Considerations on the comparative pathology of the vertebrae in Mysticeti and Odontoceti; evidence for the occurrence of discarthrosis, zygarthrosis, infectious spondylitis and spondyloarthritis

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Key words: Cetacea; Mysticeti; Odontoceti; discarthrosis; zygarthrosis; infectious spondylitis; spondyloarthritis; vertebrae.
Cleaned skeletons of 658 specimen of 47 species of Odontoceti and 44 skeletons of 10 species of Mysticeti were examined for evidence of pathological changes, especially of the vertebrae. Beside the examination of the cleaned skeletons, 132 spinal columns of seven species of Odontoceti were studied during autopsy. Four different pathological conditions were considered to occur: 1. Discarthrosis (spondylosis deformans); 2. Infectious spondylitis; 3. Diffuse idiopathic skeletal hyperostosis; and 4. Spondyloarthritis. Three cases of spondyloarthritis in cetaceans are described in detail. Spondyloarthritis had never before been recognized in any cetacean species.

"*If the immune system evolved to protect us, how is it so often tricked into such seemingly maladaptive responses?*"
Marc Lappé, 1994.

Introduction

Pathological changes of the vertebrae in Cetacea are often mentioned in the cetological and veterinary literature. There are as many diagnoses and descriptions of these changes as there are authors. The number of various pathological conditions of the vertebrae occurring in Cetacea is, however, limited, and in most cases, these can readily be distinguished.

In this article, four pathological conditions of the vertebrae are considered to occur in Cetacea: 1. Discarthrosis and zygarthrosis (spondylosis deformans); 2. Infectious spondylitis (spondylo-osteomyelitis); 3. Diffuse idiopathic skeletal hyperostosis (DISH), and 4. Spondyloarthritis (spondyloarthropathy). DISH and spondyloarthritis have not previously been described for any cetacean species. Three cases of spondyloarthritis are described in detail, one in a fin whale *Balaenoptera physalus*, and two in white-beaked dolphins *Lagenorhynchus albirostris.*

Materials and methods

Forty-four cleaned skeletons of ten species of Mysticeti and 658 cleaned skeletons of 47 species of Odontoceti were examined for evidence of pathological changes (table 1). Every vertebra was examined for the occurrence of osteophytes, marginal and non-marginal syndesmophytes, ligamentous ossification, erosion, eburnation and sclerosis of the vertebral end-plate, ankylosis with adjacent vertebrae, pathological changes of the zygapophyseal and costo-vertebral joint surfaces, metapophyses, transverse and spinal processes and laminae and, if possible, the occurrence of paradiscal ossicles. Beside the examination of the cleaned skeletons, 132 spinal columns of seven species of Odontoceti were studied during autopsy for pathological changes (table 2). The vertebral column was prepared by removing all muscles, thereby inspecting the ligaments and margins of the annulus fibrosus. When osteophytes, syndesmophytes, ankylosis or other pathological changes were visible, the relevant part of the vertebral column was submitted to further examination. In most cases, every intervertebral space was opened with a clean, sharp knife, to study the macroscopic aspect of the intervertebral disc and vertebral end-plates. When pathological tissue was found, this was photographed, collected and fixed in formalin.

Museum acronyms as follows: BMNH =British Museum (Natural History), London, England; NMSZ = National Museums of Scotland, Edinburgh, Scotland; RMNH = National Museum of Natural History, Leiden, The Netherlands (former Rijksmuseum van Natuurlijke Historie); NMR = Natuurmuseum Rotterdam, The Netherlands; ZMA = Zoological Museum Amsterdam, The Netherlands; FIS = Forschungs Institut Senckenberg, Frankfurt am Main, Germany; KBIN = Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussel, Belgium.

Table 1. Species and numbers of cleaned skeletons examined.

SPECIES	N=	SPECIES	N=
1. *Balaena mysticetus*	3	29. *Grampus griseus*	14
2. *Eubalaena glacialis*	2	30. *Tursiops truncatus*	55
3. *Eubalaena australis*	3	31. *Tursiops t. aduncus*	7
* *Eubalaena* spec.	1	32. *Stenella attenuata*	3
4. *Caperea marginata*	3	33. *Stenella longirostris*	4
5. *Balaenoptera musculus*	7	34. *Stenella coeruleoalba*	4
6. *Balaenoptera physalus*	4	35. *Delphinus delphis*	55
7. *Balaenoptera acutorostrata*	8	36. *Lissodelphis borealis*	1
8. *Balaenoptera borealis*	7	37. *Cephalorhynchus commersonii*	4
9. *Balaenoptera edeni*	2	38. *Cephalorhynchus heavisidii*	1
10. *Megaptera novaeangliae*	4	39. *Cephalorhynchus hectori*	1
11. *Platanista gangetica*	4	40. *Feresa attenuata*	1
12. *Inia geoffrensis*	4	41. *Pseudorca crassidens*	105
13. *Delphinapterus leucas*	8	42. *Orcinus orca*	17
14. *Monodon monoceros*	9	43. *Globicephala melas*	19
15. *Phocoena phocoena*	177	44. *Globicephala macrorhynchus*	9
16. *Phocoena sinus*	1	45. *Orcaella brevirostris*	2
17. *Neophocaena phocaenoides*	3	46. *Berardius arnuxii*	3
18. *Australophocoena dioptrica*	2	47. *Mesoplodon bidens*	16
19. *Phocoenoides dalli*	3	48. *Mesoplodon europaeus*	1
20. *Steno bredanensis*	1	49. *Mesoplodon layardii*	1
21. *Sousa chinensis*	2	50. *Mesoplodon hectori*	1
22. *Sotalia fluviatilis*	20	51. *Mesoplodon grayi*	2
23. *Lagenorhynchus albirostris*	50	52. *Mesoplodon mirus*	1
24. *Lagenorhynchus acutus*	12	53. *Ziphius cavirostris*	8
25. *Lagenorhynchus obscurus*	12	54. *Hyperoodon ampullatus*	20
26. *Lagenorhynchus obliquidens*	2	55. *Hyperoodon planifrons*	2
27. *Lagenorhynchus cruciger*	1	56. *Physeter macrocephalus*	7

Table 2. Species and numbers of skeletons examined during autopsy.

SPECIES	N=
1. *Phocoena phocoena*	50
2. *Lagenorhynchus albirostris*	12
3. *Lagenorhynchus acutus*	54
4. *Tursiops truncatus*	2
5. *Stenella coeruleoalba*	2
6. *Delphinus delphis*	9
7. *Physeter macrocephalus*	3

Diagnostic considerations

Considerations on the diagnosis of the pathological changes found in this study are limited to:

1. Discarthrosis and zygarthrosis (spondyloarthrosis, spondylosis deformans),
2. Infectious spondylitis (spondylo-osteomyelitis),
3. Diffuse idiopathic skeletal hyperostosis (DISH), and
4. Spondyloarthritis (spondyloarthropathy, Reiter's syndrome, enteropathic arthritis, reactive arthritis).

1. Discarthrosis and zygarthrosis

This condition is the result of degeneration of the intervertebral disc, and is defined as the structural and functional failure of the discal joint. It is, however, difficult to differentiate pathological changes of intervertebral disc disease from the normal aging process of the spine. The first manifestations of aging are visible in the intervertebral disc and subsequently, changes in the vertebrae become evident. Intervertebral disc degeneration is closely associated with aging. Degeneration of the vertebral disc includes structural changes such as reduced water and modified proteoglycan contents, and a decreased height, brown discoloration, fissuring, and crumbling of the disc. This degeneration is often followed by bone changes (discarthrosis) such as vertically formed marginal osteophytes, sclerosis and erosion of the vertebral end-plate. This condition is often found in some species of Odontoceti, but its occurrence in Mysticeti and many species of Odontoceti is questionable. Discarthrosis and other conditions (e.g. spondyloarthritis) are sometimes found in the same individual. Syndesmophytes can be formed in an intervertebral disc that previously has undergone degenerative changes. Sometimes the term mixtaosteophytes is used (Dihlmann, 1986). Zygarthrosis is defined as osteoarthrosis of the zygapophyseal joint(s), which during this study has clearly been found in *Pseudorca crassidens* and *Tursiops truncatus*.

