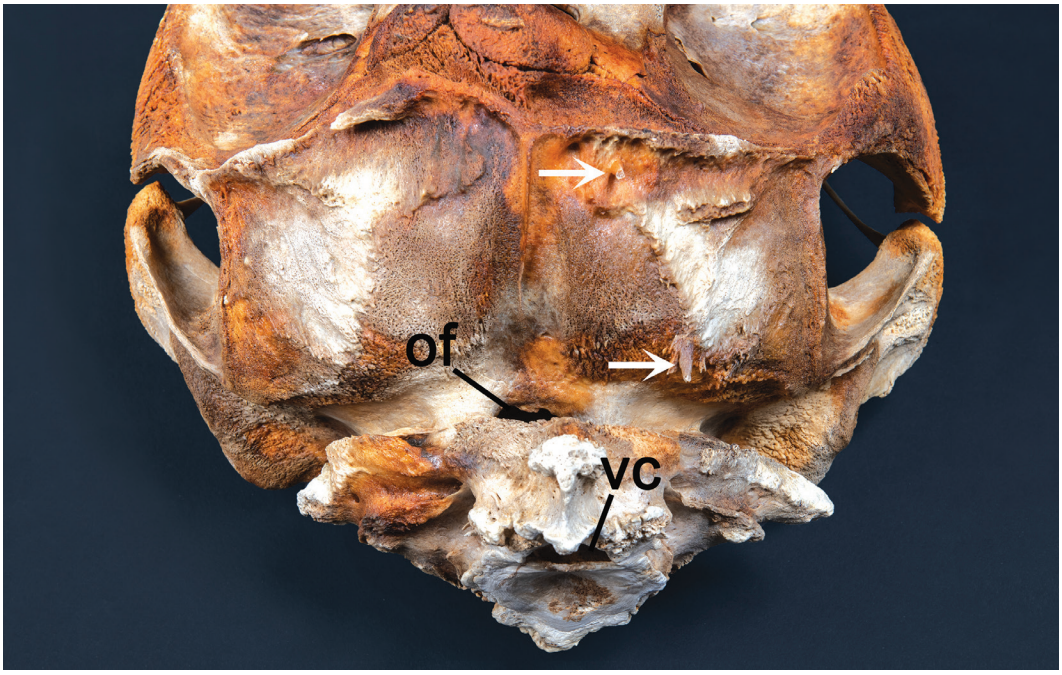

Figure 1. Caudo-dorsal view of a Risso's dolphin (*Grampus griseus*) skull with multiple skeletal anomalies. The atlas (C1) is completely fused to the occipital condyles of the skull. This fusion is misaligned such that the block formed by C1 through C6 (normally fused in this species) is deviated approximately 1.5 cm to the right, and the center of the vertebral canal (vc) does not align properly with that of the occipital foramen (of). Two bony spicules protrude from the occipital bone (arrows).

Figure 2. Right lateral view of the skull and first six cervical vertebrae of the Risso's dolphin. The atlas is completely fused to the occipital condyles of the skull. The dorsal border of the right occipital condyle is approximately 1 cm lower than that of the left, indicating an asymmetry of this region of the occipital bone. Two bony spicules protrude from the occipital bone (arrows).

degeneration and subsequent repair at the A-O joint. More specifically, based on a CT scan of the skull and first six cervical vertebrae in 1-mm slice thickness, there was a smooth and continuous transition of osseous tissue between the occipital bone and the atlas (Figure 3). A few exostoses, 1.0 to 2.5 cm long, protruded from the occipital bone (Figures 1 & 2). A few irregular osseous projections also covered the caudo-ventral region of the left mandibular ramus.

