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Vertebral column deformities in white-beaked dolphins from the eastern North Atlantic

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ABSTRACT: Five white-beaked dolphins *Lagenorhynchus albirostris* with outwardly vertebral kyphosis, kyphoscoliosis or lordosis were identified during a photo-identification survey of over 400 individuals (2002–2013) in Faxaflói and Skjálfandi Bays, Iceland. In addition, 3 stranding reports from Denmark, The Netherlands and the UK were analysed, providing both external observation and post mortem details of axial deviations of the vertebral column in this species. Two of the free-ranging cases and 2 of the stranded specimens appeared to have an acquired disease, either as a direct result of trauma, or indirectly from trauma/wound and subsequent infection and bony proliferation, although we were unable to specifically identify the causes. Our data represent a starting point to understand vertebral column deformations and their implications in white-beaked dolphins from the eastern North Atlantic. We recommend for future necropsy cases to conduct macro- and microscopic evaluation of muscle from both sides of the deformed region, in order to assess chronic or acute conditions related to the vertebral deformations and cause of death.

KEY WORDS: Vertebral column deformity · Kyphosis · Kyphoscoliosis · Lordosis · White-beaked dolphin · *Lagenorhynchus albirostris*

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

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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 (~⅔ of adult length), either seen swimming alone or in the company of an adult (excluding those in infant position) were classified as juveniles (Bearzi et al. 1997, Karczmarski 1999, Mann & Smuts 1999); individuals (<½ of adult length) always sighted swimming associated with an adult were considered calves. Neonates (<⅓ 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; Skjálfandi 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

Table 1. Eight cases of free-ranging (Cases 1–5) and stranded (Cases 6–8) white-beaked dolphins *Lagenorhynchus albirostris* with axial deformations of their vertebral columns. N_{case}: number of images taken for each case; TBL: total body length; Ukn: unknown; A: adult; J: juvenile; M: male

Case no.	N_{case}	Side photographed	Date of sighting/ stranding (dd/mm/yy)	Sex	TBL (cm)	Age class	Weight (kg)	Type of malformation
1	1	Left	23/07/2012	Ukn	Ukn	J	Ukn	Kyphosis and lordosis
2	1	Left	23/07/2012	Ukn	Ukn	J	Ukn	Kyphosis and lordosis
3	3	Left	07/11/2012	Ukn	Ukn	J	Ukn	Kyphosis and lordosis
4	1	Left	30/07/2005	Ukn	Ukn	A	Ukn	Kyphosis
5	1	Left	04/04/2012	Ukn	Ukn	J	Ukn	Kyphosis and lordosis
6	6	Both	22/02/1995	M	173	J	82.5	Kyphoscoliosis
7	22	Both	06/01/1999	M	184	J	85	Kyphosis
8	4	Both	06/04/2003	M	187	J	100	Lordosis

