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DISEASE IN WILDLIFE OR EXOTIC SPECIES

Dental and Temporomandibular Joint Pathology of the Polar Bear (*Ursus maritimus*)

J. N. Winer*, B. Arzi†, D. M. Leale†, P. H. Kass‡ and F. J. M. Verstraete†

* *William R. Pritchard Veterinary Medical Teaching Hospital,* † *Department of Surgical and Radiological Sciences and* ‡ *Department of Population Health and Reproduction, School of Veterinary Medicine, University of California, Davis, CA, USA*

Summary

Museum specimens (maxillae and/or mandibles) from 317 polar bears (*Ursus maritimus*) were examined macroscopically according to predefined criteria and 249 specimens were included in this study. The specimens were acquired between 1906 and 2011. There were 126 specimens (50.6%) from male animals, 93 (37.3%) from female animals and 30 (12.1%) from animals of unknown sex. The ages of the animals ranged from neonate to adult, with 125 adults (50.2%) and 124 young adults (49.8%) included and neonates/juveniles excluded from the study. The number of teeth available for examination was 7,638 (73.5%); 12.3% of teeth were absent artefactually, 0.8% were deemed absent due to acquired tooth loss and 13.4% were absent congenitally. With respect to tooth morphology, 20 teeth (0.26% of available teeth) in 18 specimens (7.2% of available specimens) were small vestigial structures with crowns that were flush with the level of surrounding alveolar bone. One supernumerary tooth and one tooth with enamel hypoplasia were encountered. Persistent deciduous teeth and teeth with an aberrant number of roots were not found. Relatively few teeth (3.7%) displayed attrition/abrasion, 90% of which were the maxillary and mandibular incisor teeth, in 41 polar bears (16.5%). Nearly twice as many adult specimens exhibited attrition/abrasion as those from young adults; significantly more males were affected than females. Dental fractures were noted in 52 polar bears, affecting 20.9% of specimens and 1.3% of the total number of teeth present. More adult polar bears had dental fractures than young adults. There were 21 specimens (8.4%) that displayed overt periapical disease, affecting a total of 24 dental alveoli (0.23%). Some degree of periodontitis was seen in 199 specimens (79.9%); however, only 12.6% of dental alveoli had bony changes indicative of periodontitis. Lesions consistent with temporomandibular joint osteoarthritis (TMJ-OA) were found in 23 specimens (9.2%). TMJ-OA was significantly more common in adults than in young adults and in males than in females. Although the clinical significance of dental and TMJ pathology in the polar bear remains elusive, the occurrence and severity of these lesions may play an important role in the morbidity and mortality of this species.

Keywords: dental pathology; polar bear; temporomandibular joint; *Ursus maritimus*

Introduction

The polar bear (*Ursus maritimus*) is one of eight extant species in the family Ursidae. They are the largest living bear species, with adult males typically weighing up to 700 kg and adult females up to 400 kg (Amstrup, 2003). Their range lies mostly within the Arctic Circle, limited to areas in which the sea is covered by ice for the majority of the year. Sea ice is the polar bear's primary habitat, used as a platform for hunting, traversing the landscape and mating (Galicia *et al.*, 2015). Their territory includes parts of Canada, Alaska, Greenland, Norway and Russia. Because the polar bear spends extended time at sea, it is considered to be a marine mammal.

Correspondence to: F. J. M. Verstraete (e-mail: fjverstraete@ucdavis.edu).

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The polar bear is unique in that it is the only extant ursid with an exclusively carnivorous diet (Slater *et al.*, 2010), serving as an apex predator of the Arctic marine ecosystem (Amstrup, 2003). Their preferred prey is ringed seals (*Pusa hispida*) and bearded seals (*Erignathus barbatus*) (Galicia *et al.*, 2015); however, they are opportunistic predators and scavengers, and other rarely predated species include harp seals (*Pagophilus groenlandicus*) (Derocher *et al.*, 2002), beluga whales (*Delphinapterus leucas*) (Lowry *et al.*, 1987), walruses (*Odobenus rosmarus*) (Kiliaan and Stirling, 1978), narwhals (*Monodon monoceros*) (Smith and Sjare, 1990) and white-beaked dolphins (*Lagenorhynchus albirostris*) (Aars *et al.*, 2015). Polar bears feed almost exclusively on blubber and flesh; this soft diet requires little or no mastication prior to swallowing (Slater *et al.*, 2010).

