INTRODUCTION

Axial deviations of the vertebral column have been reported in several delphinid species (e.g. Nutman & Kirk 1988, Wilson et al. 1997, Berghan & Visser 2000, Watson et al. 2004, Berrow & O’Brien 2006, Van Bressem et al. 2006, Bearzi et al. 2009, DeLynn et al. 2011, Robinson 2014). They can be classified as deformities arising from congenital causes (e.g. bottlenose dolphin *Tursiops truncatus* with congenital scoliosis, DeLynn et al. 2011) or that have been acquired following trauma (e.g. bottlenose dolphin with kyphosis due to conspecific aggression, Watson et al. 2004).

Such deformities are usually described within 3 categories (adapted from Noden & deLahunta 1985): (1) kyphosis — abnormal deviation of the vertebral column in a sagittal plane when vertebrae are fixed to produce a curvature of the vertebral column with concavity on the ventral side; (2) lordosis (opposite to...
kyphosis) — abnormal deviation of the vertebral column in a sagittal plane when vertebrae are fixed to produce a curvature of the vertebral column with concavity on the dorsal side; (3) scoliosis — abnormal deviation of the vertebral column in a dorsal plane so the vertebrae are fixed to produce a lateral curvature, possibilities of left- and/or right-sided curvatures. These deformities are often present in varying combinations.

Although cases of kyphosis have been reported in white-beaked dolphins *Lagenorhynchus albirostris* (Slijper 1936, van Assen 1975, Kompanje 1995), a review of vertebral column deformities in this species is not available. Here we review 8 cases of such deformities in white-beaked dolphins from Iceland, the UK, Denmark and The Netherlands.

**MATERIALS AND METHODS**

Data and photographs of free-ranging white-beaked dolphins in Iceland were collected during an 11 yr photo-identification study (2002−2013) in Faxaflói (64° 24' N, 22° 00' W, southwest coast, April to September in 2002−2011 and year-long in 2012−2013) and Skjálfandi Bays (66° 05' N, 17° 33' W, northeast coast, May to October in 2002−2013). The study was conducted in both bays from commercial whale-watching boats (20−25 m in length and providing multiple tours each day lasting approximately 3 h each) in sea states of 0 to 3 on the Beaufort scale. Several digital cameras equipped with different zoom lenses (55−200 to 70−300 mm for Faxafloi Bay, 28−135 to 40−150 mm for Skjalfandi Bay) were used in both study areas. Images were taken in both JPG (300 pixels inch−1) and RAW formats. Further details on the classification of ID marks and quality rating system used during data analysis are available in Bertulli et al. (2015).

The white-beaked dolphins photographed were assigned to 1 of 4 age classes (adult, juvenile, calf and neonate) based on the estimated size of each individual compared to the average length of an adult, and by association with conspecifics. Adult white-beaked dolphins measure between 2.4 and 3.1 m, with males typically longer than females (Reeves et al. 1999, Kinze 2008, Galatius et al. 2013). Shorter animals (~1/3 of adult length) always sighted swimming associated with an adult were considered calves. Neonates (~1/2 of adult length: Collet & Duguy 1981, Kinze 2008) were recognized by discolouration resulting from foetal folds (Karczmarski 1999). Additionally, cases were collected from outside Icelandic waters through the e-mailing list MARMAM (Marine Mammals Research and Conservation Discussion) in 2013. Images and post-mortem report information were shared by the UK Cetacean Strandings Investigation Programme at the Zoological Society of London (Case 6) and the Seal Rehabilitation and Research Centre in Pieterburen (Case 7), The Netherlands. A full necropsy was not conducted for Case 8, although the specimen was measured and examined at the Fisheries and Maritime Museum in Esbjerg, Denmark. The vertebrae from Case 6 were assembled by the Natural History Museum in London after being prepared by manual de-fleshing followed by non-chemical, cold-water maceration. Standard anatomical nomenclature and directional terminology was used based on the Nomina Anatomica Veterinaria (International Committee on Veterinary Gross Anatomical Nomenclature 2012).