All vertebral bodies from C6 to T5 had ventral osteophytes, in decreasing order of severity from cranial to caudal (Figures 4-8). A few very small osteophytes on the dorsal region of these vertebral bodies protruded into the vertebral canal (Figure 8). Despite the large size of some of the ventral osteophytes, there was partial fusion only between C7 and T1 through their transverse processes and dorsal arches, but not through their bodies. Articular surfaces of some of the vertebral bodies were severely eroded, far more than those of the juxtaposed vertebrae (e.g., T1 & T2, Figures 5 & 6; T3 & T4, Figures 7 & 8). There was also failure of closure of the dorsal arch of T2 (Figure 6) and complete separation of the dorsal arch of T3 from its vertebral body, accompanied by extensive erosion of its surface (Figure 7). The exposed subchondral bone of some of the zygapophyseal (facet) joint surfaces, which in Risso's dolphins extend only as far caudally as T6 and T7 (Kompanje, 1999), was partly eroded and surrounded by osteophytes (Figures 4, 5 & 8).

Fusion of the A-O joint was the most unusual lesion in this Risso's dolphin. Partial or complete ankylosis of the A-O joint resulting from either degenerative or infectious processes has been reported in odontocetes (Turnbull & Cowan, 1999; Dagleish et al., 2007; Van Bressem et al., 2007). In the present case, however, this joint did not show gross or imaging evidence of inflammation, degeneration, and subsequent repair, but, rather, a uniform transition between occipital bone and atlas on a CT scan. This and the asymmetry of the occipital condyles and foramen suggest that it was instead a congenital malformation. In odontocetes, enhanced rigidity of the neck through fusion of a few, several,

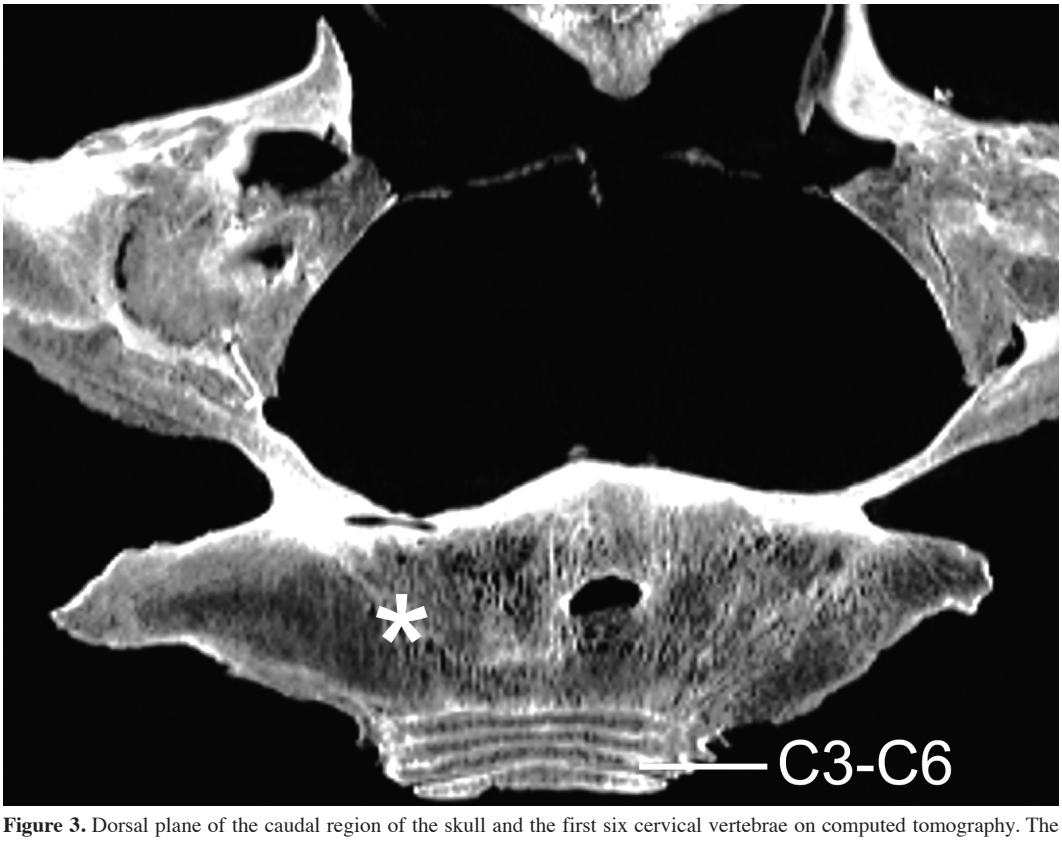

Figure 3. Dorsal plane of the caudal region of the skull and the first six cervical vertebrae on computed tomography. The fused atlanto-occipital (A-O) joint shows a uniform transition (*) between the occipital condyles of the skull and the atlas and axis. The third to sixth cervical vertebrae (C3 to C6) are clearly defined.

