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Intraspongious disc herniation (Schmorl's node) and chronic spondylodiscitis in harbour porpoises *Phocoena phocoena* (Mammalia, Cetacea)

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ABSTRACT
Pathological changes found in the vertebrae of two harbour porpoises (*Phocoena phocoena*) found along the North Sea shoreline of the Netherlands are described. One case can be diagnosed as intraspongious vertebral herniation of the nucleus pulposus (Schmorl's node). The aetiology of Schmorl's nodes is most probably resulting from idiopathic ischaemic (avascular) necrosis beneath the cartilaginous endplate, with secondary herniation of the nucleus pulposus into the vertebral body. The other case can be diagnosed as a severe case of spondylodiscitis, possibly resulting from an infection with *Brucella ceti*.

Keywords Cetacea, *Phocoena phocoena*, harbour porpoise, intraspongious disc protrusion, Schmorl's node, avascular necrosis, *Brucella ceti*, Brucellosis, spondylodiscitis

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INTRODUCTION

Pathological conditions of the bones, ligaments and other structures of the vertebral column in dolphins are frequently found during autopsies, radiographic examinations of dead and alive dolphins and during examination of cleaned skeletons stored in the collections of natural history museums.

In many cetacean species, several pathological conditions are recognised and described in the literature, among which congenital anomalies; degenerative discarthrosis and zygarthrosis (spondylosis deformans); reactive spondyloarthropathy (ankylosing spondylitis); intervertebral disc herniation (Schmorl's nodes) and infectious spondylodiscitis (spondylitis, osteomyelitis of the spine). For overviews of the literature see e.g. Kompanje (1999), Berghan & Visser (2000), Galatius *et al.* (2009), La Sala *et al.* (2012) and Groch *et al.* (2012).

This article describes the pathological changes found in the

vertebral columns of two harbour porpoises *Phocoena phocoena* found dead in 2000 and 2003 on the Dutch coast. The complete skeletons of both porpoises are kept in the collection of the Natural History Museum Rotterdam, the Netherlands.

CASE REPORTS

Case 1

In 2000, a dead female harbour porpoise was found on Neeltje Jans, Oosterschelde, province of Zeeland, the Netherlands. The length of the animal was 168 cm, the weight 54 kg. During autopsy it appeared that the porpoise was pregnant of an almost full grown fetus.

All vertebrae and intervertebral discs were studied during autopsy for pathological changes. The 4th and 5th, and 10th and 11th lumbar vertebrae were fused by a smooth ventrally protruding ankylosis. None of the other vertebrae and intervertebral discs showed any abnormality. The fused vertebrae were sectioned longitudinally, after which vertical intraspongious disc protrusions and destruction of the vertebral endplates became visible (Fig. 1). The disc protrusion between the 4th and 5th lumbar vertebrae is situated near the spinal canal (Fig. 1 A), the lesion between the 10th and 11th vertebrae near the ventral part of the vertebral body (Fig. 1 B). Both intervertebral discs