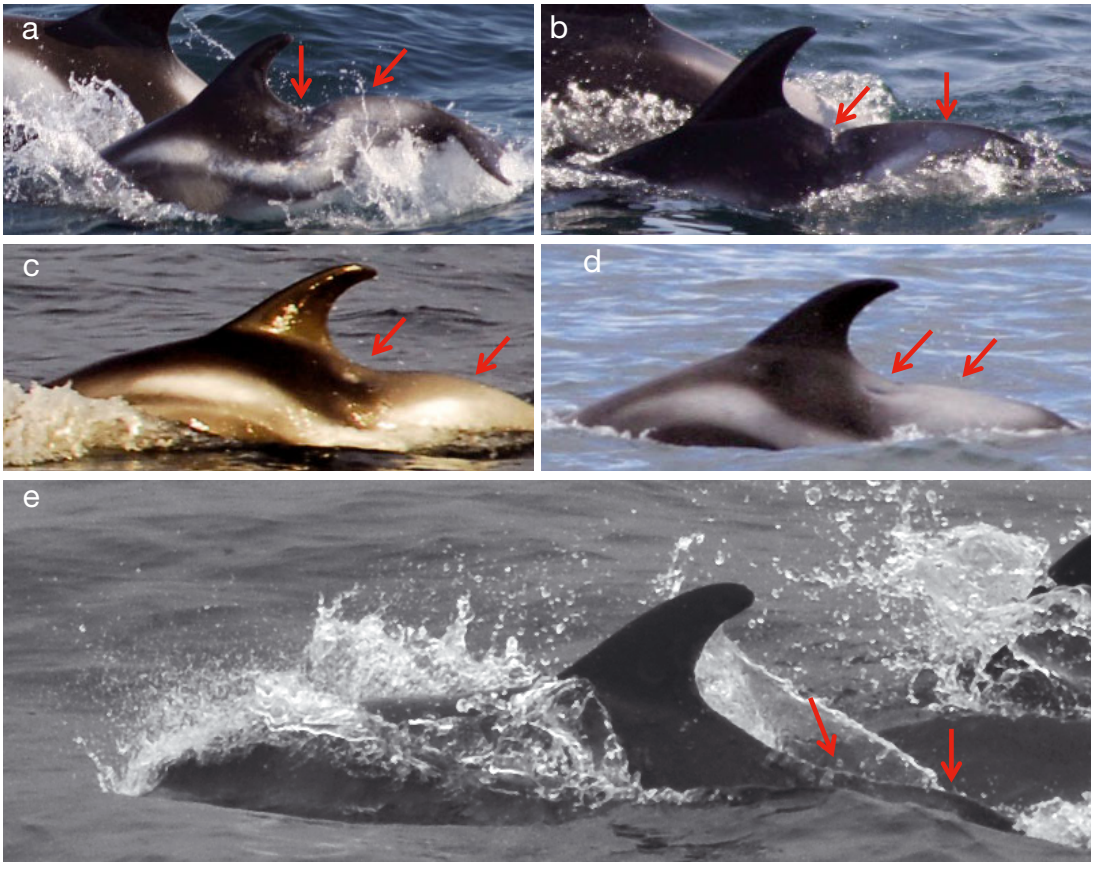

Fig. 1. Five cases of kyphosis and lordosis observed in white-beaked dolphins *Lagenorhynchus albirostris* in Icelandic waters. (a,b) Cases 1 and 2: juveniles with lordosis (left arrow) followed by kyphosis (right arrow) photographed in Skjálfandi Bay (photo credits: Zoe Burr, University of Iceland); (c) Case 3: juvenile with lordosis (left arrow) followed by kyphosis (right arrow) photographed in Faxaflói Bay (photo credit: Meggie Hudspith, University of Iceland); (d) Case 4: adult with kyphosis (right arrow) and a depressed oval wound (left arrow) photographed in Skjálfandi Bay (photo credit: Húsavík Whale Museum); (e) Case 5: juvenile with lordosis (left arrow) followed by kyphosis (right arrow) photographed in Faxaflói Bay (photo credit: Sarah Lawrence, University of Iceland)