During this study, discarthrosis and zygarthrosis were found in *Delphinapterus leucas* (BMNH 1952.10.30.1); *Lagenorhynchus albirostris* (RMNH 25152, RMNH 21046, RMNH 17847, RMNH 25029, RMNH 33038, RMNH 35130, RMNH 17968, RMNH

18067, RMNH 30513, ZMA 18.150, ZMA 17.231, ZMA 17.230, ZMA 12.982, ZMA 6815, BMNH 1933.8.); *Tursiops truncatus* (RMNH 31148, RMNH 12593, RMNH 24797, BMNH 1920.12.30.1., BMNH 1930.12., NMSZ 1994.13.33.); *Delphinus delphis* (RMNH 35131, ZMA 14.002); *Pseudorca crassidens* (BMNH 1961.6.14.3., BMNH 1961.6.14.89., BMNH 1961.6.14.93., BMNH 1961.6.14.81., BMNH 1961.6.14.82, BMNH 1961.6.14.86, BMNH 1961.6.14.23., BMNH 1961.6.14.68., BMNH 1992.243); *Globicephala macrorhynchus* (BMNH 1876.2.15.2., BMNH 1876.2.15.3, BMNH 1952.10.30.5); *Hyperoodon ampullatus* (BMNH 1992.42): *Mesoplodon hectori* (BMNH 1965.8.19.2); and *Mesoplodon mirus* (BMNH 1920.5.20.1). Discarthrosis was found in three *Lagenorhynchus albirostris* during autopsy

2. Infectious spondylitis

Exuberant and often bizarre new bone formation with destruction of the normal features of the vertebrae is regarded as the result of infectious spondylitis. Due to its destructive features, this disease can easily be distinguished from discarthrosis (Kompanje, 1995a, 1995b) and spondyloarthritis. Irregular destruction of two adjacent vertebral end-plates can be diagnostic for the results of advanced spondylodiscitis. In a case of infectious spondylitis in a harbour porpoise *Phocoena phocoena*, haemolytic streptococci were found to have caused this infection (Kompanje, 1995b). Alexander et al. (1989) described a case of vertebral osteomyelitis in an Atlantic bottlenose dolphin *Tursiops truncatus*. This dolphin was kept in captivity and was successfully treated with antibiotics. A case in a California sea lion *Zalophus californianus* had also been caused by a *Streptococcus* (Thomas-Baker, 1986). A typical case in *Balaenoptera edeni* was illustrated by Pilleri (1973, pls 9 & 10) and by Pilleri & Gihr (1974, pls 31 & 32), in *Mesoplodon bidens* by Kompanje (1995a, figs 4 & 5), and in *Balaena mysticetus* by Slijper (1931, fig. 5; 1936, fig. 241), who incorrectly diagnosed the features as spondylitis deformans. In skeletons of cetaceans in museum collections, symptoms of this condition are sometimes found, but not always recognized as the results of direct infection. Most often, they are misdiagnosed as spondylosis deformans (discarthrosis).

During this study, infectious spondylitis was found in *Balaena mysticetus* (KBIN 1532 (2333); *Balaenoptera musculus* (BMNH 1865.8.23.1.); *Phocoena phocoena* (RMNH 28590); *Lagenorhynchus albirostris* (RMNH 31207): *Lagenorhynchus acutus* (RMNH 23587); *Tursiops (truncatus) gillii* (RMNH 32350): *Tursiops truncatus aduncus* (BMNH 3.9.12.1.); *Delphinus delphis* (ZMA 15.237); *Pseudorca crassidens* (BMNH 1961.6.14.62); *Orcinus orca* (BMNH 1924.11.4.1; BMNH 1934.7.23.2; EcoMare b2.9); *Orcaella brevirostris* (BMNH 1883.11.20.2.); and *Mesoplodon bidens* (BMNH 7512).

3. Diffuse idiopathic skeletal hyperostosis (DISH)

This is a well-known condition, though of unknown etiology, in man. The principal manifestations of DISH are ligamentous calcifications and ossifications of the anterolateral (anticardiac) part of the vertebral column. The appearance of the bony outgrowths has been described as ‘dripping candle wax’ involving three or four vertebrae. There is no degeneration; however, DISH and discarthrosis are sometimes both found in one individual. Preservation of the intervertebral disc height is obvious in most isolated cases. The posterior spinal elements are not affected and the vertebral foramina are not involved. There are several claims that the pathological changes characteristic for DISH occur in several mammal species: Pleistocene mammals [e.g. *Mastodon, Equus, Smilodon, Canis*] (Rothschild, 1987; Bjorkengren et al., 1987); primates (Rothschild, 1987, 1988; Rothschild & Woods, 1989; Kompanje & Klaver, 1995). Not all cases, however, are convincing. There are also some records of DISH in fossil reptiles (Rothschild, 1987; Rothschild & Berman, 1991). The question whether DISH is a disease or a physiological aging process is worth considering.

DISH has never been described for any cetacean species. Perhaps it occurs in the fin whale *Balaenoptera physalus* discussed below, judging by the possible involvement of the ligaments in the pathological process, though the fusion of the zygapophyseal joints in the cervical and upper thoracic vertebrae is diagnostic for spondyloarthritis and atypical for DISH. At closer examination, the new bone formation may be diagnosed as non-marginal syndesmophytes rather than ligamentous calcifications.

DISH was not recognized with certainty in any cetacean species during this study.

4. Spondyloarthritis

It is now realized that certain diseases hitherto regarded as variants of rheumatoid arthritis are in fact not related to the latter. Those diseases have not only shown to be non-rheumatoid, but to be closely related to ankylosing spondylitis (also known as Bechterew's disease, which term should be avoided, see François et al., 1995). Synonyms of spondyloarthritis are spondyloarthropathy, seronegative spondarthritis and spondarthritis. The term spondyloarthropathy is widely used in the literature. François et al. (1995) recommended, however, the term spondarthritis or spondyloarthritis, because they argue that the term 'arthropathy' is too vague and does not indicate the inflammatory nature of the condition.

Spondyloarthritis in man includes a group of inflammatory diseases comprising ankylosing spondylitis, Reiter's syndrome, reactive arthritis, psoriatic arthritis and spondylitis/arthritis associated with inflammatory bowel disease (Crohn's disease and colitis ulcerosa), and maybe other conditions (François et al., 1995). The relationship between the initial diseases and spondyloarthritis is enigmatic in many respects. Spondyloarthritis in man occurs predominantly in individuals which are Human Leukocyte Antigen (HLA) b27 positive. In dogs, the association with Dogs Leukocyte Antigen (DLA) is not significant (Eichelberg et al., 1988), but from that study it is not completely clear whether the pathological changes found in the vertebral columns of the dogs are really a form of spondyloarthritis. The bony outgrowths found on the vertebrae in cases of spondyloarthritis are called syndesmophytes. These are slim, horizontally disposed bony outgrowths replacing the outer parts of the annulus fibrosus and the shorter and longer perivertebral ligaments, thus leading to an intervertebral bridge by means of complex processes involving ossification. It is often stated that syndesmophytes are to be regarded as calcifications of the longitudinal ligaments, but it has clearly been shown that they are caused primarily by ossification of the layer of perivertebral connective tissue fibers just outside the annulus fibrosus. This explains the position of the paradiscal ossicles between the vertebral margins in case 2 below. This contrasts with the vertical and chunky osteophytes seen in discarthrosis (François et al., 1995), and the often bizarre new bone formation formed in infectious spondylitis. Syndesmophytes can be marginal and non-marginal (Rothschild et al., 1994). When the syndesmophyte is not inserted to the margin of the vertebral body, but extends some distance beyond, it is called parasyndesmophyte (Dihlmann, 1986; François et al., 1995) or non-marginal syndesmophyte (Rothschild et al., 1994). The form, symmetry and position are characteristic for the different forms of spondyloarthritis (Dihlmann, 1986).

During this study, spondyloarthritis has been identified in cetaceans, judging by the smoothly formed paradiscal ossicles, the occurrence of non-marginal syndesmophytes, the absence of signs of degeneration of the intervertebral disc, and the (partial) fusion or erosion of the zygapophyseal joint surfaces. It has not previously been described for cetacean species.

Three different forms of spondyloarthritis are considered here:

1. Spondyloarthritis associated with inflammatory bowel disease;
2. Reiter's syndrome;
3. Reactive spondylitis.

Spondyloarthritis associated with inflammatory bowel disease is also known as enteropathic arthropathy. The etiology of the manifestations is, as in all forms of spondyloarthritis, based on a combination of genetic and environmental factors.

Reiter's syndrome in man is associated with enteric bacterial infections or a sexually transmitted micro-organism. The involvement of the vertebrae usually is limited. Spondylitic involvement of the vertebrae is discontinuous, with skip areas. The syndesmophytes are usually non-marginal and are bulkier in appearance than those seen in spondylitis associated with inflammatory bowel disease or the osteophytes seen in discarthrosis. The syndesmophytes found in vertebral columns of cetaceans seem to be of this kind.

In reactive arthritis/spondylitis, a microorganism infecting a distant organ (e.g. *Salmonella* infection of the bowels) triggers sterile arthritis by an immunological reaction (Kingsley & Sieper, 1996). Reactive arthritis affect selected joints, primarily the spinal and larger peripheral joints, suggesting that the arthritis result from immune reactivity to a site-specific antigen. However, there is also substantial evidence that reactive arthritis results from a constant, localized immune-inflammatory activity stimulated by bacterial debris lodged in the joint tissues (Griffiths, 1995), though attempts to culture bacteria from the joints have been negative. In this form, there is an additional association with several co-diseases, but spondyloarthritis often is the only manifestation. There is a synovial immune response with accompanying antibodies against organisms such as *Chlamydia* and *Yersinia*, but the host shows no overt evidence of the infection. This implicates an immune reaction to those bacteria and the presence of a smoldering subclinical infection in the pathogenesis of the disease.

Besides well-known cases in man, these kinds of spondyloarthritis have been described for several mammal species. Rothschild (1988, 1993) and Rothschild & Woods (1989, 1992) recognized this condition in several species of New and Old World primates, Rothschild et al. (1993) and Kompanje & Klaver (1998) in Ursidae, Rothschild & Rothschild (1994) in Hyaenidae, and Rothschild et al. (1994) in Proboscidea.

Other forms of spondyloarthritis known to occur in man and possibly in other terrestrial mammal species, such as ankylosing spondylitis, psoriatic arthritis/spondylitis, juvenile chronic polyarthritis and acute anterior uveitis, are not taken into consideration in diagnosing the pathological changes found in cetaceans.