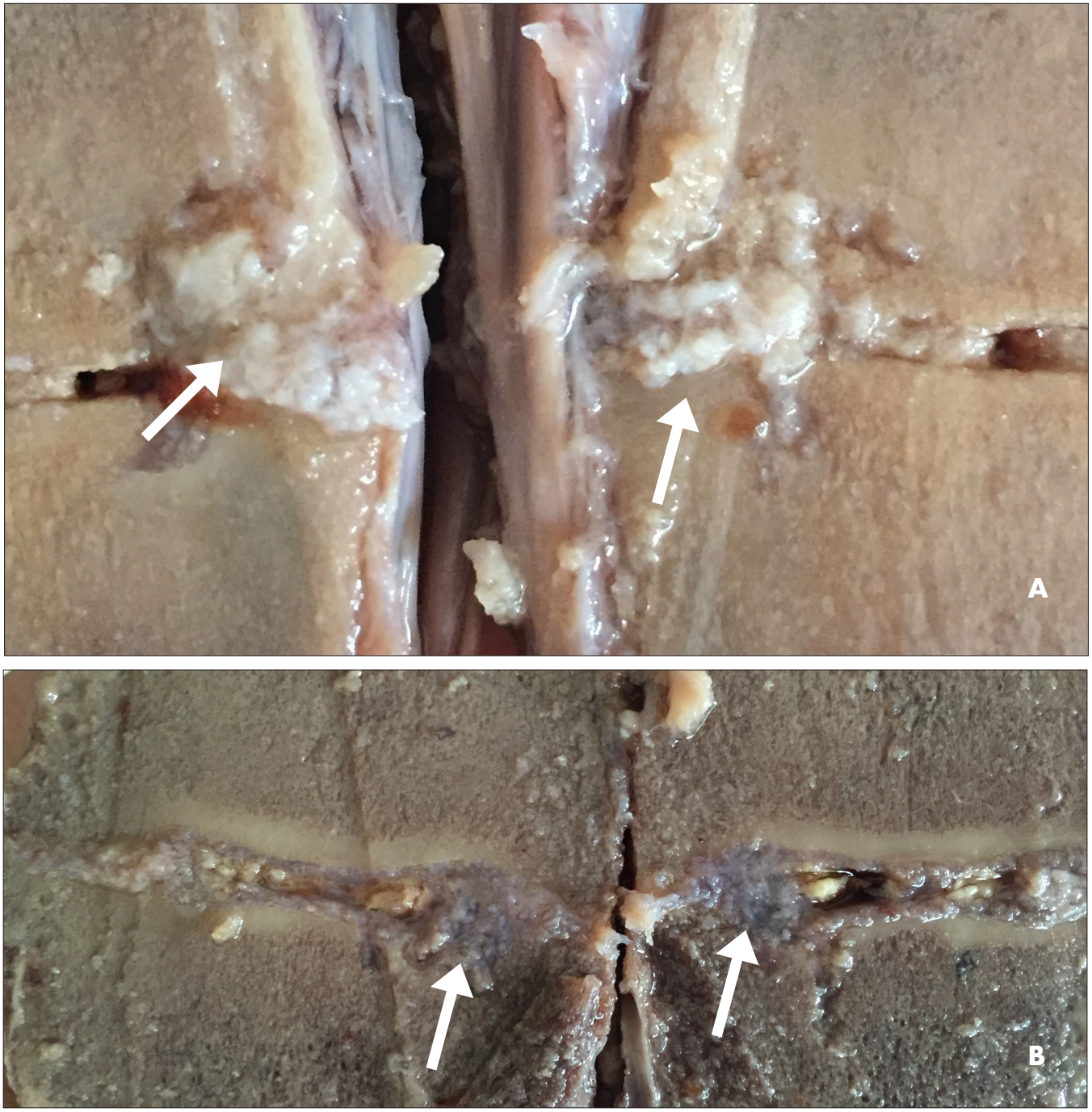

Figure 1 Case 1: *Phocoena phocoena*, adult female (NMR 9990-001402). **A** Longitudinally sectioned 4th and 5th lumbar vertebrae, showing protrusion of the intervertebral disc near the spinal canal and destruction of the vertebral endplate. **B** Longitudinally sectioned 10th and 11th lumbar vertebrae, showing protrusion of the intervertebral disc near the ventral part of the vertebral body. Intervertebral disc shows an advanced stage of degeneration. (Erwin Kompanje)