As a result of its specialized diet, the polar bear has evolved multiple dental adaptations that set it apart from the other ursids (Kurtén, 1964; Slater *et al.*, 2010), despite sharing the same dental formula: I 3/3, C 1/1, P 4/4, M 2/3 (Fig. 1). Their molar teeth have a reduced surface area for grinding compared with the omnivorous brown bear (*Ursus arctos*), from which polar bears evolved less than 250,000 years ago (Amstrup, 2003; Sacco and Van Valkenburgh, 2004; Slater *et al.*, 2010). Polar bears lack the well-developed secodont carnassial teeth (i.e. maxillary fourth premolar teeth and mandibular first molar teeth) typical of other hypercarnivores; it has been hypothesized that the relatively underdeveloped carnassial teeth can be attributed to discrepancy between polar bear size and the size of their typical prey (Sacco and Van Valkenburgh, 2004). Polar bears often weigh significantly more than their prey; this disparity suggests that polar bears rely on their brute force to process carcasses, rather than depending on specialized dental function beyond their prominent canine teeth (Sacco and Van Valkenburgh, 2004).

In 2008, the polar bear was listed as a globally threatened species under the US Endangered Species Act, primarily due to the threat of rapidly declining Arctic sea ice (Atwood *et al.*, 2015). While habitat loss is the polar bear's main threat, dental and temporomandibular joint (TMJ) lesions, which are common in certain wildlife species, may be important contributors to morbidity and mortality (Verstraete *et al.*, 1996a,b).

A series of papers has been published on dental and TMJ pathology of marine mammal species, including the northern elephant seal (*Mirounga angustirostris*) (Abbott and Verstraete, 2005), the southern sea otter (*Enhydra lutris nereis*) (Winer *et al.*, 2013; Arzi *et al.*, 2013b), the California sea lion (*Zalophus californianus*) (Sinai *et al.*, 2014; Arzi *et al.*, 2015), the northern fur seal (*Callorhinus ursinus*) (Aalderink *et al.*, 2015a) and the Eastern Pacific harbour seal (*Phoca vitulina richardii*) (Aalderink *et al.*, 2015b). In general, museum collections of skulls, such as those making up the aforementioned studies and this study, are obtained from strandings, carcass recovery and donations by rehabilitation centres. Specific to Alaska, museum specimens are sourced additionally from permitted hunting for subsistence purposes and wildlife deaths as a result of 'Defense of Life and Property' laws. Pathological conditions are likely overrepresented in stranded animals as compared with the general population (Cowan, 2002); high numbers of stranded animals may be considered sentinels of emerging diseases (Gulland, 1999). The aim of this study was to determine the nature and prevalence of dental and TMJ pathology in the polar bear by examining museum specimen skulls.

Materials and Methods

Macroscopic examination of 317 maxillae and/or mandibles from the Department of Mammalogy, Museum of the North, University of Alaska, Fairbanks, was performed. Each specimen had been labelled with a unique catalogue number and the specimen's sex, collection location and collection date. 'Adult' versus 'young adult' categorization was determined by prominence of cranial sutures and prominence of the sagittal crest; 'juvenile' ageing was based on the presence of physiological deciduous or mixed dentition (Winer *et al.*, 2013), which disqualified further study of pathology in these specimens.

The teeth present, surrounding bone and the TMJs were inspected systematically according to predefined criteria (Table 1) utilized in former studies (Abbott and Verstraete, 2005; Winer *et al.*, 2013; Sinai *et al.*, 2014; Aalderink *et al.*, 2015a,b). Care was taken to rule out post-mortem trauma or preparation artefacts such as hairline cracks, artefactual sharp-edged fractures and flaked off enamel, potentially due to excessive heating and/or drying during skull preparation.