During this study, pathological changes suspect for spondyloarthritis have been found in cleaned skeletons of *Balaenoptera physalus* (RMNH 373); *Megaptera novaeangliae* (BMNH 1829a); *Phocoena phocoena* (RMNH 11686; RMNH 7892; RMNH 4254; ZMA 18.156); *Lagenorhynchus albirostris* (RMNH 18067; RMNH 33038; ZMA 17.232; ZMA 17.231; ZMA 17.230; ZMA 12.982; ZMA 11.368; BMNH 1933.8; BMNH 1866.2.1.28.); *Lagenorhynchus acutus* (RMNH 23587; BMNH 1920.6.281.; BMNH 1928.19.); *Lagenorhynchus obliquidens* (BMNH 1992.83); *Delphinus delphis* (BMNH 1973.107.; ZMA 14.002); *Tursiops truncatus* (NMSZ 1994.13.33.; BMNH 1952.7.30.5); and *Orcaella brevirostris* (BMNH 1883.11.20.2.). Paradiscal ossicles without syndesmophytes, suspect of spondyloarthritis, have been found in two cases, one in *Steno bredanensis* (BMNH 1954.6.25.2.) and one in *Grampus griseus* (RMNH 21586). Spondyloarthritis was found in one female *Lagenorhynchus albirostris* during autopsy.

Three cases of spondyloarthritis will be discussed here in more detail.

Case 1. *Balaenoptera physalus* (Linnaeus, 1758)

An adult female fin whale *Balaenoptera physalus* with a total length of 2150 cm was found on 11 November 1914 on the beach near Wissekerke, province of Zeeland, The Netherlands (fig 1). The whale is thought to be a victim of the First World War (seamine or bombing, see Anonymous, 1919, 1922). The complete skeleton was collected and is preserved in the National Museum of Natural History, Leiden, The Netherlands (RMNH 373). Van Deinse (1918) mentioned the pathological changes of the vertebrae and Slijper (1931, 1936) described these in more detail. The latter author arrived at the diagnosis of spondylitis deformans.

Normally, in the fin whale the seven cervical vertebrae are all separate (Reche, 1904; Allen, 1916). There are normally 15 or 16 thoracic, between 13 and 16 lumbar, and between 24 and 27 caudal vertebrae (True, 1904; Allen, 1916; Aguilar, 1995). In RMNH 373, some of the last caudal vertebrae are missing.

Cervical vertebrae (1-7)

All cervical vertebrae are fused by new bone formation (fig. 3), which can be described as non-marginal syndesmophytes. The syndesmophytes are especially antero-laterally disposed. The first three cervical vertebrae are fused on all sides, with the exception of both lateral sides, where the fusion shows some open areas. The zygapophyseal joints are fused. There originally was a fusion between the 3rd and 4th cervical vertebrae by a small, non-marginal syndesmophyte which, however, has become fractured during storage of the skeleton (figs 3A & 4A). The 4th and 5th cervical vertebrae are fused on the ventral and right antero-lateral side (figs 3 & 4). The 5th

Fig. 1. Fin whale *Balaenoptera physalus*, female, Wissekerke, The Netherlands, 11 November 1914 (archive National Museum of Natural History, Leiden).

Fig. 2. White-beaked dolphin *Lagenorhynchus albirostris*, female, Kijkduin, The Netherlands, 20 July 1969 (archive National Museum of Natural History, Leiden).

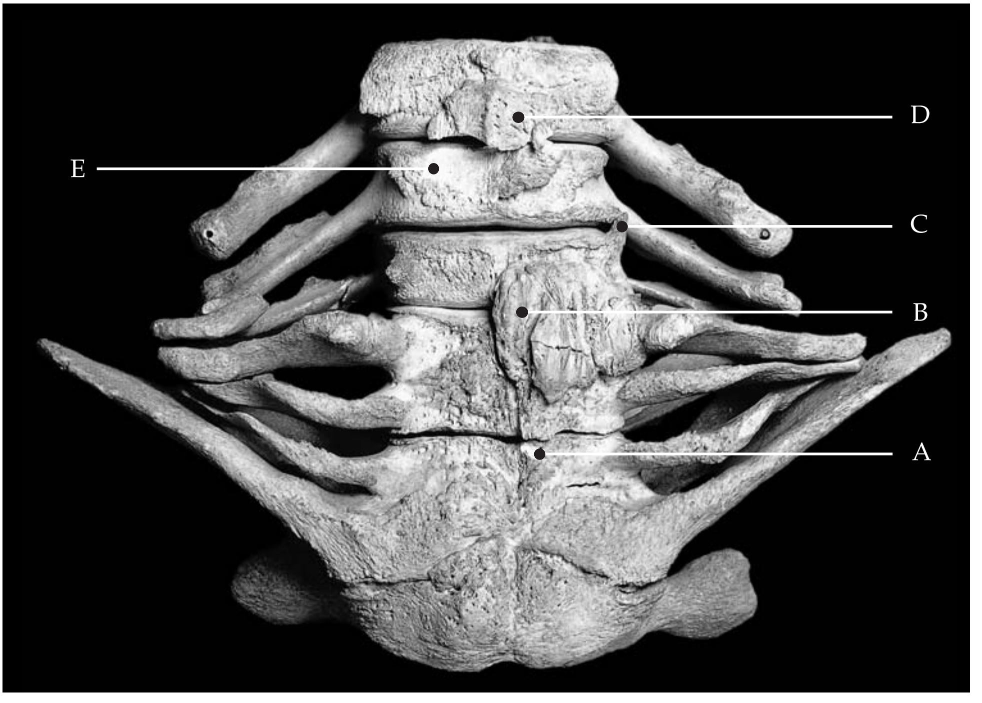

Fig. 3. *Balaenoptera physalus*, cervical and first thoracic vertebrae, dorsal view (adult female, RMNH 373).
A, fractured syndesmophyte between the 3rd and 4th cervical vertebra; B, large syndesmophyte between the 5th and 6th cervical vertebra; C, lipping between syndesmophytes of the 6th and 7th cervical vertebra; D, new bone formation on the mid-ventral part of the 7th cervical and 1st thoracic vertebra; E, fracture of the syndesmophyte during storage in the museum.

and 6th cervical vertebrae are fused by a large syndesmophyte on the right antero-lateral side (fig 3B & 4B). The vertebral end-plates between these vertebrae are normal, as is the caudal end-plate of the 6th. Antero-lateral and dorso-lateral marginal syndesmophytes are found on the caudal side of the 6th cervical vertebra. Between the 3rd and 4th cervical vertebra, small syndesmophytes without ankylosis are found on the left dorsal side. Marginal syndesmophytes on the right antero-lateral side are lipping with small syndesmophytes on the right antero-lateral side of the 7th cervical vertebra (figs 3C & 4C). Ankylosis is found between the 7th cervical and the 1st thoracic vertebra. This smoothly shaped new bone formation is disposed on the mid-ventral part of the vertebra (figs. 3D & 4D). The syndesmophyte between this vertebra has become fractured during storage of the skeleton in the museum (figs 3E & 4E); a large piece of this syndesmophyte is missing. The vertebral end-plates of these vertebrae are completely normal, as are the zygapophyseal joint surfaces.

Thoracic vertebrae (1-14)

In the living whale, there has been an ankylosis between the 1st and the 2nd thoracic vertebra, which is, however, fractured, in the cleaned skeleton. An ankylosis