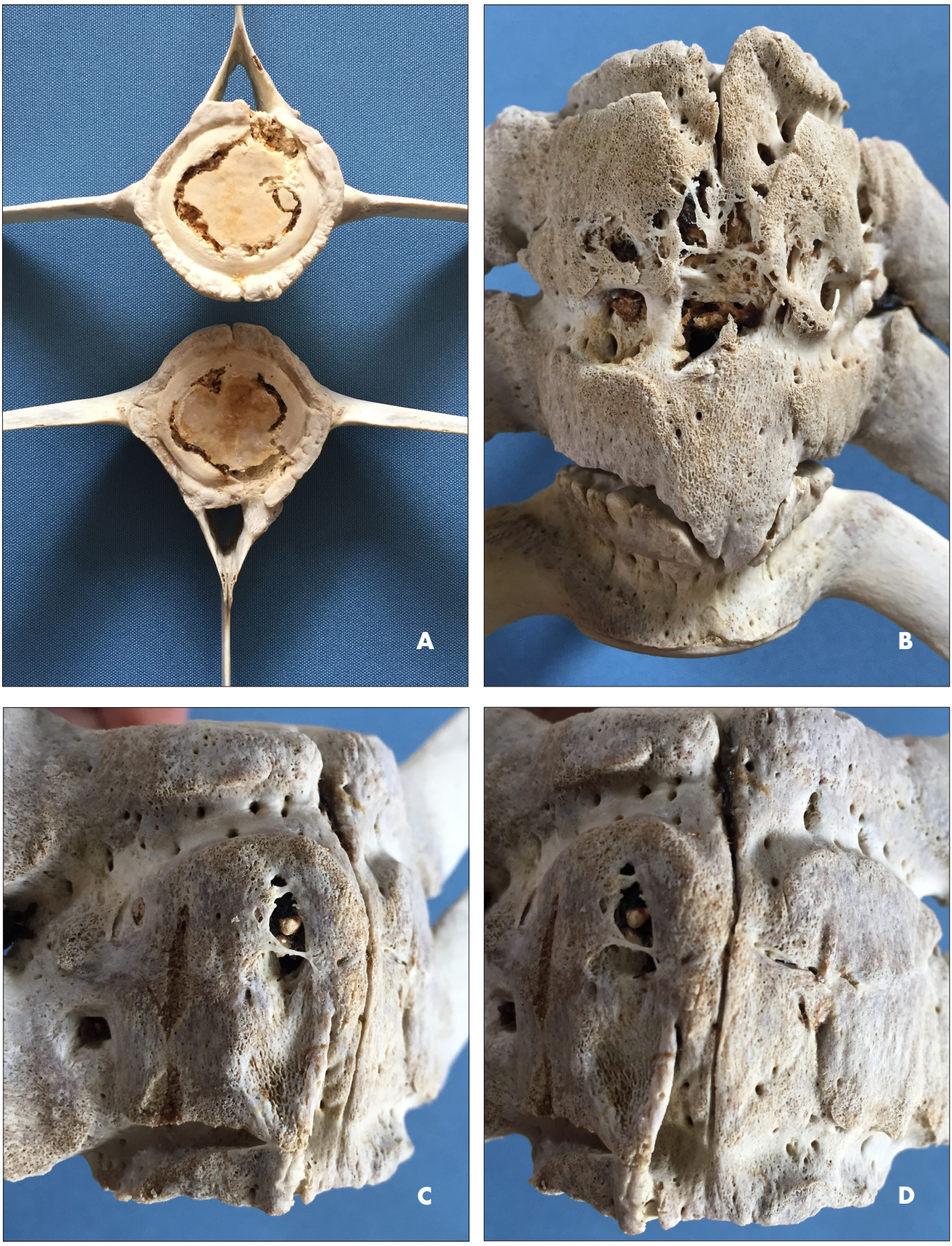

Figure 2 Case 2: *Phocoena phocoena*, adult female (NMR 9990-001429). **A** 9th and 10th lumbar vertebrae. The distal endplate of the 9th and the proximal endplate of the 10th lumbar vertebrae show ring-formed destruction of the vertebral endplate. Marginal osteophytes. **B** 11th-13th lumbar vertebrae. On the margins of the distal endplate of the 11th lumbar vertebra a corona of osteophytes is visible lipping with osteophytes on the 12th lumbar vertebra. The 12th-13th lumbar vertebrae are fused by a massive new bone formation and ossification of vertebral ligaments. **C** 14th-15th lumbar vertebrae. Complete fusion. Lateral view. **D** 14th-15th lumbar vertebrae, ventral view; complete fusion. (Erwin Kompanje)

showed an advanced stage of degeneration.