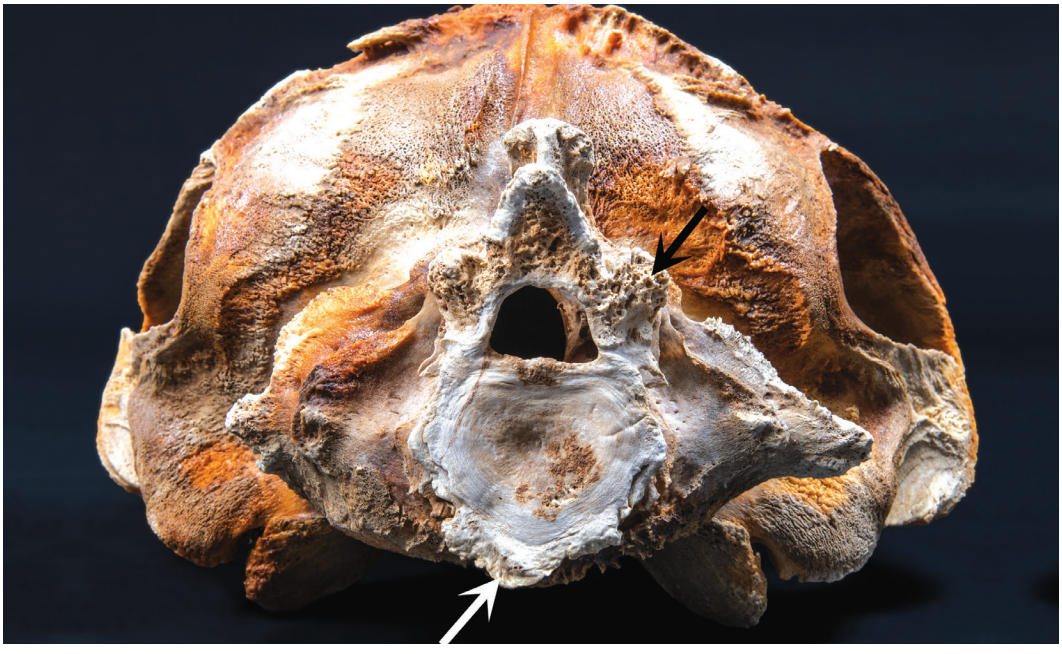

Figure 4. Caudal view of the skull and of the caudal surface of C6. The dorsal arch and subchondral bone of the zygapophyseal (facet) joints (black arrow) of C6 are severely eroded. Large osteophytes are present along the ventral region of its vertebral body (white arrow). Part of the occipital bone can be seen on the right through the vertebral canal, indicating misalignment with slight dextral deviation of the cervical vertebrae.