The presence or absence (i.e. congenital, acquired or artefactual) of all teeth was recorded. Missing teeth were taken into account when calculating the prevalence of abnormally formed teeth, attrition/abrasion, dental fractures and enamel hypoplasia; a full complement of teeth was assumed when calculating prevalence of supernumerary teeth, bony changes consistent with periodontitis and periapical lesions.

Teeth were assessed for normal or abnormal form. The number of roots was determined primarily by assessing the visible part of the coronal root, as many of the teeth were glued into their alveoli. The number of roots on mobile teeth was counted, or the alveoli

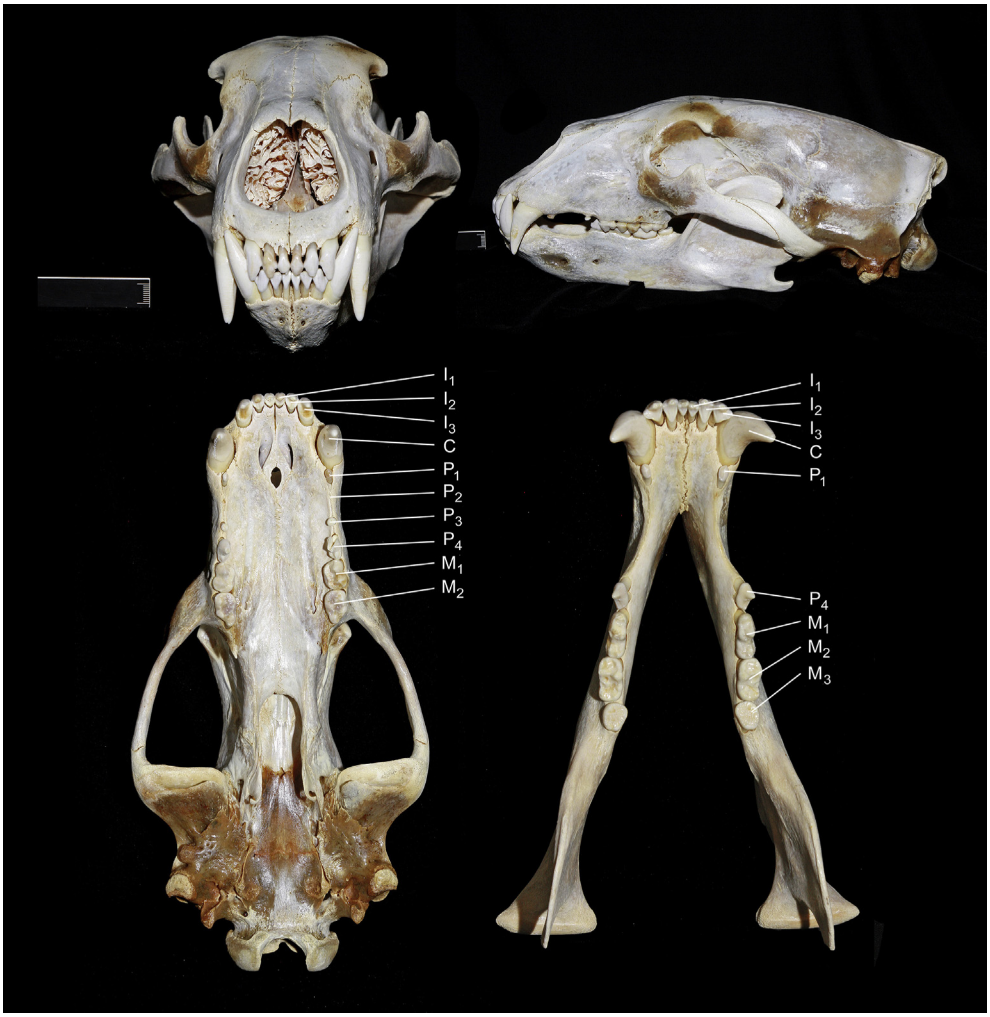

Fig. 1. Representative dentition of the polar bear. Note that the mandibular second and third premolar teeth are absent in this specimen. Bar, 1 cm.