The complete disarticulated skeleton is kept in the Natural History Museum Rotterdam (NMR 9990-001402).

Case 2

On 26 December 2003 a dead adult female harbour porpoise was found on the beach between Camperduin and Egmond aan Zee (beachmarker 31), province of Noord-Holland, the Netherlands. The length of the animal was 157 cm.

During autopsy all vertebrae and intervertebral discs were studied for pathological changes. Severe pathological changes were found in several lumbar vertebrae. The first lumbar vertebra is completely normal. The 2nd-4th lumbar vertebrae are fused by a smooth ventrally protruding ankylosis. The 5th-8th are normal. On the distal endplate of the 9th lumbar vertebra and the proximal endplate of the 10th lumbar vertebrae ring-formed destruction is visible (Fig. 2 A). On the margins osteophytes are found. On the margins of the distal endplate of the 11th lumbar vertebra a corona of osteophytes is visible lipping with osteophytes on the 12th lumbar vertebra. The 12th -13th lumbar vertebrae are fused by a massive new bone formation and ossification of vertebral ligaments (Fig. 2 B). The 14th -15th lumbar vertebrae are also fused (Fig. 2 C D). None of the other vertebrae and intervertebral discs show any abnormality. The 1st -5th lumbar vertebrae were sectioned longitudinally, after which destruction of the intervertebral discs and vertebral endplates and severe narrowing of the intervertebral spaces became visible (Fig. 3). The intervertebral discs show an advanced stage of pathological changes (browning, dried out appearance).

The complete skeleton is stored in the Natural History Museum Rotterdam (NMR 9990-001429). The sectioned 1st-5th lumbar vertebrae are preserved in alcohol.

DISCUSSION

Herniation of the intervertebral disc is defined as a localized protrusion of part of the intervertebral disc beyond its normal boundaries. A protrusion of the central part of the intervertebral disc, the nucleus pulposus, or the annulus fibrosis, or the cartilage, through a defect in the annulus fibrosis and eventually the paravertebral ligaments, is named vertebral disc protrusion. Vertebral disc protrusion can occur as a dorsal, a ventral or ventrolateral prolapse. But also, prolapses can direct in anterior or posterior direction, through the vertebral endplate, into the spongiosa of the vertebral body. Such herniations are named intraspongious disc herniations or Schmorl's nodes, after their first description in human spines in 1927 by the German pathologist Christian Georg Schmorl (1861-1932) (Schmorl 1927). Protrusion of parts of the intervertebral disc, a well-known condition in man and wild and domesticated terrestrial mammals, was unknown in cetacean species before 2001.

Schmorl's nodes

In 2001, Kompanje & Garcia Hartmann reported, for the first time, on intraspongious disc herniation in five harbour porpoises *Phocoena phocoena* and one white-beaked dolphin *Lagenorrhynchus albirostris* (Kompanje & Garcia Hartmann 2001). Also in 2001, Hopley, reported on a single Schmorl's node in a plesiosaur (Hopley 2001). Several causes are mentioned in literature concerning the aetiology of Schmorl's nodes, and include developmental factors, degeneration, infection, malignancy and trauma (Peng *et al.* 2003). The Schmorl's node is characterised by destruction of parts (mostly the central part) of the cartilaginous endplate of the vertebra and subsequent herniation of the nucleus pulposus into the vertebral body. Peng *et al.* (2003) found loosely textured fibrous tissue with multiple small blood vessels replacing the bone marrow of the vertebral body underlying the ruptured cartilaginous endplate. Within the marrow cavities they found fibrosis and disappearance of fat cells. They also found an increase in reactive woven bone with thickened trabeculae and prominent osteoclasts and osteoblasts (Peng *et al.* 2003). This could result from altered mechanical stress, with subsequent vascular disturbance leading to osteonecrosis.