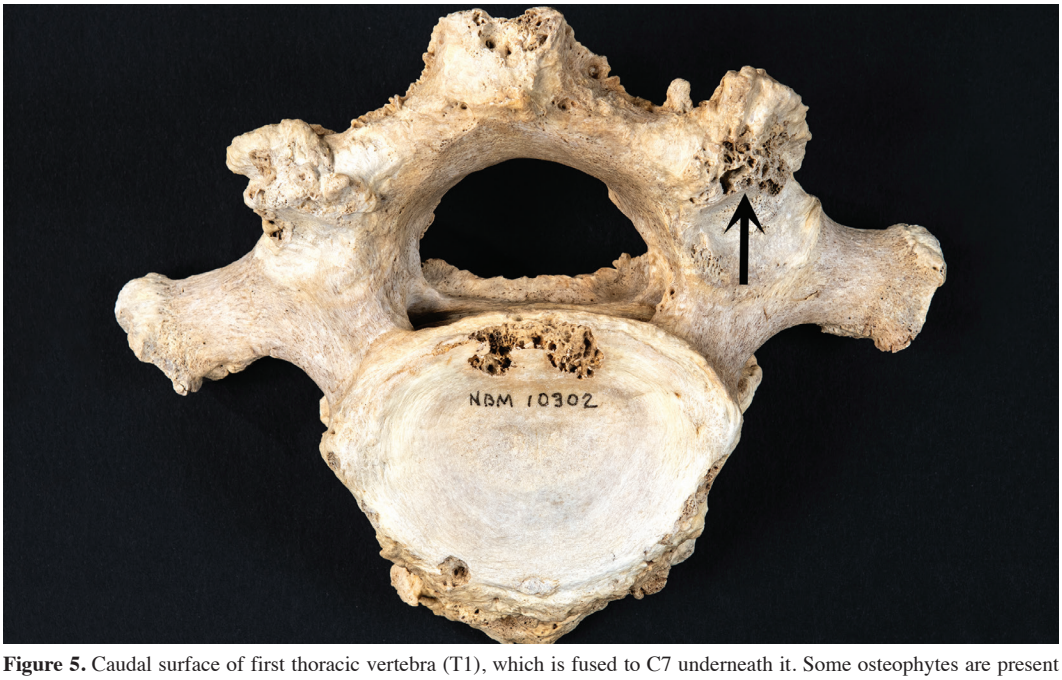

Figure 5. Caudal surface of first thoracic vertebra (T1), which is fused to C7 underneath it. Some osteophytes are present along the ventral border of the vertebral body. There is erosion of the dorsal region of the articular surface (although much less severe than on the adjacent cranial articular surface of T2; see Figure 6). There is also marked irregularity and erosion of the dorsal arch and subchondral bone of zygapophyseal joints (arrow).

Figure 6. Cranial surface of T2. Large osteophytes are present along the ventral border of the vertebral body. There is severe erosion of the ventral region of the articular surface, and the dorsal arch has failed to close.

or all cervical vertebrae increases the stability of the large head and contributes to the hydrodynamic properties of the body. The highly movable A-O joint is thus responsible for all movements of the head relative to the rest of the body (Cozzi et al., 2016). Head movements may be important in echolocation (Verfuß et al., 2009). Fusion of the A-O joint, also known as A-O assimilation or occipitalization of the atlas, is the most common congenital malformation involving the cranio-vertebral junction in humans and is caused by a failure of segmentation between the fourth occipital sclerotome and the first cervical sclerotome. Most patients are thought to remain asymptomatic (Zong et al., 2017). Conversely, dysplasia of the occipital bone in a recently born harbor seal (*Phoca vitulina*) resulted in cerebellar herniation and atlanto-axial subluxation with compression of the spinal cord and increasingly severe neurologic signs, necessitating euthanasia within a few weeks (Dennison et al., 2009).

Failure of closure of the dorsal arch of T2 and the complete separation of the dorsal arch from T3 could also represent congenital malformations. Incomplete closure of vertebral arches, involving cervical or thoracic vertebrae, has often been observed in odontocetes (Cowan, 1966; Van Bressem et al., 2007; Costa et al., 2016; San Martín et al., 2016). It was observed in 11 of 28 (39%) bottlenose dolphins (*Tursiops truncatus*), leading the authors to suggest that this osseous change could represent a normal individual variation within the population instead of a true anomaly (Costa et al., 2016). Alternatively, separation of the dorsal arch from T3 may have resulted from a pathologic fracture, considering the extensive erosion of the surface of the dorsal arch.

This Risso's dolphin also had severe erosive and proliferative lesions in C6, C7, and the cranial region of its thoracic vertebral column. Besides congenital processes, chronic vertebral lesions can be of infectious, degenerative, or traumatic origin. Infectious vertebral osteomyelitis and infectious discospondylitis usually follow hematogenous spread of bacteria to the actively growing vertebral epiphyseal plates of young animals or to the periphery of the annulus fibrosus, respectively (Craig et al., 2015). Lesions are not expected to affect several contiguous vertebral bodies, nor are

Figure 7. Caudal surface of T3. Large osteophytes are present along the ventral border of the vertebral body, and there is severe erosion of the ventral and dorsal regions of the articular surface. The dorsal arch is completely separated from the rest of the vertebra.

they expected to affect zygapophyseal joints as was the case in this dolphin.