**RESULTS**

Non-systematic photo-identification surveys conducted in Faxaflói and Skjálfandi Bays resulted in 426 photo-identified individuals (C. G. Bertulli unpubl. data). Among them, 5 dolphins (7 images) showed axial deviations suggestive of vertebral column deformities (Table 1), with an overall prevalence of 1.2%. Dolphins in Cases 1, 2, 4 and 5 were observed and photographed on only 1 occasion, whereas Case 3 was observed and photo-identified on 3 separate occasions.

Case 1 was a juvenile observed in July 2011 in a group of 20 dolphins, showing a marked dorsal convexity caudal to the fin, most likely involving the lumbar and caudal vertebrae and indicating kyphosis. On the left side was a deep, healing wound with granulation tissue along the dorsal ridge. There was evidence of lordosis in the region of the wound. Multiple scars were visible on the flank, peduncle and at the base of the fin (Fig. 1a; ID nDEM41; Skjalfandi Bay).

Case 2 was a juvenile observed in July 2011 with lordosis followed by kyphosis swimming within the same aggregation of 20 dolphins in which Case 5 was photographed. It had a deep wound on the left side
transversely across the dorsal ridge, 10 cm caudal to the fin, caudal to which was the dorsal hump (Fig. 1b; ID nDEM42; Skjálfandi Bay).

Case 3 was a juvenile observed in November 2012 with lordosis and kyphosis. The dolphin was photographically recaptured 9 mo later in Faxaflói Bay (August 2013), with the same deformity. There was an oval-shaped scar on the left flank caudal to the fin, which was only seen in November 2012 (Fig. 1c; ID nDEM85; Faxaflói Bay).
Case 4 was a juvenile observed in July 2005 with a dorsal convexity suggesting kyphosis. There was a depressed oval wound on the left flank caudal to the fin (Fig. 1d; ID nDEM84; Skjálfandi Bay).

Case 5 was a presumed juvenile photographed in April 2012 with a slight lordotic curvature of the vertebral column in the lumbo-caudal region followed by kyphosis (convex region in the peduncle) (Fig. 1e; not catalogued No. 2; Faxaflói Bay).

Three stranded white-beaked dolphin carcasses with vertebral deformities were reported from Europe: 1 from the UK, 1 from The Netherlands and 1 from Denmark (Table 1):

Case 6 was a juvenile male (total body length, TBL: 173 cm; 82.5 kg), stranded in a fresh condition (Code 2 sensu Rowles et al. 2001) in Bridlington, Humberside, England, on 22 February 1995. The dolphin was in a moderate nutritional condition (girth cranial to the fin of 112 cm; blubber thickness cranial to the fin, 11 mm mid-dorsal, 11 mm mid-lateral, 14 mm mid-ventral). The lateral extremities of the left and right flukes were cut off approximately 5 cm from the lateral tips, although the cut-off part of the right fluke was still attached to the rest of the fluke by a thin piece of epidermis. These wounds were consistent with mortality due to entrapment in fishing gear (e.g. Read & Murray 2000, Barco & Moore 2013). Midline to the caudal insertion of the fin and orientated at right angles to the long axis of the body was an older, deep, transverse chronic wound with underlying fibrosis of the blubber layer and surrounding epithelial nodular hyperplasia. The wound had a red base of granulation tissue surrounded by raised nodular epithelial tissue forming a deep cleft (Fig. 2a,b). The dorsal muscle mass was grossly normal. Skeletal preparation of the vertebral column revealed a marked kyphoscoliosis just caudal to the fin at the approximate level of the cutaneous wound. The transverse and spinous processes of the lumbar vertebrae were deformed, the transverse processes appearing progressively ‘bent’ dorsally and then ventrally, depending on the region of the vertebral column. Additionally, there was considerable periosteal reaction and new bone proliferation around the vertebral arches of the first few caudal vertebrae (Fig. 2c). There was no significant stenosis of the vertebral canal in the affected vertebrae. More caudally there was additional periosteal bone reaction on the ventral and ventrolateral aspects of the vertebral bodies of several caudal vertebrae, particularly Caudals 9, 10 and 11, without ankylosis, intervertebral disc compromise or erosion of the epiphyses (Fig. 2c). These changes were suggestive of severe osteomyelitis, perhaps originating from the dorsal wound.