The aetiology and pathophysiology of intraspongious disc herniation is still enigmatic. Some authors conclude that avascular necrosis of the vertebral body beneath the endplate stands on the basis of the Schmorl's nodes (Peng *et al.* 2003), an opinion that is shared by later authors (Mattei & Rehman 2013). Abnormalities of the vertebral blood vessels during the development in some vertebrae will subsequently lead to an avascular adult intervertebral disc. This weakens the vertebral endplate, facilitating herniation into the subchondral bone. Another attractive theory is that the Schmorl's nodes result from ischemic necrosis beneath the cartilaginous endplate, making the herniation a secondary phenomenon. Avascular necrosis can occur when blood flow is interrupted or reduced after an injury. But in many other cases the cause is unknown.

As all other vertebrae and intervertebral discs, with exception of the isolated vertebrae and intervertebral discs with the Schmorl's nodes in Case 1, are completely healthy, this supports these theories. Other authors find a connection with osteoporosis en compression fractures. There were, in the studied dolphins, no signs of a vertebral compression fracture or osteoporosis, in which avascular necrosis (Kummel disease) can complicate matters (Freedman & Heller 2009). In Case 1, the pathological changes can be diagnosed as Schmorl's nodes.

Brucellosis

Spondylodiscitis, encompassing vertebral osteomyelitis, spondylitis and discitis, is a common manifestation of haematogenous osteomyelitis. Bacteria can infect the spine via three routes: (1) haematogenous spread, (2) by direct inoculation or (3) by spread from distant contiguous tissues (Gouliouris *et al.* 2010). The haematogenous arterial spread is predominant. A wide range of (micro)organisms have been associated with spondylodiscitis, including fungi, bacteria, mycobacteria and parasites. However, in most cases there is one species of bacterium causing the infection. Among these, infections with *Staphylococcus aureus* and streptococci are common. In endemic areas, infection with *Brucella* sp. can account for up to 50% of infectious spondylodiscitis in humans. It is also a common agent of spinal infection in domestic mammals (Megid *et al.* 2010). In humans, one third of chronically infected patients suffer from osteoarticular manifestations (Aydin *et al.* 2005). In adult mam-