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 Luksenburg

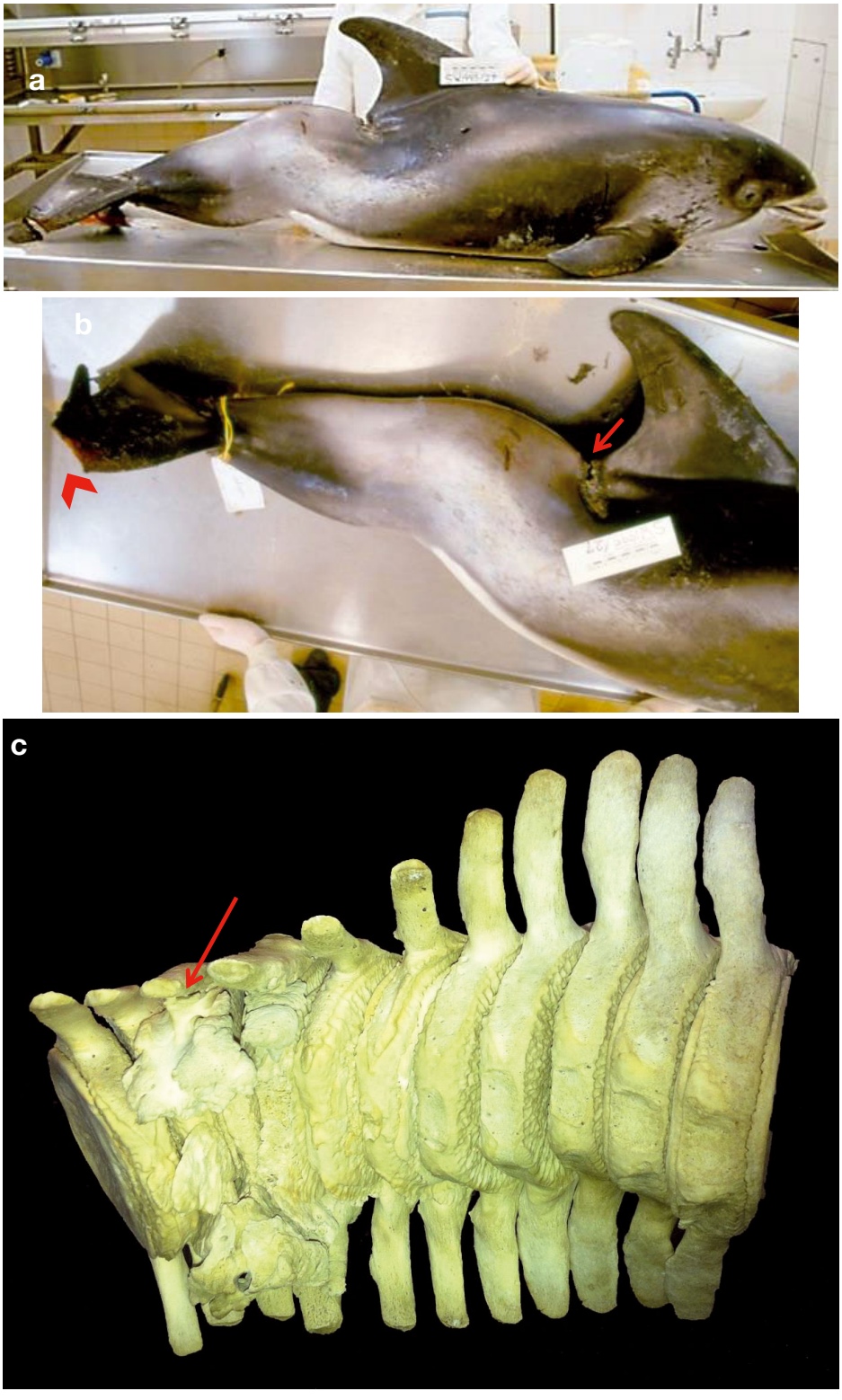

Fig. 2. Juvenile male white-beaked dolphin *Lagenorhynchus albirostris* (total body length: 173 cm) with kyphoscoliosis stranded on the coast of England (Case 6). (a) Entire right lateral view, (b) detail of wound at caudal base of fin (arrow) and cut-off right fluke tip (arrowhead). (Photo credits: 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)