Spondyloarthritis refers to a group of inflammatory diseases in humans and other mammals. These diseases result from a combination of genetic and environmental factors whereby some infection in a distant organ triggers sterile arthritis through an immunological reaction (Kompanje, 1999). Lesions include syndesmophytes, potentially leading to vertebral ankylosis. Intervertebral disc spaces are preserved, but there can be erosion of the articular surfaces of some of the affected vertebral bodies. Involvement of zygapophyseal joints, including their fusion, is also characteristic of this disease (Kompanje, 1999). Vertebrae along the whole vertebral column can be affected as would be expected from a disease process of a systemic nature. Spondyloarthritis has been diagnosed in various species of odontocetes, although no association between this condition and one of the co-diseases described in terrestrial mammals was firmly identified (Kompanje, 1999; Sweeny et al., 2005; Van Bressem et al., 2007). Zygapophyseal joints were affected in this Risso's dolphin; however, lumbar and caudal vertebrae were intact, whereas all cases of spondyloarthritis described in cetaceans include involvement of the lumbar and caudal regions of the vertebral column.

Discarthrosis (spondylosis deformans) is an age-related degenerative process affecting the ventral peripheral region of the annulus fibrosus and resulting in the formation of osteophytes, potentially leading to ankylosis. It is a common disease of the vertebral column, particularly the thoracolumbar region, in domestic and wild mammals, together with arthropathy of some of the appendicular joints, collectively referred to as degenerative joint disease (Wobeser & Runge, 1975; Peterson, 1988; Craig et al., 2015). Discarthrosis has been diagnosed in the lumbar and caudal regions of the vertebral column of cetaceans and attributed to mechanical stress acting on these regions during aquatic locomotion (Kompanje, 1999; Galatius et al., 2009). Involvement of the cervico-thoracic region in this early-adult Risso's dolphin is not suggestive of this condition.