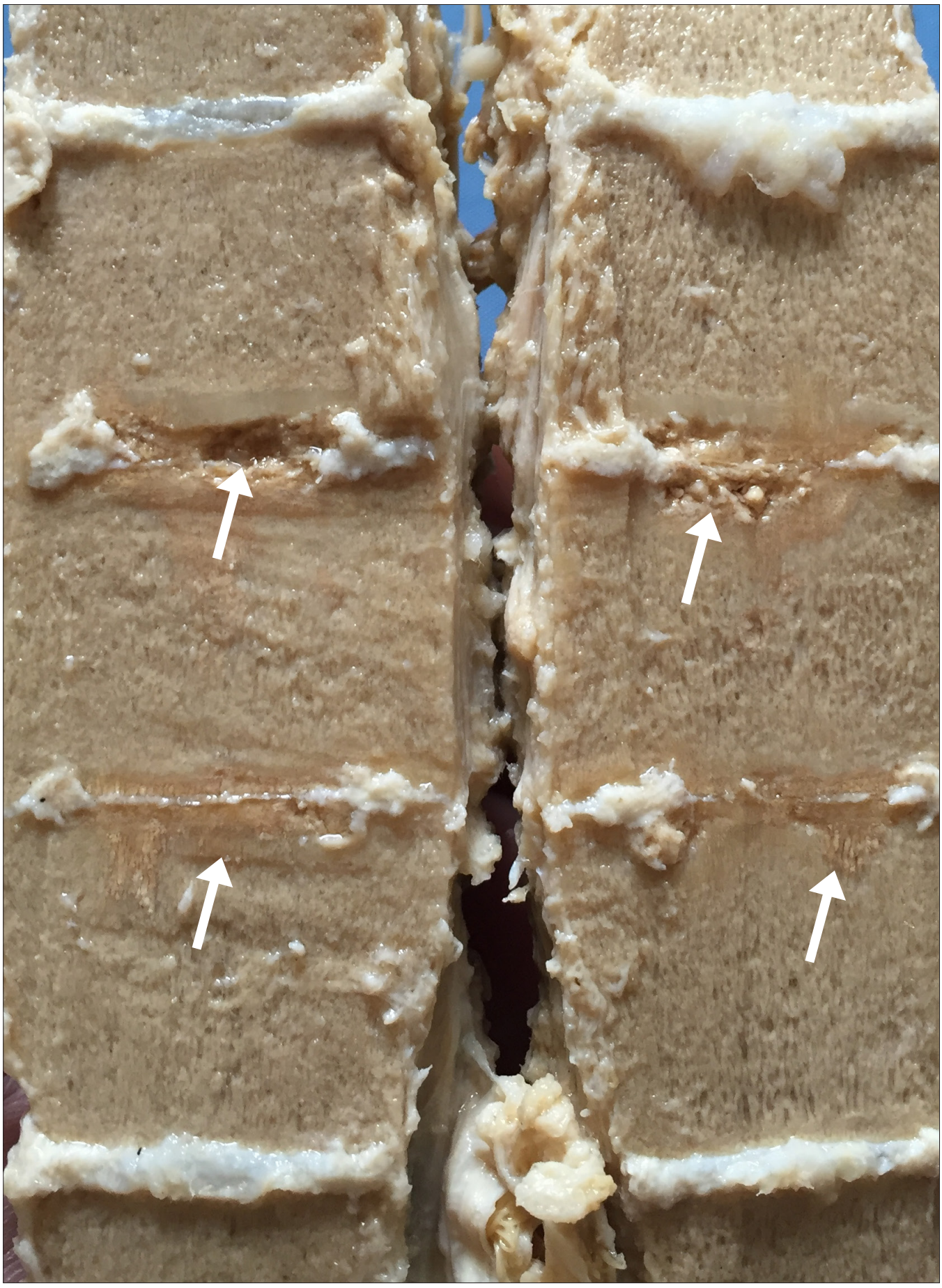

Figure 3 Case 2: *Phocoena phocoena*, adult female (NMR 9990-001429); section of the 1st-5th lumbar vertebrae. Destruction of the intervertebral discs and vertebral endplates and severe narrowing of the intervertebral spaces are visible. The intervertebral discs show an advanced stage of pathological changes: browning, dried out appearance. (Erwin Kompanje)

mals, the intervertebral discs are avascular, effectively creating end arteries. A septic embolus in such an end artery results in a large infarct. The subsequent spread of the infection to the intervertebral disc and vertebral bone creates the characteristic lesion of spondylodiscitis. Extensive infarction leads to wedging, cavitation and compression fractures. In humans and terrestrial mammals, haematogenous pyogenic spondylodiscitis affects preferentially the lumbar vertebrae.

Since 1994, infections caused by *Brucella* spp. and subsequent complicating lesions are found in several dolphin species, such as *Tursiops truncatus* (Miller *et al*. 1999, Goertz *et al*. 2011, Isodoro-Ayza *et al*. 2014), *Stenella coeruleoalba* (González *et al*. 2002, Davison *et al*. 2009, Hernández *et al*. 2008, González-Barrientos *et al*. 2010), *Lagenorhynchus acutus* (Foster *et al*. 2002, Dagleish *et al*. 2007), *Delphinus delphis* (Foster *et al*. 2002, Bogomolni *et al*. 2008) and *Phocoena phocoena* (Foster *et al*. 2002, Dagleish *et al*. 2008, Neimanis *et al*. 2008, Jauniaux *et al*. 2010, Maio *et al*. 2014). Including pinnipeds, at least 53 species of marine mammals have been described as seropositive for *Brucella* sp. (Hernández-Mora *et al*. 2014). Maio *et al*. (2013) tested 112 dead harbour porpoises from the Dutch coast for *Brucella*. In seven animals (6.3%) at least one of the used methods detected *Brucella*. *Brucella ceti* has been cultured from different organs of harbour porpoises (lung, mesenteric lymph node and in parasitic lungworms from the respiratory tract).