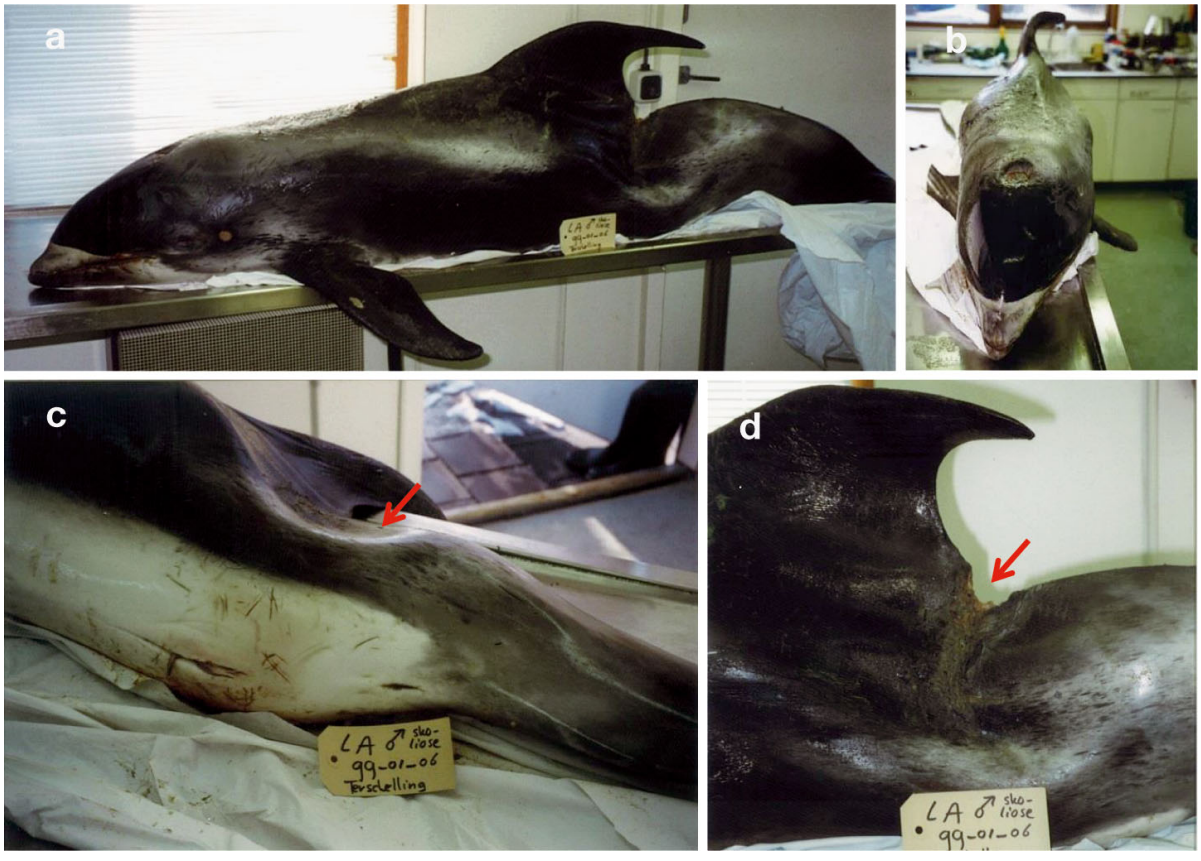

Fig. 3. Juvenile male white-beaked dolphin *Lagenorhynchus albirostris* (total body length 184 cm) with kyphosis stranded on the Dutch island of Terschelling (Case 7). (a) Entire left lateral view with wound caudal to the fin and visible kyphotic hump, (b) entire dorsal view with visibly deformed fin, (c) partial ventral view with visible 'depression' on left flank (arrow), (d) partial left lateral view with detail of wound at caudal base of fin (arrow). (Photo credits: Seal Rehabilitation and Research Centre, Pieterburen)

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 Luksenburg 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.

Fig. 4. Juvenile male white-beaked dolphin *Lagenorhynchus albirostris* (total body length 187 cm) with lordosis stranded on the coast of Denmark (Case 8). (a) Entire left lateral view with pronounced concavity in the dorsal lumbar area indicative of lordosis, (b) the pronounced S-shaped deformation of the vertebral column, (c) entire right lateral view with visible lordosis. A: anus; P: preputial opening. (Photo credits: C. C. Kinze)

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 scoliokyphosis 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 vertebral 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).

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