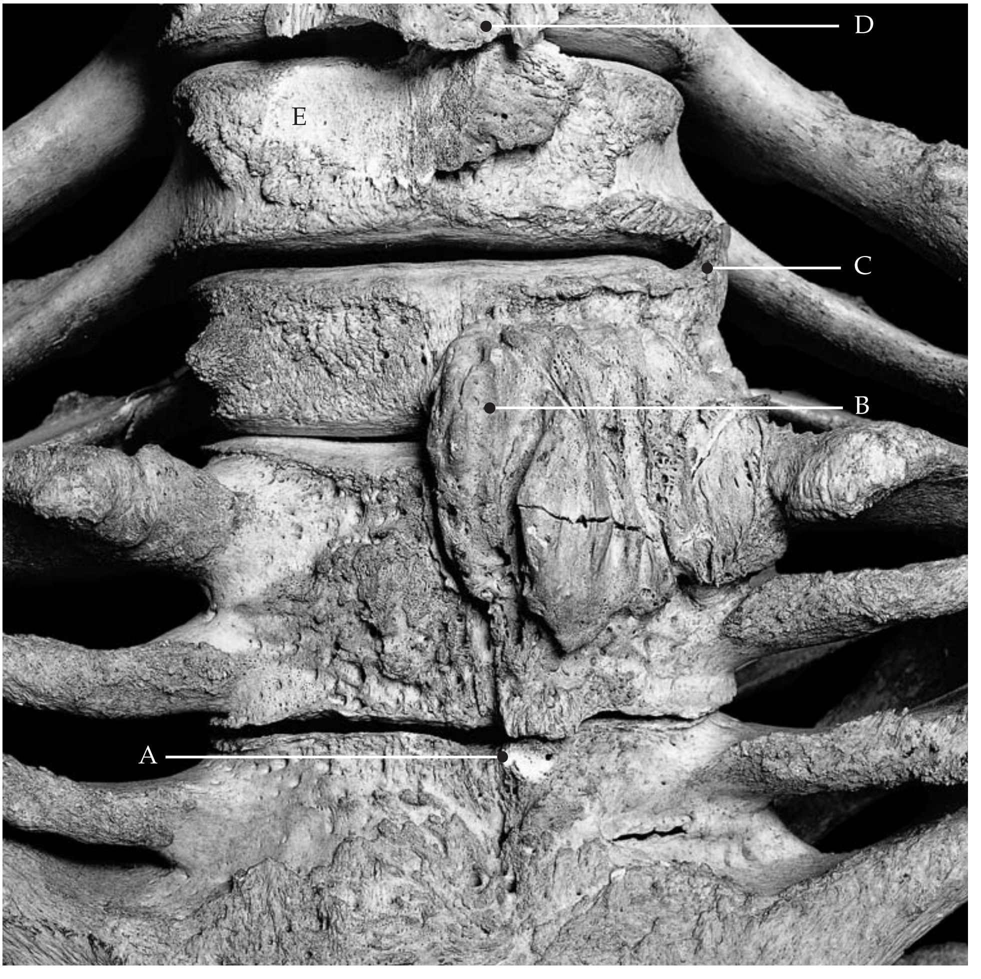

Fig. 4. *Balaenoptera physalus,* cervical and first thoracic vertebrae, dorsal aspect (adult female, RMNH 373) in closer view.
A, fractured syndesmophyte between the 3rd and 4th cervical vertebra; B, large syndesmophyte between the 5th and 6th cervical vertebra; C, lipping between syndesmophytes of the 6th and 7th cervical vertebra; D, new bone formation on the mid-ventral part of the 7th cervical and 1st thoracic vertebra; E, fracture of the syndesmophyte during storage in the museum.

between all cervical and the first five thoracic vertebrae too, has been present. A complete ankylosis exists between the 2nd-5th thoracic vertebrae. It is formed by large, bridging, bulky syndesmophytes on the left antero-lateral side. The intervertebral disc spaces are normal, as are the vertebral end-plates of the fused vertebrae. The zygapophyseal joint surfaces between the 2nd and 3th thoracic vertebra have been destroyed and a beginning of ankylosis is visible. Ankylosis is found on the left antero-dorsal side between the 2nd-5th thoracic vertebrae. The vertebral end-plate of the 5th shows some erosion, which is, however, not related to primary degeneration of the intervertebral disc. The caudal and cranial epiphyses of the 6th thoracic verte-

Fig. 5. *Balaenoptera physalus*, 6th thoracic vertebra, posterior epiphysis showing erosion of the vertebral end-plate and partly healed fracture lines (adult female, RMNH 373).

bra show partly healed fracture lines (fig. 5). The cranial epiphysis shows some erosion next to these fracture lines. The vertebral end-plate of the 7th thoracic vertebra is normal. The 7th-10th thoracic vertebrae are normal in all aspects. A ventrally disposed syndesmophyte is visible on the 11th thoracic vertebra. The vertebral end-plates are normal. The 12th and 13th thoracic vertebrae again are normal.

Lumbar vertebrae (1-15)

The 1st-11th lumbar vertebrae are normal. The 12th lumbar vertebra shows a large, antero-laterally disposed non-marginal syndesmophyte on the left caudal side. On the right antero-lateral side, marginal syndesmophytes are formed. The cortex of both laminae is thickened and shows new bone formation, including one third of the

Fig. 6. *Balaenoptera physalus*, left lamina and metapophysis of the 12th lumbar vertebra showing thickening and new bone formation (adult female, RMNH 373).

spinous process on both sides (fig. 6). It is not clear what may have caused this. The spinal canal is narrowed by this pathological change. The metapophyses are normal and not involved in the process. A complete ankylosis occurs between the 13th lumbar and 1st caudal vertebrae (fig. 7). Grotesque new bone formation has developed on the ventral and antero-lateral sides of these vertebrae. The intervertebral disc spaces are normal and the vertebral end-plates are not involved (fig. 8). The chevron of the 1st caudal vertebra is displaced by and fused with the new bone formation. On both laminae of the 13th lumbar vertebra, thickening of the cortex is observed. The spinous process and the metapophyses are not involved. Between the 13th and 14th lumbar vertebra, the bony fusion extends just above the transverse process on the left side. On the right side, it ends c. 10 cm below this point. Between the 14th and 15th lumbar vertebra, the ankylosis also extends above the transverse process on the left side, and

Fig. 7. *Balaenoptera physalus,* 13-15th lumbar and 1st caudal vertebrae in dorsal aspect showing complete ankylosis with large bulky syndesmophytes (adult female, RMNH 373).

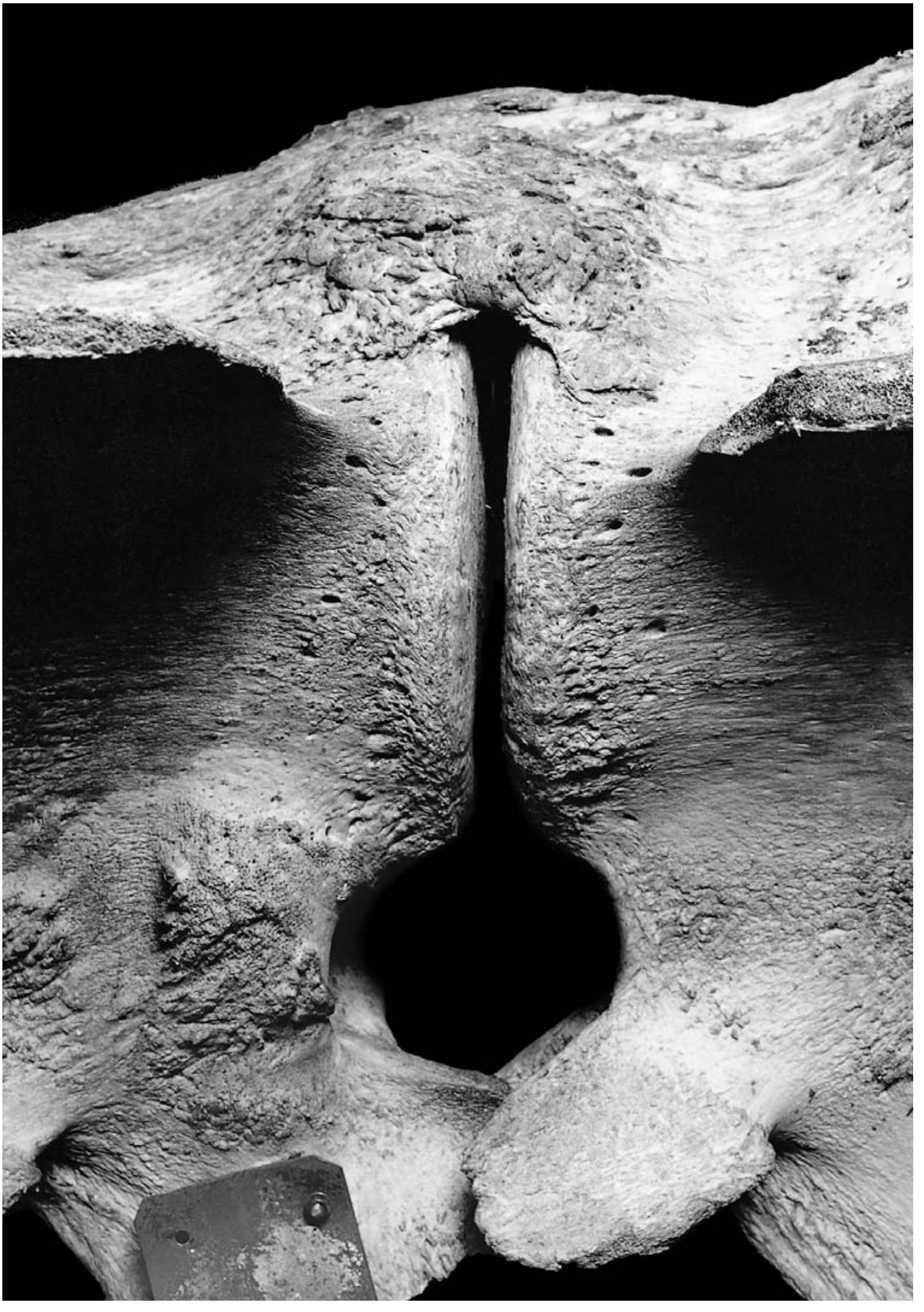

Fig. 8. *Balaenoptera physalus*, 13th and 14th lumbar vertebra in lateral aspect showing preserved intervertebral disc space (Adult female, RMNH 373).

Fig. 9. *Balaenoptera physalus*, 2nd caudal vertebra showing a grotesque non-marginal syndesmophyte (adult female, RMNH 373).

on the right side c. 18-cm posterior to the transverse process. Between the 15th lumbar and 1st caudal vertebra, the ankylosis ends c. 20-cm posterior to the transverse process on the left side, and 10 cm below the transverse process on the right side. Above these levels, no new bone formation has developed. One can see the normal vertebral end-plates of the posterior side of the vertebrae (fig. 8).