Several authors report *Brucella ceti* isolated from affected bones and joints in cetacean species (Foster *et al*. 2002, Dagleish *et al*. 2007, Maquart *et a*l. 2009, González-Barrientos *et al*. 2010). Dagleish *et al*. (2007) described a severe case of bone involvement by *Brucella* infection in a white-sided dolphin (*Lagenorhynchus acutus*), resulting in catastrophic deformation and remodelling of the atlanto-occipital joint. Maquart *et al*. (2009) isolated *Brucella* sp. from a spinal lesion in a harbour porpoise (*Phocoena phocoena*) and Foster *et al*. (2002) found a *Brucella* related spondylodiscitis of the 7th-8th thoracic vertebra in a harbour porpoise (*Phocoena phocoena*); however of no clinical/functional significance. Goertz *et al*. (2011) and Isidoro-Ayza *et al*. (2014) described a *Brucella*-spondylodiscitis involving two caudal vertebrae in two bottlenose dolphins (*Tursiops truncatus*). A similar lesion in two caudal vertebrae in another bottlenose dolphin is described by Alexander *et al*. (1989), but without proof of the causative organism. Sweeney *et al*. (2005) described the pathological changes they found in long-finned pilot whales (*Globicephala melas*), diagnosing them as ankylosing spondylitis. However, the features are more familiar with infectious spondylodiscitis, making this latter diagnosis more likely. Galatius *et al*. (2009) is often cited as describing *Brucella* induced skeletal pathology in white-beaked dolphins (*Lagenorhynchus albirostris*), but they do not describe or illustrate any typical pathological changes pointing in that direction.

The pathological lesions in Case 2 are very similar to *Brucella*-spondylodiscitis as found in humans and domestic mammals (Doige 1980, Castro Figueira de Mello *et al*. 2007, Megid *et al*. 2010), with involvement of the cartilage endplate leading to narrowing of the disc space, erosion, sclerosis, vertebral collapse and osteomyelitis. There is however no characteristic finding compared to other bacterial infections. Although *Brucella* lesions of the spine can occur at any level, in humans and domestic mammals it involves the lumbar spine most commonly, as in the described harbour porpoise. The lesions in this porpoise are without doubt resulting from a bacterial infection given rise to the severe spondylodiscitis. Although speculative, and without proof by the isolation of *Brucella* microorganisms, the causative species could be *Brucella ceti*. Spondylodiscitis and osteomyelitis of the vertebrae can be caused by several species of bacteria, making detection of *Brucella* spp. DNA from core bone samples by PCR difficult (La Sala *et al*. 2012).

It is highly unlikely that the lesions we found caused the death of the harbour porpoise, as they were long-standing and chronic with remodelling of bone tissue by osteophytes and ligament ossification. In humans, the attributable mortality of spondylodiscitis is less than 5% (Gouliourus *et al*. 2010).

CONCLUSIONS

Case 1 can be diagnosed as an isolated intravertebral disc herniation (Schmorl's node). Two aetiological theories can explain Schmorl's nodes in cetacean species.

(a) Abnormalities of vertebral blood vessels development in some vertebrae will subsequently lead to an avascular adult intervertebral disc. This subsequently weakens the vertebral endplate, facilitating herniation into the subchondral bone.

(b) The Schmorl's nodes result from ischemic necrosis beneath the cartilaginous endplate, making the herniation of the nucleus of the intervertebral disc possible, after which the remains of the disc degenerate and the two adjacent vertebrae will fuse by a smooth ankylosis. This all is a secondary phenomenon to the avascular necrosis. As a rule, as all other vertebrae and intervertebral discs, with exception of the vertebrae and intervertebral discs with the Schmorl's nodes are completely healthy, this supports these theories.

The vertebral lesions in Case 2 are without any doubt caused by a haematogenous bacterial infection, possibly with *Brucella ceti*.

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