Case 7 was a juvenile male (TBL 184 cm, 85 kg) with girth cranial to the fin of 105 cm. It stranded on the island of Terschelling, The Netherlands, on 6 January 1999 in a fresh condition (Code 2; Rowles et al. 2001). It had several skin marks and lacerations on the melon and lower jaw, possibly associated with fishery interactions (e.g. Read & Murray 2000, Barco & Moore 2013). The dolphin had a healed wound, approximately 2–3 cm deep caudal to the fin, immediately cranial to a prominent dorsal kyphotic hump (Fig. 3a,d). An unusual ‘depression’ was visible on the left flank ventrocaudal to the fin (Fig. 3c), and the vertebral anomalies extended from 17 cm caudal to the insertion of the fin to the level of the anus. The total length of the deformed region measured 72 cm.

Case 8 was a juvenile male (TBL 187 cm, 100 kg) stranded at Husby Klit, central west coast of Jutland, Denmark, on 6 April 2003. A full necropsy was not performed, and only the skull was recovered. Caudal to the fin there was a pronounced concavity indicative of lordosis (Fig. 4). Blubber thickness was only 14 mm, considerably less than the normal values for this time of year (25 mm, C. C. Kinze unpubl. data).

**DISCUSSION**

During this study, 8 white-beaked dolphins (5 free-ranging and 3 stranded) were observed with confirmed or probable kyphosis, lordosis or kyphoscoliosis. We were unable to specifically identify the cause in the 5 free-ranging dolphins from Iceland. However, 4 cases (free-ranging: Cases 1 and 2; stranded: Cases 6 and 7) showed indications of being caused by trauma, with linear (Figs. 1a,b & 2) or semi-circular (Fig. 3) shaped wounds caudal to the fin on the dorsal ridge. The remaining 3 free-ranging dolphins (Cases 3, 4 and 5) did not have any visible signs of previous trauma. In 2 stranded white-beaked dolphins from England (Case 6) and The Netherlands (Case 7), there was a clear association between trauma and kyphoscoliosis. These lesions may have led to osteomyelitis in Case 6.

The trauma that caused these deformities were most likely of anthropogenic origin. Deep oblique incision wounds across the dorsal lumbar region caudal to the fin in a free-ranging bottlenose dolphin (Fig. 1 in Dwyer et al. 2014) and killer whales (Fig. 1 in Visser 1999) have been suggested to be propeller strike wounds. Similar wounds in 8 Atlantic spotted dolphins *Stenella frontalis* (Fig. 3a in Luksenbug
Fig. 2. Juvenile male white-beaked dolphin *Lagenorhynchus albirostris* (total body length: 173 cm) with kyphoscoliosis stranded on the coast of England (Case 6). (a) Entire right lateral view, (b) detail of wound at caudal base of fin (arrow) and cut-off right fluke tip (arrowhead). (Photo credits: Zoological Society of London.) (c) Ventral view of the caudal vertebrae (2–12; cranial is to the right), showing periosteal bone reaction on the ventral and ventrolateral aspects of caudal vertebrae 9–11, which is suggestive of a severe osteomyelitis (arrow). (Photo credit: The Natural History Museum, London)
2014) and 4 Indo-Pacific bottlenose dolphins *Tursiops aduncus* (Fig. 4 in Kiszka et al. 2008) were reported to have anthropogenic origins (e.g. probably interaction with fishing gear). Additionally, propeller cut wounds were described on the dorsal ridge cranial to the fin in an Indo-Pacific humpback dolphin *Sousa chinensis* (Fig. 1 in Parsons & Jefferson 2000). With the exception of the wounds observed in the humpback dolphin, all lesions were located caudal to the fin and associated with deep incisions in the skin, as in our study. Furthermore, the wounds observed in our white-beaked dolphins were single, linear, approximately transverse marks similar to those reported in Atlantic spotted dolphins (Fig. 3a in Luksemburg 2014) and Indo-Pacific bottlenose dolphins (Fig. 4 in Kiszka et al. 2008), which is in contrast to the multiple roughly parallel curved, Z- or S-shaped or straight lacerations resulting from vessel interactions (Barco & Moore 2013). White-beaked dolphins are bycaught in gillnet and longline fisheries (Víkingsson & Ólafsdóttir 2004, Pike et al. 2009) and in trawl nets (Kinze et al. 1997), but specific resultant wounds have not been reported. Whales, dolphins and porpoises swim by bending their vertebral column and moving the peduncle and flukes dorsoventrally (Fish & Hui 1991, Long et al. 1997, Pabst 2000). Thus, it is the interaction between muscles, tendons, vertebrae and ligaments which allows movement (Fish & Hui 1991, Long et al. 1997). As a result, severe consequences for the survival and movement of cetaceans may occur when a lesion compromises the elasticity or changes the normal arrangement of the vertebrae in the column (DeLynn et al. 2011).