Caudal vertebrae (1-20)

The 2nd caudal vertebra also shows a grotesque non-marginal syndesmophyte, which impinges with the new bone formation on the 1st caudal vertebra (figs 7 & 9). As in the latter, the chevron of both vertebrae is fused with the new bone formation (fig. 9). The syndesmophyte is mainly situated on the right side. On the 3rd caudal vertebra too, an enormous non-marginal syndesmophyte is found (fig. 10). This

Fig. 10. *Balaenoptera physalus*, 3rd caudal vertebra with an enormous non-marginal syndesmophyte and fusion with the chevron (adult female, RMNH 373).

again, is mainly on the right ventral and antero-lateral side of the vertebra. Erosion is seen on the syndesmophyte of the 3rd caudal vertebra, where it meets the new bone formation of the 2nd. Non of the metapophyses is involved. An old, partly healed, but still open fracture line (c. 25 × 5 cm) is visible at c. 7 cm from the margin, on the cranial end-plate of the 3rd caudal vertebra (fig. 10). It looks as if friction of the large syndesmophytes has caused this fracture. The caudal end-plate of the 2nd caudal vertebra is normal. The 4th-20th caudal vertebrae are normal.

The scapulae, humeri, radii, ulnae, metacarpalia, phalanges, hyoid, most chevron bones, sternum and costae show no gross pathological changes. The skull was not examined.

Case 2. *Lagenorhynchus albirostris* Gray, 1846

On 20 July 1969, an adult female white-beaked dolphin *Lagenorhynchus albirostris* was found on the beach near Kijkduin, province of Zuid-Holland, The Netherlands (fig. 2). The skeleton of this dolphin is kept in the National Museum of Natural History, Leiden (RMNH 21046). No detailed autopsy was performed.

In the white-beaked dolphin, normally the first seven cervical vertebrae are fused. There are 14-16 thoracic, 24-27 lumbar, and 43-47 caudal vertebrae (Van Oort, 1918; Brown, 1994). Almost the complete vertebral column of RMNH 21046 shows severe pathological changes.

Cervical vertebrae (1-7)

The first four cervical vertebrae are fused. The 5th is separate, but the 6th and 7th are fused on the ventral and both lateral sides.

Thoracic vertebrae (1-14)

The 1st thoracic vertebra shows some pathological lesions on prezygapophyses, postzygapophyses and costo-vertebral joint surfaces, in the form of subcortical lytic lesions and cyst formation. The zygapophyseal joints of the 2nd-8th thoracic vertebrae also show subcortical lytic lesions and cyst formation. The costo-vertebral joint surfaces of these vertebrae look normal. No ankylosis of the zygapophyseal joints was found. The last zygapophyseal surface with synovial joint is between the 8th and 9th thoracic vertebra. On the margins of the corpora of the 1st-8th thoracic vertebrae, small, vertically disposed osteophytes are visible. On the left lateral side of the 5th thoracic vertebra, a smoothly formed syndesmophyte is visible on the cranial margin. On the same side of the 6th thoracic vertebra, there are severe pathological changes. Horizontally disposed irregular new bone formation is found on the cranial margin and the whole left lateral body. It looks as if the large, non-marginal syndesmophyte, which is formed on the left lateral side of the 7th thoracic vertebra, has impinged on the lesion of the 6th. Vertically disposed osteophytes, as a sign of an aging spine, are also found on the right lateral margin of the 6th and 7th thoracic vertebra. The 8th thoracic vertebra also shows a large, 'swollen', non-marginal syndesmophyte on the left antero-lateral side. As far as visible, the vertebral end-plates in this region look normal. Surprisingly, minimal pathological changes are found in the lower thoracic

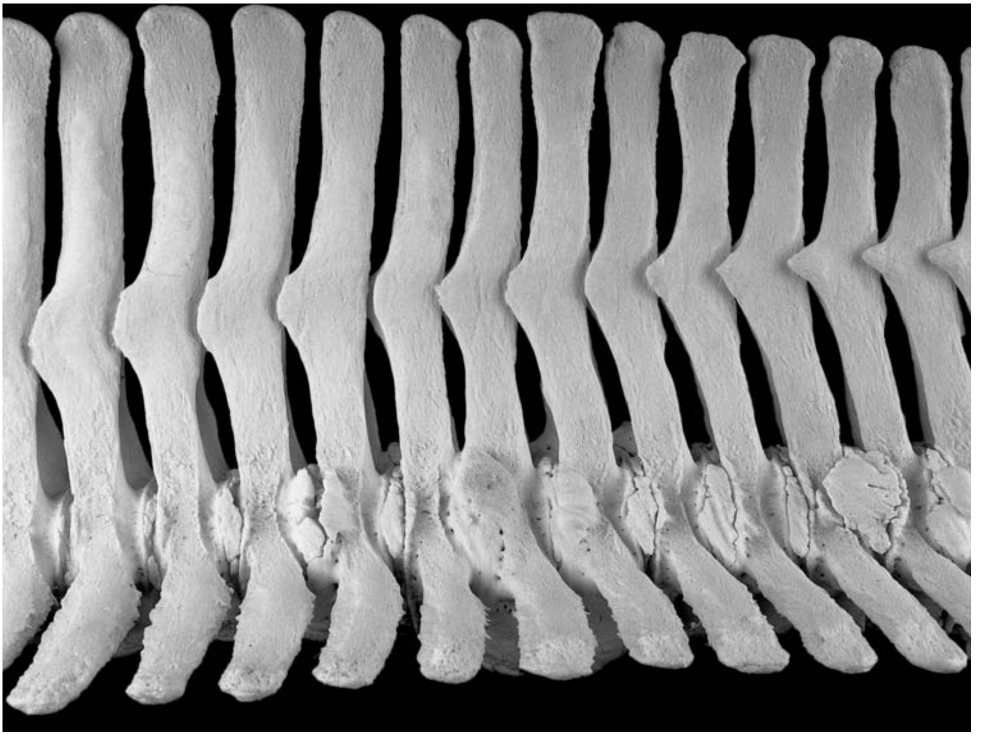

Fig. 11. *Lagenorhynchus albirostris*, 15-25th lumbar vertebrae showing paradiscal ossicles and ankylosis between vertebrae (adult female, RMNH 21046).

vertebrae. Small, vertically disposed osteophytes are found on all corporal margins. The costo-vertebral joints and metapophyses look normal.

Lumbar vertebrae (1-26)

The first two lumbar vertebrae look normal. Small, vertically disposed osteophytes are found on the corporal margins of all lumbar vertebrae, but are more pronounced after the 3rd, especially on the antero-lateral and ventral margins. Between the 5th and 6th lumbar vertebra, small paradiscal ossicles are found on the lateral and dorsal parts of the annulus fibrosus. Similar small paradiscal ossicles (maximally 5 × 2 mm) are found on the dorsal side between the 14th thoracic and 1st lumbar, 1st and 2nd lumbar, 3rd and 4th, and 4th and 5th lumbar vertebrae. Vertically disposed osteophytes are visible on all following lumbar vertebrae. Impressive pathological changes are found between the 10th and 23rd lumbar vertebrae (figs 11 & 12). Between the 10th and 11th lumbar vertebra, irregularly formed, non-marginal syndesmophytes are found on the right antero-lateral side, which impinge on each other, but are not fused? The 11th and 12th lumbar vertebrae are fused by a smoothly formed, non-marginal syndesmophyte on the right antero-lateral side. A smaller ankylosis shows on the left antero-lateral side. Between the 12th and 13th lumbar vertebra, small paradiscal ossicles and irregular marginal osteophytes are present. A

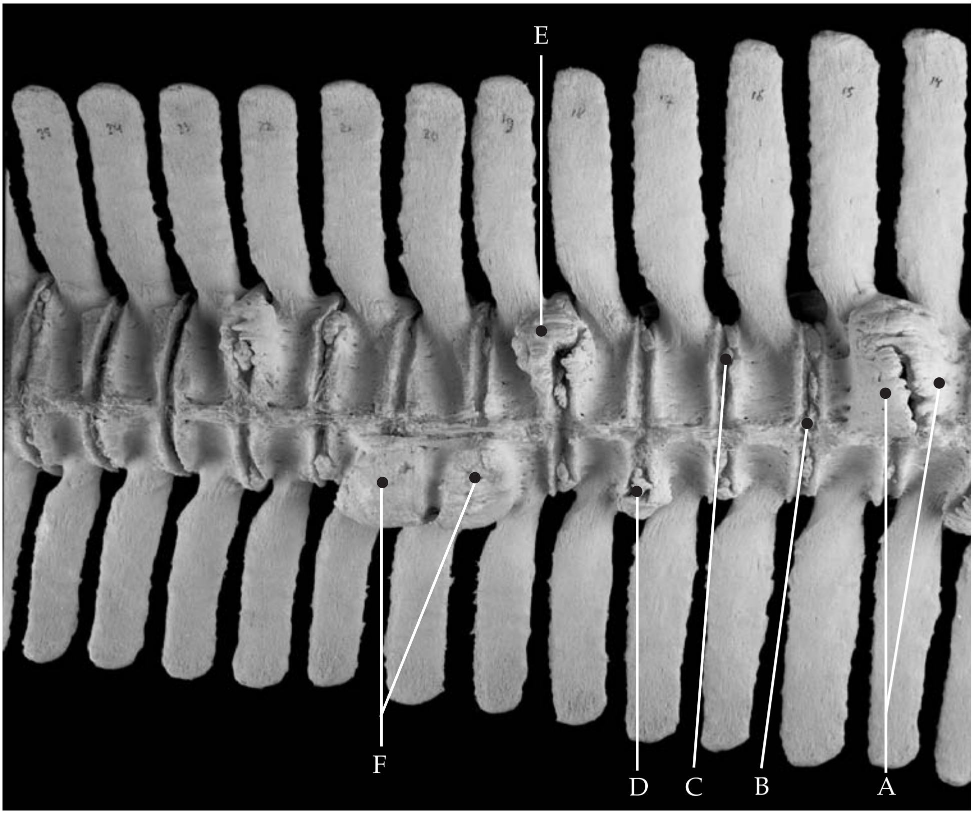

Fig. 12. *Lagenorhynchus albirostris* , 25-14th lumbar vertebrae in dorsal aspect (adult female, RMNH 21046).
A, bizarre looking syndesmophytes between the 14th and 15th lumbar vertebra; B,C,D, paradiscal osiicles between the 15th and 16th lumbar vertebra; E, syndesmophyte between the 18th and 19th lumbar vertebra, formed by paradiscal ossicles; F, large syndesmophytes between 19-21th lumbar vertebrae.