themselves were examined when a tooth was artefactually absent. The presence of supernumerary teeth adjacent to the normal dentition was looked for, as were any persistent deciduous teeth. Attrition/abrasion was assigned to describe the wear of cusp tips. Six fracture types were assigned according to the World Health Organization classification of human dental fractures, as modified for use in carnivores (Verstraete, 2003). Periapical lesions were considered as a bony fenestration or a periosteal reaction overlying the apex of a tooth. Periodontal status was assessed based on an established classification system adapted for use on skulls (Verstraete *et al.*, 1996a,b).

Periodontitis stages 2–4 were assigned to the bony lesions indicative of periodontitis; stage 1 was excluded, as it refers to gingivitis, a soft tissue lesion that could not be assessed. Stage 2 shows increased vascularity (i.e. increased bone porosity) at the alveolar margin. Stage 3 shows rounding of the alveolar margin with more than 3 mm of vertical or horizontal bone loss. Periodontitis stage 4 shows widening of the alveolar margin with severe vertical or horizontal bone loss and teeth that are unstable in the alveoli or missing secondary to alveolar changes. Enamel changes consistent with the clinical signs of enamel hypoplasia were recorded.

In examining the TMJs, the mandibular heads and mandibular fossae of the squamous temporal bone were inspected independently. A semiquantitative scoring system (Arzi *et al.*, 2013a,b) for osteoarthritis (OA) was applied to each affected bone. Stages of TMJ-OA were scored from mild to severe. Mild OA was designated for early periarticular new bone formation/osteophytes with minimal or no subchondral bone change, or for increased porosity or irregular texture of the articular surface(s). Moderate OA was designated for more pronounced periarticular new bone formation and/or subchondral bone destruction. Severe OA was designated for severe periarticular new bone formation/osteophytes,

Table 1
Congenital, developmental and acquired abnormalities noted, and inclusion criteria

Observation	*Criteria*
Tooth artefactually absent	Jaw fragment missing or tooth absent, but a well-defined, sharp-edged, normally shaped, empty alveolus present; tooth presumed lost during preparation or post-mortem manipulation of the skull.
Tooth absent – presumably acquired	Tooth absent; alveolus or remnant alveolus visible; alveolar bone shows pathological signs (i.e. rounding of the alveolar margin, shallow alveolus, periosteal reaction on alveolar bone, increased vascular foramina).
Tooth absent – presumably congenital	Tooth and alveolus absent; smooth, morphologically normal bone present at the site; no physical space for that tooth to have occupied.
Malformed tooth	Presence of an abnormally shaped crown.
Number of roots	The number of roots, inspected directly or inferred from an empty alveolus or from the portion of root(s) visible within the alveolus (if the tooth is glued in place).
Supernumerary tooth	Presence of a supernumerary tooth adjacent to an expected tooth (or alveolus).
Persistent deciduous tooth	A persistent deciduous tooth adjacent to an erupted or unerupted permanent tooth.
Attrition/abrasion	Exposure of dentin on the cuspal tip, with or without tertiary dentine formation.
Enamel fracture	A chip fracture or crack of the enamel only.
Uncomplicated crown fracture	A fracture involving enamel and dentine, but not exposing the pulp.
Complicated crown fracture	A fracture involving enamel and dentine, with pulp exposure.
Uncomplicated crown-root fracture	A fracture involving enamel, dentine and cementum, but not exposing the pulp.
Complicated crown-root fracture	A fracture involving enamel, dentine and cementum, with pulp exposure.
Root fracture	A fracture affecting dentine, cementum and the pulp.
Periapical lesions	Macroscopically visible periapical bone loss, root tip resorption, sinus tract formation originating periapically or obvious focal periosteal reaction overlying the apex.
Periodontitis stage 2	Evidence of increased vascularity at the alveolar margin (more prominent vascular foramina in, and slightly rougher texture of, the bone of the alveolar margin).
Periodontitis stage 3	Rounding of the alveolar margin; moderate horizontal or vertical bone loss.
Periodontitis stage 4	Widening of the periodontal space; severe horizontal or vertical bone loss; tooth mobile in the alveolus.
Enamel hypoplasia	Irregular pitting or a band-shaped absence or thinning of the enamel, consistent with the clinical signs of enamel hypoplasia.
Mild TMJ osteoarthritis	Evidence of early periarticular new bone formation/osteophytes with minimal or no subchondral bone change.
Moderate TMJ osteoarthritis	Periarticular new bone formation and/or subchondral bone changes.
Severe TMJ osteoarthritis	All previously described signs are present and more pronounced; subchondral bone lysis present; partial or complete ankylosis may be observed.