In this study, 1 white-beaked dolphin (Case 6, Fig. 2) was affected by kyphoscoliosis. Although such a deformity is likely to impair normal locomotory functions, this dolphin had been able to catch food as indicated by the presence of fish bones in the oesophagus and remnants of partially digested fish in the fore-stomach compartment.
Without more extensive data, it is difficult to assess the impact of these vertebral column abnormalities upon the survival of affected dolphins, although their longevity would probably be influenced by the extent of the abnormalities and the resulting complications (Berghan & Visser 2000, Haskins & Robinson 2007). There are some reported cases of individuals coping with a vertebral column deformity for several months, as in the case of a captive bottlenose dolphin surviving 12 mo with slight kyphoscoliosis (Watson et al. 2004) or a Risso’s dolphin with abnormalities in the vertebral column estimated to have existed for several months but no longer than a year (Nutman & Kirk 1988). Berghan & Visser (2000) also reported a bottlenose dolphin (their Case 6 ‘Quasimodo’) with 2 prominent kyphotic deformations which did not show any apparent changes for 8 consecutive years, while Haskins & Robinson (2007) identified a female bottlenose dolphin with slight lordosis which was photographically recaptured over 7 yr and gave birth to calves twice during that time. A male common bottlenose dolphin with wounds on the fin caused by a boat propeller and scoliosis of the peduncle (acquired prior to the boat strike) was also reported to have survived at least 25 yr after the accident (Wells et al. 2008).

Our results indicate that vertebral column deformities occur in white-beaked dolphins and that some individuals may live with such anomalies for several months. With 426 identified white-beaked dolphins in Icelandic coastal waters (C. G. Bertulli unpubl. data), the overall prevalence of vertebral column deformities in this sample was 1.2%. However, an over- or under-identification of dolphins with deformities might have affected our results due to the lack of a formal stranding network in Iceland—a specimen with a deformity might not be regularly reported—and due to an increased observed elusive behaviour displayed by certain local individuals over the years (C. Bertulli pers. obs.). Prevalence of verte-
bral deformities varies among dolphin species and populations. Kyphosis and scoliosis affected 0.18% (N = 545, 1990−1994) and 0.32% (N = 314, 1985−1989) of long-beaked common dolphins Delphinus capensis in Peru, respectively (Van Bressem et al. 2006), whereas axial conformational deformities in bottlenose dolphins from northeast Scotland was estimated at 4.9% (Fig. 2i in Wilson et al. 1997).

A better understanding of the aetiology of these vertebra column deformities will be facilitated through appropriate necropsy examination of future cases, especially a microscopic evaluation of the musculature on either side of the deformed region(s).

Acknowledgements. We thank all Faxaflói and Skjálafandi Cetacean Research volunteers who helped collect data from 2007 to 2014. Thanks are also due to the volunteers from the Húsavík Whale Museum and the Húsavík Research Center. Our immense gratitude goes to Elding Whale-watching and North Sailing for providing their vessels. Nykøping Oising helped gather data and information about the malformed specimen from The Netherlands. Thygje Jensen (1919−2014) and Svend Tougaard examined and measured a specimen (Case 8). The necropsy of the UK stranded white-beaked dolphin was conducted under the aegis of the UK Cetacean Strandings Investigation Programme, which is jointly funded by Defra and the Devolved Administrations of Scotland and Wales. David J. Janiger of the Natural History Museum of Los Angeles County provided valuable literature. We are grateful to 3 anonymous reviewers for their detailed and helpful suggestions, which have improved the manuscript.