large, non-marginal syndesmophyte is found on the left antero-lateral side of the 13th lumbar vertebra, which is clearly formed by ossification of the annulus fibrosus on the left lateral side. Smaller ossicles are found on the margins of the annulus fibrosus between these vertebrae. Bizarre looking large syndesmophytes are visible on the right antero-lateral side of the 14th and 15th lumbar vertebrae (fig. 12A). On some points, these are ankylosed with each other. Between the 15th-16th, 16th-17th and 17th-18th lumbar vertebrae, multiple ossifications of the annulus fibrosus are found all around the discs (fig. 12B, C, D). Between the 18th and 19th lumbar vertebra, these ossicles have formed smooth syndesmophytes on the right antero-lateral side (fig. 12E). Between the 19th and 21st lumbar vertebra, a very large, smoothly formed syndesmophyte is visible, which forms an ankylosis between these three vertebrae (fig. 12F). The intervertebral disc space between these vertebrae looks normal. Between the 19th and 20th lumbar vertebra, the ankylosis is also found above the level of the transverse process (fig. 11). Between the 21th-25th lumbar vertebrae, multiple, small

Fig. 13. *Lagenorhynchus albirostris*, 12-28th caudal vertebrae in lateral aspect (adult female, RMNH 21046) showing multiple paradiscal ossicles and irregular new bone formation of the 26-27th caudal vertebrae.

paradiscal ossicles and bulky syndesmophytes are found on all sides, all originating from the annulus fibrosus, as is clearly shown in figs 11 and 12.

Caudal vertebrae (1-45)

Multiple, paradiscal ossicles and syndesmophytes are visible on the margins of the intervertebral discs of the first 21 caudal vertebrae (fig. 13). Between the 19th and 20th caudal vertebra, a smoothly formed ankylosis is found. The following 24 vertebrae and intervertebral spaces are normal, with the exception of the 26th and 27th. These show irregular new bone formation on all sides.

The humeri, ulnae, radii, metacarpalia, phalanges, scapulae, pelvic bones, hyoid and sternum show no pathological changes. The left mandible shows a complicated fracture, with secondary osteomyelitis. The fracture was not healed at the time of death of the dolphin. Almost all teeth had fallen out during life.

Case 3. *Lagenorhynchus albirostris* Gray, 1846

On 23 November 1974, the decomposed remains of a white-beaked dolphin *Lagenorhynchus albirostris* of unknown sex were found on the island of Terschelling, The Netherlands. The skeleton is kept in the Zoological Museum of Amsterdam (ZMA 17.232).

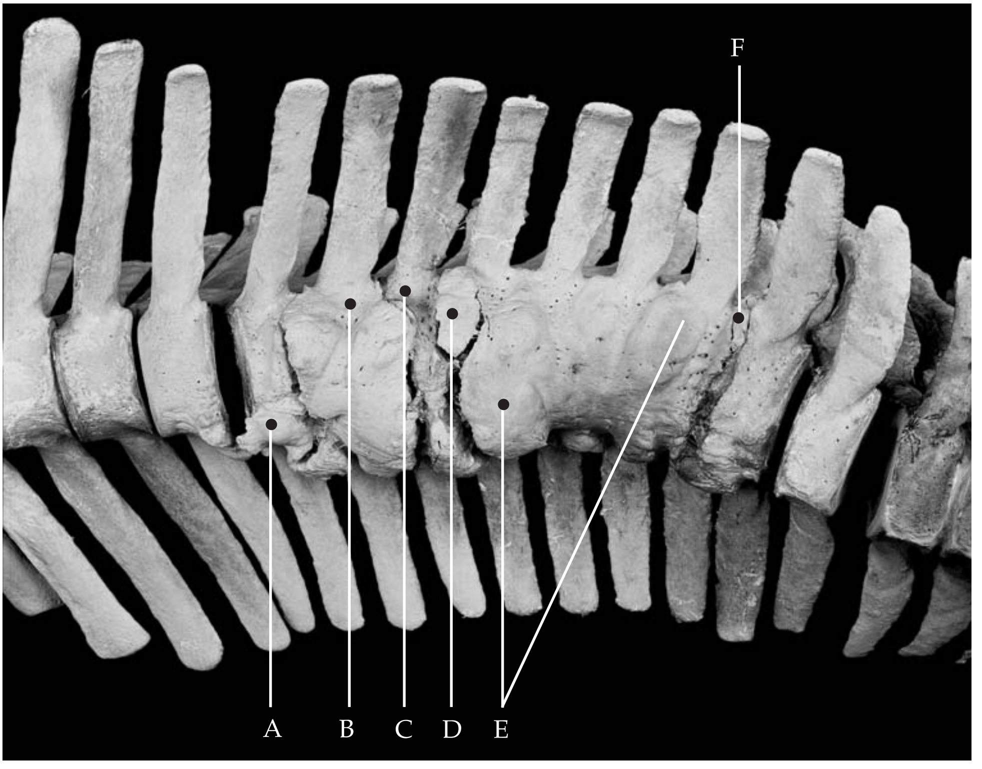

Fig. 14. *Lagenorohynchus albirostris,* 2nd-10th lumbar vertebrae in dorsal aspect (sex unknown, ZMA 17.232).
A, large syndesmophyte on the 3th lumbar vertebra; B, large new bone formation over the 4th lumbar vertebra; C, remains of the 5th lumbar vertebra; D, partly fused paradiscal ossicles between the 5th-6th lumbar vertebrae; E, large new bone formation fusing the 6th-9th lumbar vertebrae.

The vertebral column of ZMA 17.232 shows severe deformations. Most striking is the kyphosis between the 12th lumbar and 17th caudal vertebrae (illustrated by Kompanje, 1995a figs 7 & 12), which will not be discussed here. Severe pathological changes are also found in the 2nd-10th lumbar vertebrae, which at first sight are atypical of discarthrosis. The features found in the vertebrae of this dolphin were briefly described and illustrated by Kompanje (1995b). Ventrally and antero-laterally, located marginal and non-marginal syndesmophytes are found between the 2nd and 10th lumbar vertebrae. All metapophyses in this part are normal. On the 2nd lumbar vertebra, a smooth, non-marginal syndesmophyte is found caudally on the right antero-lateral side. Small ossifications (max. 12 × 4 mm) of the annulus fibrosus are also visible in this region. The vertebral end-plates are normal. On the 3rd lumbar vertebra a large, ventrally disposed, non-marginal syndesmophyte is visible on the right side, which impinges with the syndesmophyte of the 2nd lumbar vertebra (fig. 14A). Smaller new bone formation is found on both antero-lateral sides. On the right side, paradiscal ossicles with marginal new bone formation are present. The 4th lumbar vertebra shows grotesque new bone formation. On both sides large, antero-laterally disposed, non-marginal syndesmophytes are found of the cranial part of the vertebra. These impinge with the syndesmophytes of the 3rd lumbar vertebra. A large new bone formation is found on the caudal part of the 4th vertebra. A thick, non-marginal syndesmophyte is formed over the ventral and both antero-lateral sides of the vertebral body (fig. 14B). This bone formation impinges with syndesmophytes, which are found, on the cranial side of the 5th lumbar vertebra. The 5th lumbar vertebra is strangely deformed. The normal form of the vertebral body is only found posteriorly. A large, non-marginal syndesmophyte has displaced the vertebral body of the 6th lumbar vertebra on the right antero-lateral side (fig. 14E) and impinges with new bone formation of the 6th lumbar vertebra, which is laterally positioned. The 6th-9th lumbar vertebrae show a complete ankylosis (fig. 14E). A large ossification of the annulus fibrosus is present on the left lateral side between the 5th and 6th vertebra (fig. 14D). Dorso-lateral ossification of the annulus fibrosus (dorsally of the processus transversus) has occurred between the 6th and 7th, 7th and 8th, and 8th and 9th lumbar vertebra on the right side, and between the 7th and 8th, and 8th and 9th on the left side. This ossification has a smooth surface. Between the 9th and 10th lumbar vertebra, several paradiscal ossicles are present which are incompletely fused (fig. 14F). Between the 9th and 10th lumbar vertebra too, two small pieces of ossified annulus fibrosus are visible on the dorsal side. The body of the 11th lumbar vertebra looks normal. The metapophyses of this vertebra show some thickening of the cortex and slight erosion of unknown cause.

Table 3. Diagnosis of pathological changes of the vertebrae in recent Mysticeti and Odontoceti. Review of the literature. Cases of (healed) fractures of the vertebral corpus, spinal or transverse processes and pathological changes of the chevrons are not included in this table.