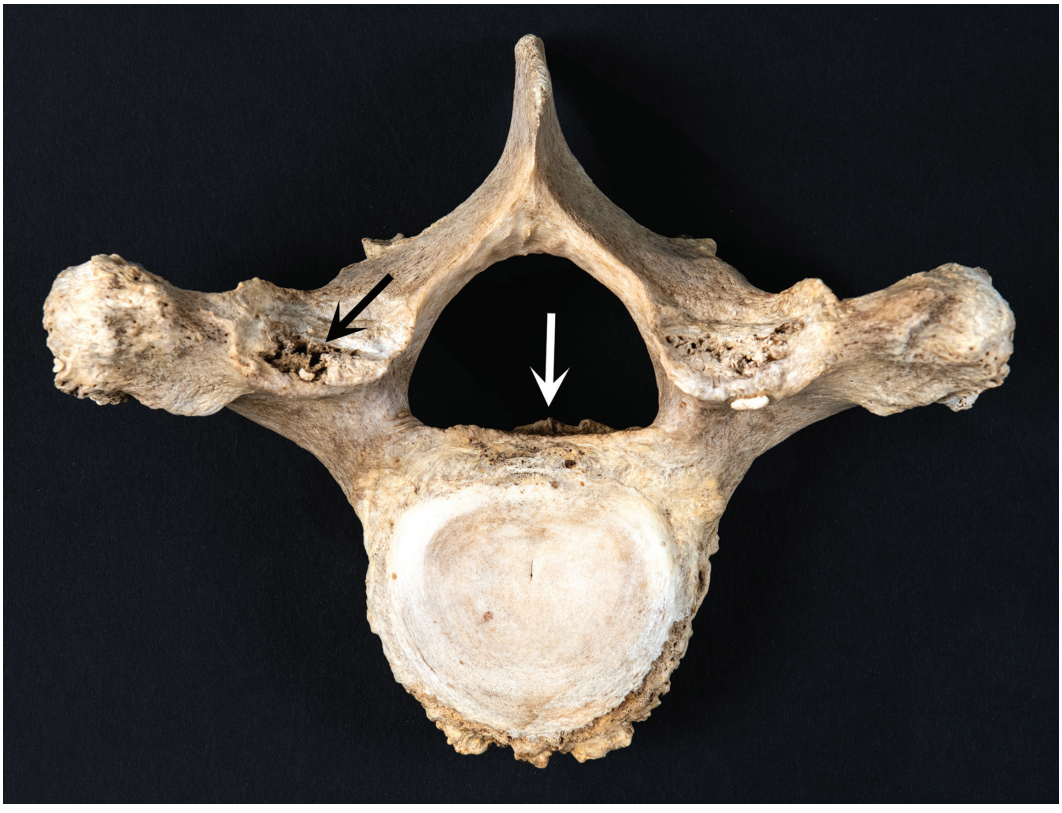

Figure 8. Cranial surface of T4. Small osteophytes are present along the ventral border of the vertebral body. The articular surface is normal (in contrast to the severely eroded adjacent articular surface of T3; see Figure 7). There is marked erosion of the subchondral bone of the left and right zygapophyseal joints (black arrow). Small osteophytes visible through the vertebral canal (white arrow) protrude slightly from the dorsal border of the caudal surface of the vertebral body.

Chronic vertebral lesions may result from direct trauma to the vertebral column (Nutman & Kirk, 1988; Sharp et al., 2019) or from abnormal forces secondary to antecedent vertebral anomalies. Severe secondary degenerative vertebral osteoarthritis was described in the thoraco-lumbar region of an adult bottlenose dolphin with congenital scoliosis caused by lumbar hemivertebrae and fused lateral and dorsal processes of thoracic vertebrae; this animal had already raised two calves and had died of an unrelated cause (DeLynn et al., 2011). We suggest that the erosive and proliferative vertebral lesions in this Risso's dolphin also resulted from compensatory processes caused by abnormal forces on the cervico-thoracic portion of the vertebral column due to the congenital inflexibility of the A-O joint. Concurrently, the exostoses observed on the surface of the occipital bone and of the left mandibular ramus may represent heterotopic ossification of the tendinous attachments of muscles joining the skull (including occipital bone and mandible) to other regions of the axial and appendicular skeleton, which are important in flexion and rotation of the head (Cozzi et al., 2016). These muscles may have sustained abnormal strains in trying to better control the movements of the head, resulting in chronic mechanical overload followed by inflammation and repair by endochondral ossification (Zhang et al., 2020).

The potential clinical consequences of skeletal lesions in free-living cetaceans are important to address. They have varied from presumably or probably absent to possibly lethal (Sweeny et al., 2005; Galatius et al., 2009; DeLynn et al., 2011; San Martín et al., 2016; Robinson et al., 2020). The marked skeletal lesions in the skull and cervico-thoracic region of the vertebral column of this Risso's dolphin were not thought to have contributed to its death. These skeletal lesions were chronic, yet this animal was considered in good nutritional condition, indicating that they had not interfered with its ability to swim and forage. As the caudal thoracic, lumbar, and caudal regions of the vertebral column were intact, the full propulsive force of the epaxial muscle mass on the flukes would have been unaffected, thus

allowing normal swimming (Pabst, 2000). This and other cases (e.g., DeLynn et al., 2011; San Martín et al., 2016; Robinson et al., 2020) demonstrate the remarkable ability of some free-living animals to adapt to, and compensate for, skeletal abnormalities. Although less easily examined than other body systems, pathological changes in the cetacean skeleton and their potential causes and influence on survival deserve more attention.

Acknowledgments

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Literature Cited

Costa, A. P. B., Loch, C., & Simões-Lopes, P. C. (2016). Variations and anomalies in the vertebral column of the bottlenose dolphin (*Tursiops truncatus*) from southern Brazil. *Latin American Journal of Aquatic Mammals*, *11*(1-2), 212-219. https://doi.org/10.5597/lajam00230

Cowan, D. F. (1966). Pathology of the pilot whale *Globicephala melaena*. *Archives of Pathology*, *82*, 178-189.