LITERATURE CITED

Barco S, Moore K (2013) Handbook for recognizing, evaluating, and documenting human interaction in stranded cetaceans and pinnipeds. US Department of Commerce, NOAA, Technical Memorandum, NOAA-TM-NMFS-SWFC-510. Available at https://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-510.pdf (last accessed 02.09.2015)

Bearzi G, Notarbartolo di Sciara G, Politi E (1997) Social ecology of bottlenose dolphins in the Kvarneri (Northern Adriatic Sea). Mar Mamm Sci 13:650−668

Bearzi M, Rapoport S, Chau J, Saylan C (2009) Skin lesions and physical deformities of coastal and offshore common bottlenose dolphins (Tursiops truncatus) in Santa Monica bay and adjacent areas, California. Ambio 38:66−71

Berghen J, Visser IN (2000) Vertebral column malformations in New Zealand delphinids: with a review of cases worldwide. Aquat Mamm 26:17−25

Berrow SD, O’Brien J (2006) Scoliosis in bottlenose dolphins Tursiops truncatus (Montagu) in Ireland. Ir Nat J 28:219−220

Bertulli CB, Tetley MJ, Magnúsdóttir EE, Rasmussen MH (2015) Observations of movement and site fidelity of white-beaked dolphins (Lagenorhynchus albirostris) in Icelandic coastal waters using photo-identification. J Cetacean Res Manag 15:27−34

Collet A, Duguy R (1981) Lagenorhynchus albirostris (Cetacea, Odontoceti): espèce nouvelle pour la faune de France. Mammalia 45:387−388

DeLynn R, Lovewell G, Wells RS, Early G (2011) Congenital scoliosis of a bottlenose dolphin. J Wildl Dis 47:979−983

Dwyer SL, Kozmian-Ledward L, Stockin KA (2014) Short-term survival of severe propeller strike injuries and observations on wound progression in a bottlenose dolphin. NZ J Mar Freshw Res 48:294−302

Fish FE, Hui CA (1991) Dolphin swimming—a review. Mammal Rev 21:181−195

Galaburda A, Jansen OE, Kinze CC (2013) Parameters of growth and reproduction of white-beaked dolphins (Lagenorhynchus albirostris) from the North Sea. Mar Mamm Sci 29:348−355

Haskins GN, Robinson KP (2007) Visually-detectable attributes of spinal malformations in free-ranging bottlenose dolphin calves in northeast Scotland. Proc 21st Annu Conf European Cetacean Society, San Sebastian, Spain, 22−23 April 2007. Available at www.crru.org.uk/cust_images/pdfs/Haskins_Robinson_ECS2007.pdf (last accessed 10.03.2013)

International Committee on Veterinary Gross Anatomical Nomenclature (2012) Nomina Anatomica Veterinaria, 5th edn (revised). Editorial Committee of the International Committee on Veterinary Gross Anatomical Nomenclature, Hannover. Available at www.wava-amav.org/Downloads/nav_2012.pdf

Karczmarski L (1999) Group dynamics of humpback dolphins (Sousa chinensis) in the Algoa Bay region, South Africa. J Zool (London) 249:283−293

Kinze CC (2008) White-beaked dolphin Lagenorhynchus albirostris. In: Perrin WF, Würsig B, Thewissen JGM (eds) Encyclopedia of marine mammals, 2nd edn. Williams & Wilkins, Baltimore, MD

Kiszka J, Pelourdeau D, Rideaux V (2008) Body scars and dorsal fin disfigurement as indicators of interaction between small cetaceans and around the Mozambique Channel Island of La Mayotte. West Indian Ocean J Mar Sci 7:185−193

Kompanje EJO (1995) On the occurrence of spondylistis deformans in white-beaked dolphins Lagenorhynchus albirostris (Gray, 1846) stranded on the Dutch coast. Zool Meded (Leiden) 69:231−250