marked subchondral bone destruction or partial or complete ankylosis.

Data from all adult and young adult specimens were pooled according to tooth type and were analyzed with descriptive statistics. Prevalence of lesions was compared with age group and sex. Significance was calculated by Fisher's exact test and $P < 0.05$ was considered significant.

Results

The collection date of specimens ranged from 1906 to 2011. Of the 317 specimens available, 249 were included in this study; the others were omitted due to mixed dentition (neonatal or juvenile status) or excessive ante-mortem or post-mortem trauma, preventing the ability to analyse teeth for pathology. Of the 249 included specimens, three had only the maxillae available with no mandibles present for review; the other 246 specimens were complete skulls, with both maxillae and mandibles available. Of the specimens included in this study, 126 (50.6%) were from male animals, 93 (37.3%) were from female animals and 30 (12.1%) were from animals of unknown sex. Adult and young adult specimens comprised 125 (50.2%) and 124 (49.8%) of the total included specimens, respectively.

Presence of Teeth

The total number of teeth available for examination was 7,638 (73.5%) out of a theoretical potential maximum of 10,392. Artefactual absence (i.e. loss during the specimen preparation process) accounted for 1,281 (12.3%) teeth; 85 (0.8%) teeth were deemed absent due to acquired tooth loss (i.e. lost during the course of the animal's life) and 1,388 (13.4%) were absent congenitally. The most common location for acquired tooth loss was the right and left mandibular first premolar teeth (29.4% of all cases). There were

52 specimens with acquired tooth loss, with significantly more adult polar bears displaying this lesion than young adults (27.2% of adults [$n = 34$] versus 14.5% of young adults [$n = 18$], $P = 0.0189$). A similar proportion of males and females had lost at least one tooth *ante mortem* (21.4% and 22.6%, respectively, $P = 0.8697$). The second and third premolar teeth were frequently absent congenitally: 75.1% of maxillary second premolar teeth were congenitally absent (out of a potential maximum of 498 teeth), 95.7% of mandibular second premolar teeth (out of a potential maximum of 492 teeth) and 97.2% of mandibular third premolar teeth (out of a potential maximum of 492 teeth); the remaining teeth were rarely absent congenitally.

Tooth Form

The majority of teeth were normal in morphology. However, there were 20 teeth (0.26% of available teeth) in 18 specimens (7.2% of available specimens) that exhibited the same malformation; these teeth were small vestigial structures with crowns that were flush with the level of the surrounding alveolar bone. The affected teeth were as follows: nine mandibular second premolar teeth, eight maxillary second premolar teeth, two mandibular third premolar teeth and one mandibular first premolar tooth. There were two specimens with two vestigial teeth each; otherwise, the specimens yielding vestigial teeth possessed one each.

Number of Roots

All teeth possessed the expected number of roots.

Supernumerary Teeth

One adult male specimen possessed a supernumerary left maxillary first premolar tooth (Fig. 2). No other specimens displayed supernumerary teeth.

Persistent Deciduous Teeth

None of the 249 adult or young adult specimens exhibited persistent deciduous teeth. Specimens with physiological mixed dentition were excluded from the study.