Cozzi, B., Huggenberger, S., & Oelschläger, H. (2016). *Anatomy of dolphins: Insights into body structure and function*. Academic Press.

Craig, L. E., Dittmer, K. E., & Thompson, K. G. (2015). Bones and joints. In M. G. Maxie (Ed.), *Jubb, Kennedy & Palmer's pathology of domestic animals: Vol. 1* (6th ed., pp. 16-163). Elsevier. https://doi.org/10.1016/B978-0-7020-5317-7.00002-3

Dagleish, M. P., Barley, J., Howie, F. E., Reid, R. J., Herman, J., & Foster, G. (2007). Isolation of *Brucella* species from a diseased atlanto-occipital joint of a Atlantic white-sided dolphin (*Lagenorhynchus acutus*). *The Veterinary Record*, *160*, 876-878. https://doi.org/10.1136/vr.160.25.876

DeLynn, R., Lovewell, G., Wells, R. S., & Early, G. (2011). Congenital scoliosis of a bottlenose dolphin. *Journal of Wildlife Diseases*, *47*(4), 979-983. https://doi.org/10.7589/0090-3558-47.4.979

Dennison, S. E., Forrest, L. J., Fleetwood, M. L., & Gulland, F. M. D. (2009). Concurrent occipital bone malformation and atlantoaxial subluxation in a neonatal harbor seal (*Phoca vitulina*). *Journal of Zoo and Wildlife Medicine*, *40*(2), 385-388. https://doi.org/10.1638/2008-0147.1

Fox, H. (1939). Chronic arthritis in wild mammals. *Transactions of the American Philosophical Society*, *31*(2), 73-148. https://doi.org/10.2307/1005560

Galatius, A., Sonne, C., Kinze, C. C., Dietz, R., & Jensen, J-E. B. (2009). Occurrence of vertebral osteophytosis in a museum sample of white-beaked dolphins (*Lagenorhynchus albirostris*) from Danish waters. *Journal of Wildlife Diseases*, *45*(1), 19-28. https://doi.org/10.7589/0090-3558-45.1.19

Groch, K. R., Catão-Dias, J. L., Groch, K. R., Kolesnikovas, C. K. M., de Castilho, P. V., Moreira, L. M. P., Barros, C. R. M. B., de Medeiros, C. R. M., Renault-Braga, E. P., Sansone, M., & Díaz-Delgado, J. (2019). Pathologic findings and causes of death in southern right whales *Eubalaena australis*, Brazil. *Diseases of Aquatic Organisms*, *137*, 23-31. https://doi.org/10.3354/dao03424

Hartman, K. L. (2018). Risso's dolphin. In B. Würsig, J. G. M. Thewissen, & K. M. Kovacs (Eds.), *Encyclopedia of marine mammals* (3rd ed., pp. 824-827). Academic Press/Elsevier. https://doi.org/10.1016/B978-0-12-804327-1.00219-3

Kompanje, E. J. O. (1999). Considerations on the comparative pathology of the vertebrae in Mysticeti and Odontoceti; evidence for the occurrence of discarthrosis, zygarthrosis, infectious spondylitis and spondyloarthritis. *Zoologische Mededelingen, Leiden*, *73*(5), 99-130.