AUTHOR	SPECIES	DIAGNOSIS
1. Camper (1820)	*Delphinus delphis*	*'Vertèbres étaient ankilosées'*
2. Burmeister (1867)	*Balaenoptera acutorostrata*	*'...vertebrae united together.. consequence of disaese during life..'*
3. Oliver (1922)	*Mesoplodon grayi*	*'the 8th and 9th caudals are jointed by a bony growth'*
4. Lönnberg (1931)	*Baleanoptera edeni*	*'the 45th vertebra... is completely covered with big exostoses;...minor exostoses are also seen...44th and 40th vertebrae..'*
5. Slijper (1931)	*Balaena mysticetus*	
	Balaenoptera physalus	
	Balaenoptera acutorostrata	
	Phocoena phocoena	
	Tursiops truncatus	
	Lagenorhynchus albirostris	
	Orcinus orca	
	Delphinus delphis	
	Kogia breviceps	*'Konstitutionelle Disposition für exostotische Prozesse; 'Degenerationserscheinung' (Exostosen, Synostosen der*

		Chevrons und Dornfortsätze)'
6. Korschelt (1932)	*Balaena mysticetus*	*'Verwachsung zweier Kaudalwirbel'*
	Balaenoptera physalus	*'Verletzter und geheilter Wirbel'*
	Balaenoptera edeni	*'Verwachsung'*
	Megaptera novaeangliae	*'Vollständige Verwachsung'*
	Monodon monoceros	*'Skoliose'*
	Tursiops truncatus	*'Knochenwucherungen'*
	Orcinus orca	*'Synostose zweier Wirbel'*
7. Slijper (1936)	*Balaena mysticetus*	*'Spondylitis deformans'*
	Balaenoptera physalus	
	Megaptera novaeangliae	
	Phocoena phocoena	
	Orcinus orca	
	Orcaella brevirostris	
	Globicephala melas	
	Tursiops truncatus	
	Delphinus delphis	
	Lagenorhynchus albirostris	
	Hyperoodon ampullatus	
	Mesoplodon bidens	
	Mesoplodon grayi	
	Lagenorhynchus acutus	*'Kongenitale Kyphose'*
8. Slijper (1938)	*Balaena mysticetus*	*'Spondylitis deformans'*
	Mesoplodon bidens	
9. Van Bree & Nijssen (1964)	*Lagenorhynchus albirostris*	*'Spondylitis deformans'*
10. Yamada (1954)	*Feresa attenuata*	*'Osteoma'*
11. Cowan (1966)	*Globicephala melas*	*'Osteoarthritis'; 'Congenital block vertebrae'*
12. Van Bree & Duguy (1970)	*Lagenorhynchus albirostris*	*'Spondylitis deformans'*
	Tursiops truncatus	*'Les premières vertèbres soudées au crâne'*
13. De Smet (1972)	*Lagenorhynchus albirostris*	*'Spondylite'*
14. Lagier (1977)	*Balaenoptera* spec.	*'Spondylosis'*
15. Pilleri (1973) Pilleri & Gihr (1974)	*Balaenoptera edeni*	*'Osteomyelitic process with exostatic structures'*
16. Omura (1975)	*Balaenoptera acutorostrata*	*'The 2nd, 3rd, and 4th caudal vertebrae are developed abnormally, possibly from some pathological cause'*
17. De Smet (1977)	*Tursiops truncatus*	*'Ankylosing vertebral hyperosteosis'; 'periostitis'; 'spondylitic osteophytes'*
18. Toussaint (1977)	'Dauphin'	*'Ostéite des vertèbres'*
19. Robineau (1981)	*Delphinus delphis*	*'Coulées osseuses, ostéoporose, ostéomalacie, ostéolyte excessive'*
20. Ross (1984)	*Stenella attenuata*	*'Pathological fusion of the occipital condyles and the first three cervical vertebrae'*
21. Paterson (1984)	*Balaenoptera edeni*	*'Spondylitis deformans'*
22. Walker et al. (1986)	*Lagenorhynchus obliquidens*	*'Osteonecrosis'*
23. Kinze (1986)	*Phocoena phocoena*	*'Spondylitis deformans'*
24. Martineau et al. (1988)	*Delphinapterus leucas*	*'Ankylosing spondylitis'*
25. Alexander et al. (1989)	*Tursiops truncatus*	*'Vertebral osteomyelitis, disko-spondylitis'*

26. Baker & Martin (1992)	*Phocoena phocoena*	*'Ankylosing spondylitis'*
27. Klima (1992)	No species mentioned	*'Spondylosis deformans'*
28. Stede (1994), Meyer (1994)	*Megaptera novaeangliae*	*'Osteoperiostitis ossificans hypertrophicans'*
29. Miyazaki & Perrin (1994)	*Steno bredanensis*	*'Osteospondylitis; arthritis'*
30. Best & Abernethy (1994)	*Cephalorhynchus heavisidii*	*'Spondylitis'*
31. De Guise et al. (1994)	*Delphinapterus leucas*	*'Spondylosis ankylosans'*
32. Klima (1995)	*Balaenoptera physalus* *Balaena mysticetus* *Delphinus delphis*	*'Spondylosis deformans'*
33. De Guise et al. (1995)	*Delphinapterus leucas*	*'Ankylosing spondylosis'*
34. Kompanje (1995a)	*Lagenorhynchus albirostris*	*'Spondylosis deformans; spondylo-osteomyelitis; kyphosis'*
35. Kompanje (1995b)	*Lagenorhynchus albirostris* *Mesoplodon bidens* *Phocoena phocoena* *Lagenorhynchus acutus*	*'Spondylosis deformans'* *'Spondylo-osteomyelitis'*
36. Kompanje (1995c)	*Orcinus orca*	*'Spondylo-osteomyelitis'*
37. Paterson & Van Dyck (1995)	*Balaenoptera musculus*	*'hyperostotic changes of two vertebrae'*
38. Siebert et al. (1996)	*Phocoena phocoena*	*'Spondylosis/ankylosis of the vertebrae'*
39. Kompanje (1996)	*Lagenorhynchus albirostris*	*'Degeneration of the intervertebral disc; discarthrosis'*
40. Siebert et al. (1997)	*Phocoena phocoena* *Lagenorhynchus albirostris*	*'spondylosis with or without ankylosis'*

Discussion

In the literature, various terms are used to describe pathological changes of the vertebrae in cetaceans (table 3). This has resulted in considerable confusion, because it is not always clear what exactly the author has found, especially when neologisms or obsolete terms are used or when the contemporary diagnostic criteria have not been taken into consideration. Many cases have thus been incorrectly diagnosed.

Obsolete terms

Obsolete names for discarthrosis, such as '*spondylitis deformans*', are often used, but should be avoided. François et al. (1995) also recommend avoiding the term '*spondylosis deformans*'. According to these authors, the adjective '*deformans*' makes no sense, for most pathological conditions result in morphological changes. Furthermore, they stated that too many meanings have been given to the term '*spondylosis*'. They recommend using the term '*discarthrosis*' for arthrosis of the discal joint, which has been followed in this article. However, the term '*spondylosis*' is widespread and often used.

Neologisms

Terms such as *'osteonecrosis'* and *'osteospondylitis'* are neologisms and do not describe any known disease or condition.

Vague descriptions

'Spondylitis' by itself is too vague. A further qualification (e.g. 'infectious' or 'reactive') is needed. Moreover, in most cases it is not clear whether the term *'spondylitis'* is used in the meaning of the obsolete term for *'spondylosis'*, or whether infected vertebrae are found. Furthermore, to describe the pathological changes only as *'ankylosis'* or *'fusion'* is too vague as well and these terms should be used in a different way. They describe features of a disease or condition, not the disease itself.

Incorrect use of terms

De Smet (1977) used the term *'ankylosing vertebral hyperostosis'*, which is a synonym for DISH. Most probably, however, he does not mean this condition, because he also wrote about *'spondylitic osteophytes'* and *'spondylosis'*. He concluded that *'rheumatic affections'* are quite common in cetaceans. This conclusion should be rejected, because spondylosis is not a rheumatic condition and to date rheumatic diseases have not been found in cetaceans. The terms *'ankylosing spondylosis'* or *'spondylosis ankylosans'* cause confusion, because they describe only fused vertebrae. In many cases, spondylosis (discarthrosis) does not lead to ankylosis and those cases in reality may pertain to spondyloarthritis. Cowan (1966) found two cases of fused vertebrae in the pilot whale *Globicephala melas,* which he diagnosed as *'congenital block vertebrae'*. The vertebrae are fused by smoothly formed ankylosis, but one can see in his fig. 9 that the dorsal part of the intervertebral space, with the end-plates between the two vertebrae, is still visible. This is atypical for congenital block vertebrae, but can be seen in acquired vertebral synostosis. A diagnosis of spondyloarthritis seems more probable in this case. De Guise et al. (1994, 1995) found ulcerative enteritis and *'thick bridges of bone that solidly fused the ventral portions of the bodies of the 10th and 11th thoracic vertebrae'* in a white whale *Delphinapterus leucas.* They diagnosed the vertebral condition as *'ankylosing spondylosis'*. No bacteria from the intestine were isolated. Possibly, this case represents a reactive spondylitis of the Reiter's type (spondyloarthritis) rather than discarthrosis. Walker et al. (1986) mentions a high incidence of vertebral pathological changes (54% of the examined individuals) in *Lagenorhynchus obliquidens*. It seems likely that this sample includes cases of discarthrosis and spondyloarthritis, as was found by Kompanje (1995b, this study). Martineau et al. (1988) used the term *'ankylosing spondylitis'*, which is nowadays known as one of the forms of spondyloarthritis; however, this form has not been recognized in any cetacean to date. Possibly, this case refers to another form of spondyloarthritis or to a case of discarthrosis. The pathological changes of the vertebrae in a female *Feresa attenuata* described and illustrated by Yamada (1954) most probably represent a case of spodyloarthritis rather than an*'osteoma'*.