Lokkenburg JA (2014) Prevalence of external injuries in small cetaceans in Aruban waters, southern Caribbean. PLoS ONE 9:e88988

Mann J, Smuts B (1999) Behavioral development in wild bottlenose dolphin newborns (Tursiops sp.). Behaviour 136:529−566

Noden D, de Lahunta A (1985) The embryology of domestic animals, developmental mechanisms and malformations. Williams & Wilkins, Baltimore, MD

Nutman AW, Kirk EJ (1988) Abnormalities in the axial skeleton of a Risso’s dolphin, Grampus griseus. NZ Vet J 36:91−92
Bertulli et al.: Vertebral column deformities in *L. albirostris* 67

- Pabst DA (2000) To bend a dolphin: convergence of force transmission designs in cetaceans and scombrid fishes. Am Zool 40:146–155
- Parsons ECM, Jefferson TA (2000) Post-mortem investigations on stranded dolphins and porpoises from Hong Kong waters. J Wildl Dis 36:342–356
- Pike DG, Paxton CGM, Gunnaugsson T, Vikingsson GA (2009) Trends in the distribution and abundance of cetaceans from aerial surveys in Icelandic coastal waters, 1986–2001. NAMMCO Sci Pub 7:117–142
- Read AJ, Murray KT (2000) Gross evidence of human-induced mortality in small cetaceans. Tech Memo NMFS-OPR-15. US Department of Commerce, NOAA, available at www.nmfs.noaa.gov/pr/pdfs/health/human_induced_mortality.pdf (last accessed 04.03.2015)
- Reeves RR, Smeenk C, Kinze CC, Brownell RL, Lien J (1999) White-beaked dolphin, *Lagenorhynchus albirostris* Gray, 1846. In: Ridgway SH, Harrison SR (eds) Handbook of marine mammals, Vol 6. The second book of dolphins and porpoises. Academic Press, San Diego, CA, p 1–30
- Robinson KP (2014) Agonistic intraspecific behavior in free-ranging bottlenose dolphins: calf-directed aggression and infanticidal tendencies by adult males. Mar Mamm Sci 30:381–388
- Rowles TK, Van Dolah F, Hohn AA (2001) Gross necropsy and specimen collection protocols. In: Dierau LA, Gulland FM (eds) CRC handbook of marine mammal medicine, 2nd edn. CRC Press, New York, NY, p 449–470
- Slijper EJ (1936) Die Cetaceen vergleichend-anatomisch und systematisch. Capita Zoologica, Vol 7. M Nijhoff, The Hague
- van Assen R (1975) Over een merkwaardige witsnuitdolfijn van het strand van Terschelling. Levende Nat 78:63–64
- Van Bressem MF, Van Waerebeek K, Montes D, Kennedy S and others (2006) Diseases, lesions and malformations in the long-beaked common dolphin *Delphinus capensis* from the Southeast Pacific. Dis Aquat Org 68: 149–165
- Vikingsson GA, Ólafsdóttir D (2004) White-beaked dolphin. In: Hersteinsson P (ed) Icelandic mammals. Vaka-Helgafell, Reykjavik, p 154–157
- Visser IN (1999) Propeller scars on and known home range of two orca (*Orcinus orca*) in New Zealand waters. NZ J Mar Freshw Res 33:635–642
- Watson A, Bahr RJ, Alexander JW (2004) Thoracolumbar kyphoscoliosis and compression fracture of a thoracic vertebra in a captive bottlenose dolphin (*Tursiops truncatus*). Aquat Mamm 30:275–278
- Wells RS, Allen JB, Hofmann S, Bassos-Hull K and others (2008) Consequences of injuries on survival and reproduction of common bottlenose dolphins (*Tursiops truncatus*) along the west coast of Florida. Mar Mamm Sci 24: 774–794
- Wilson B, Thompson PM, Hammond PS (1997) Skin lesions and physical deformities in bottlenose dolphins in the Moray Firth: population prevalence and age-sex differences. Ambio 26:243–247

Editorial responsibility: Michael Moore, Woods Hole, Massachusetts, USA

Submitted: December 23, 2014; Accepted: July 7, 2015
Proofs received from author(s): September 4, 2015