Moore, M. J., & Early, G. A. (2004). Cumulative sperm whale bone damage and the bends. *Science*, *306*(5705), 2215. https://doi.org/10.1126/science.1105452

Nutman, A. W., & Kirk, E. J. (1988). Abnormalities in the axial skeleton of a Risso's dolphin. *New Zealand Veterinary Journal*, *36*(2), 91-92. https://doi.org/10.1080/00480169.1988.35490

Pabst, D. A. (2000). To bend a dolphin: Convergence of force transmission designs in cetaceans and scombrid fishes. *American Zoologist*, *40*(1), 146-155. https://doi.org/10.1093/icb/40.1.146

Peterson, R. O. (1988). Increased osteoarthritis in moose from Isle Royale. *Journal of Wildlife Diseases*, *24*(3), 461-466. https://doi.org/10.7589/0090-3558-24.3.461

Robinson, K. P., Haskins, G. N., Eisfeld-Pierantonio, S. M., Sidiropoulos, T., & Bamford, C. C. G. (2020). Presenting vertebral deformities in bottlenose dolphin *Tursiops truncatus* calves from a protected population in northeast Scotland. *Diseases of Aquatic Organisms*, *140*, 103-108. https://doi.org/10.3354/dao03498

San Martín, A. A., Macnie, S. V., Goodall, R. N. P., & Boy, C. C. (2016). Pathology in skeletons of Peale's dolphin *Lagenorhynchus australis* from southern South America. *Diseases of Aquatic Organisms*, *120*(1), 9-15. https://doi.org/10.3354/dao03010

Sharp, S. M., McLellan, W. A., Rotstein, D. S., Costidis, A. M., Barco, S. G., Durham, K., Pitchford, T. D., Jackson, K. A., Daoust, P-Y., Wimmer, T., Couture, E. L., Bourque, L., Frasier, T., Frasier, B., Fauquier, D., Rowles, T. K., Hamilton, P. K., Pettis, H., & Moore, M. J. (2019). Gross and histopathologic diagnoses from North Atlantic right whale (*Eubalaena glacialis*) mortalities between 2003 and 2018. *Diseases of Aquatic Organisms*, *135*(1), 1-31. https://doi.org/10.3354/dao03376

Sweeny, M. M., Price, J. M., Jones, G. S., French, T. W., Early, G. A., & Moore, M. J. (2005). Spondylitic changes in long-finned pilot whales (*Globicephala melas*) stranded on Cape Cod, Massachusetts, USA, between

1982 and 2000. *Journal of Wildlife Diseases*, *41*(4), 717-727. https://doi.org/10.7589/0090-3558-41.4.717

Turnbull, B. S., & Cowan, D. F. (1999). Synovial joint disease in wild cetaceans. *Journal of Wildlife Diseases*, *35*(3), 511-518. https://doi.org/10.7589/0090-3558-35.3.511

Van Bressem, M-F., van Waerebeek, K., Reyes, J. C., Félix, F., Echegaray, M., Siciliano, S., Di Beneditto, A. P., Flach, L., Viddi, F., Avila, I. C., Herrera, J. C., Tobón, I. C., Bolaños-Jiménez, J., Moreno, I. B., Ott, P. H., Sanino, G. P., Castineira, E., Montes, D., Crespo, E., Flores, P. A. C., . . . Fragoso, A. B. (2007). A preliminary overview of skin and skeletal diseases and traumata in small cetaceans from South American waters. *Latin American Journal of Aquatic Mammals*, *6*(1), 7-42. https://doi.org/10.5597/lajam00108

Verfuß, U. K., Miller, L. A., Pilz, P. K. D., & Schnitzler, H-U. (2009). Echolocation by two foraging harbour porpoises (*Phocoena phocoena*). *Journal of Experimental Biology*, *212*(6), 823-834. https://doi.org/10.1242/jeb.022137

Wobeser, G., & Runge, W. (1975). Arthropathy in white-tailed deer and a moose. *Journal of Wildlife Diseases*, *11*(1), 116-121. https://doi.org/10.7589/0090-3558-11.1.116

Zhang, Q., Zhou, D., Wang, H., & Tan, J. (2020). Heterotopic ossification of tendon and ligament. *Journal of Cellular and Molecular Medicine*, *24*(10), 5428-5437. https://doi.org/10.1111/jcmm.15240

Zong, R., Yin, Y., Qiao, G., Jin, Y., & Yu, X. (2017). Quantitative measurements of the skull base and craniovertebral junction in congenital occipitalization of the atlas: A computed tomography-based anatomic study. *World Neurosurgery*, *99*, 96-103. https://doi.org/10.1016/j.wneu.2016.11.062