Diagnosing vertebral pathology

Detailed post-mortem examinations of Mysticeti have rarely been reported in the literature (e.g. Di Guardo et al., 1995). Due to the large size of most of these whales, autopsy on stranded animals faces great operational difficulties. Due to the rapid putrefaction of the whale on the beach, it is difficult to collect useful material for diagnosing diseases. Some early pathological investigations were conducted in connection with commercial whaling (e.g. Cockrill, 1960). Skeletons of larger stranded whales, on the other hand, are often collected and stored in natural history museums. Pathological changes in these skeletons can be studied without problems, but are often difficult to interpret when one is not familiar with the differential diagnostic criteria used in vertebral pathology. As a result, those changes nearly always have been described as spondylosis deformans (or under its obsolete name *'spondylitis deformans'*; see Slijper, 1931, 1936; Lagier, 1979; Paterson, 1984; Klima, 1995; see table 1), which in almost all cases seems to be an incorrect interpretation of features that are atypical for discarthrosis. Discarthrosis has not been recognized in any baleen whale during this study.

From Odontoceti, more detailed autopsy findings are known. Inflammation of the small intestine is described for several cetacean species (e.g. Bossart et al., 1991; Di Guardo et al., 1995; unpublished data National Museum of Natural History, Leiden [M. García-Hartmann]). This enteritis could be seen as a co-disease associated with some form of spondyloarthritis. In man, secondary amyloidosis in some cases affects patients with spondyloarthritis. Amyloidosis has recently been diagnosed in four out of 21 (19%) bottlenose dolphins *Tursiops truncatus* (see Cowan, 1995).

Some authors described how sterile spondyloarthritis can complicate infections by certain intestinal parasites in man (Aho et al., 1985; Bocanegra et al., 1981). Cetaceans are often seriously infected with intestinal parasites. Further research in this direction seems useful.

The skeleton of cetaceans is modified for an aquatic life and is thus quite different from that of terrestrial mammals. The skeleton of cetaceans is non-weight-bearing. The cortex is thin and the bones are without medullary cavities and have a porous or spongy structure throughout. Therefore, it would seem possible that the bone tissue of cetaceans reacts in a different way to external stress than that of other mammals. However, the mammalian bone has only limited possibilities of reacting to pathological or traumatic disturbances. The pathological reactions seen in cetacean skeletons are, without exception, similar to those seen in terrestrial mammals. The features found as the result of degeneration of the intervertebral disc in cetaceans are quite similar to those found in terrestrial mammals, and the same holds true for infectious spondylitis. Degeneration of the intervertebral disc displays the same features during autopsy as it does in terrestrial mammals (Kompanje, 1995b).

Comparing spondyloarthritis as it is found in terrestrial mammals with the features found in cetaceans poses some difficulties. Sacroiliitis is one of the most consistent criteria for spondyloarthritis. Since cetaceans have no functional pelvis, this diagnosis is not possible here. The same applies to the involvement of the zygapophyseal joint surfaces, which in terrestrial mammals is diagnostic for spondyloarthritis. In cetaceans, vertebrae with zygapophyseal surfaces and synovial joints only extend as far as the middle thoracic vertebrae. The rest of the metapophyses are only attachment points for tendons and cannot be regarded as synovial joints (Rommel, 1990). The most posterior zygapophyseal surfaces with synovial joints were found during the present study in, e.g., *Grampus griseus* between Th. 6-7, in *Globicephala melas* between Th. 4-5/6-7, in *Mesoplodon bidens* between Th. 4-5, in *Delphinus delphis* between Th. 7-8, in *Tursiops truncatus* between Th. 6-7, and in *Lagenorhynchus albirostris* between Th. 9-10. The metapophyses after this point cannot be involved in the fusing process in spondyloarthritis. In humans, the manubriosternal articulation is often involved in the pathological process. In most dolphins, however, there normally is a fusion between manubrium and sternabrae in adult animals (see, e.g., Perrin, 1975), so any involvement of the manubriosternal articulation is not detectable. No association between spinal pathological features and one of the co-diseases of spondyloarthritis as described for terrestrial mammals has been demonstrated for cetaceans. We do not know anything about familial clustering or familial 'overlap' (two or more spondyloarthritic conditions in the same family) of spinal pathological features in cetaceans. Research on bycaught cetaceans which have been captured as a group and which are possibly related may give more information on this aspect. In contrast with man and other terrestrial mammals, peripheral joint involvement will be absent in cetaceans affected by spondyloarthritis, in view of the different anatomy of the elbow, metacarpus and carpus. The only joint in which arthritis could possibly be found in cetaceans is the shoulder. Axial involvement will therefore be dominant.

Diagnosis in the three described cases

The pathological changes found in the vertebrae of the examined fin whale could not be diagnosed as the results of infectious spondylitis or DISH and are atypical for discarthrosis, which is associated with degeneration of the intervertebral disc. There is no evident narrowing of the intervertebral disc space in the fused parts, no erosion or sclerosis of the vertebral end-plates (related to degeneration), and no vertically disposed marginal osteophytes. The grotesque new bone formation found in this whale is to be identified as non-marginal syndesmophytes rather than osteophytes. There are two blocks of four fused vertebrae, one in the cervical/thoracic and one in the lumbar/caudal region. The syndesmophytes are horizontally disposed and mainly on the ventral and antero-lateral side of the vertebrae. In the cervical region the ankylosis is smoothly formed, with some antero-laterally and ventrally disposed syndesmophytes. In the thoracic region the syndesmophytes are situated on the left side. The disc spaces are normal. There is fusion of the cervical and some of the thoracic zygapophyseal joints. The syndesmophytes in the fused vertebrae in the lumbar/caudal region cover the whole ventral part of the vertebrae. In this part too, the disc spaces and vertebral end-plates are normal. A diagnosis as spondyloarthritis with skip areas of non-marginal syndesmophytes, most probably of the Reiter's type, seems most likely in this case.

The typical, non-marginal ('bullhorn-shaped') syndesmophytes and paradiscal ossicles originating from the margins of the intervertebral discs in the two white-beaked dolphins discussed here, are typical for spondyloarthritis. Beside these typical features, marginal osteophytes as a sign of ageing and degeneration of the intervertebral disc were found (see also Kompanje, 1995b). Ossifications of the annulus fibrosus in combination with the typical syndesmophytes excluded a diagnosis as DISH, discarthrosis or infectious spondylitis. The ossifications are typical of spondyloarthritis of the Reiter's type and psoriatic spondylitis. Rothschild & Rothschild (1994) illustrated this feature for Hyaenidae and Rothschild et al. (1993) for Ursidae. Piechoki (1962) described and illustrated pathological changes of the vertebral column of beavers *Castor fiber*, in which ossifications of the annulus fibrosus typical for spondyloarthritis are clearly visible. His diagnosis, however, is not correct. The syndesmophytes in *Lagenorhynchus albirostris* case 2 are chunky and there are skip areas. This could be diagnostic for spondyloarthritis of the Reiter's type. Initial alterations in both cases of *L. albirostris* are apparent at the thoracolumbar and lumbar/caudal junctions, similar to those observed in man and other terrestrial mammals.

Spondyloarthritis has not previously been distinguished from discarthrosis (spondylosis deformans) or infectious spondylitis in cetaceans.

I reject my earlier statement that spondylitis of the spondyloarthritis-type does not occur in cetaceans, and that new bone formation on the vertebrae can only be diagnosed as discarthrosis (Kompanje, 1993).

Conclusion

The conclusion of the present study is that vertebral new bone formation in aged individuals of at least some species of Odontoceti can be diagnosed as:

1. Discarthrosis (spondylosis deformans),
2. Infectious spondylitis/discitis (spondylo-osteomyelitis),
3. Spondyloarthritis (spondyloarthropathy, Reiter's syndrome, reactive spondylitis).

None of these conditions is, however, very common. Diffuse idiopathic skeletal hyperostosis was not recognized during this study. Some species of Odontoceti and Mysticeti, e.g., dolphins of the genus *Lagenorhynchus*, are probably vulnerable to degeneration of the intervertebral disc and to autoimmune reactions after some kind of infection, resulting in the typical pathological changes of the vertebral column. Further study of species in this genus is recommended.

Probably, spondyloarthritis, previously mostly diagnosed as discarthrosis (spondylosis), occurs in more cetacean species. Discarthrosis in cetaceans seems to be less common. Re-examination of cases of pathological changes in the vertebral column of cetaceans is recommended. Further research during autopsies focussed on autoimmune reactions, as well as on the occurrence of syndesmophytes on the ventral side of the vertebral column, is needed to understand these conditions more properly. Recently, the first case of spondyloarthritis has been recognized during autopsy in a white-beaked dolphin (data National Museum of Natural History, Leiden [E.J.O. Kompanje]).

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