Attrition/Abrasion

Relatively few teeth (3.7%) displayed attrition/abrasion, 90% of which were the maxillary and mandibular incisor teeth. Of all of the incisor teeth present, 9.7% were affected by attrition/abrasion. Forty-one polar bears (16.5%) were affected by attrition/abrasion. The proportion of adult specimens with attrition/abrasion was almost twice that of young adult specimens ($n = 27$ versus $n = 14$, respectively; 21.6% of all adults had some degree of attrition/abrasion versus 11.3% of young adults; $P = 0.0395$). Furthermore, there was a significantly higher proportion of males affected by attrition/abrasion than females ($n = 28$ versus $n = 8$, respectively; 22.2% of all males versus 8.6% of females; $P = 0.0092$).

Tooth Fractures

Dental fractures were noted in 52 polar bears, affecting 20.9% of specimens and 1.3% of the total number of present teeth ($n = 98$). There was a higher proportion of adult polar bears with dental fractures than young adults ($n = 38$ versus $n = 14$, respectively; 30.4% of adults had at least one fractured tooth versus 11.3% of young adults; $P = 0.0003$). There was a higher proportion of male specimens with fractured teeth than females; however, this finding was not significant ($n = 25$ versus $n = 19$, respectively; 19.8% of all males versus 20.4% of females; $P = 1.0$). Of the six dental fracture types, four were represented in the pooled data: complicated crown-root fractures (55.1% of fractures) (Fig. 3), complicated crown fractures (41.8%), uncomplicated crown fractures (2.0%) and one root fracture (1.0%). The canine teeth were most often fractured, accounting for 26.5% of all fractured teeth, followed by the second incisor teeth, accounting for 23.5% of all fractured teeth. A greater proportion of males (7.1%) than females (3.2%) possessed one or more fractured canine teeth; however, this association did not reach statistical significance ($P = 0.2446$). About half ($n = 28$) of the polar bears with dental fractures possessed a single fractured tooth, while the remaining 24 specimens with dental fractures had at least two fractured teeth. There were 13 bears with two fractured teeth, five bears with three fractured teeth, three bears with four fractured teeth, two bears with five fractured teeth and one bear with seven fractured teeth.

Periapical Disease

There were 21 specimens (8.4%) with overt periapical disease, affecting 24 dental alveoli (0.23%). Of the periapical lesions, five (20.8%) were associated with complicated dental fractures (Fig. 3), two were associated with teeth that could not be assessed for fractures due to artefactual loss and one was associated with a tooth that was lost *ante mortem*; the other 16 lesions were associated with teeth with no

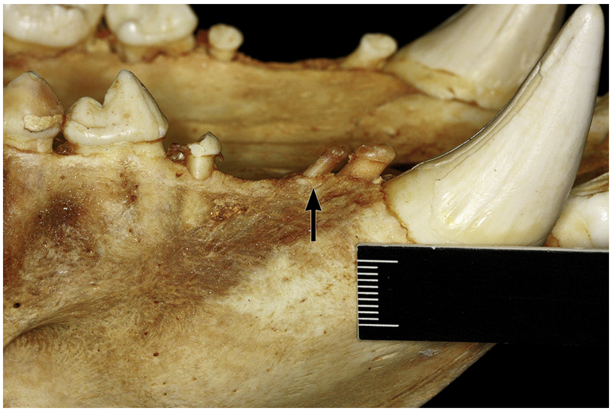

Fig. 2. Supernumerary tooth (arrow) associated with the left maxillary first premolar tooth in an adult male specimen. Bar, 1 cm.

obvious dental fractures. There were more adult polar bears with periapical disease than young adults ($n = 13$ versus $n = 8$, respectively; 10.4% of all adult specimens versus 6.5% of young adults; $P = 0.3622$). There were over three times as many males with periapical disease as females ($n = 13$ versus $n = 4$, respectively; 10.3% of all male specimens versus 4.3% of females; $P = 0.1275$). It is likely that this association did not reach statistical significance due to the low number of specimens affected by periapical disease.

Alveolar Bony Changes Consistent with Periodontitis

There were 199 specimens (79.9%) affected by some degree of periodontitis; however, only 12.6% of dental alveoli, either with or without teeth, were associated with bony changes indicative of periodontitis. The proportion of adult and young adult polar bears affected was nearly identical, with 99 adults (79.2%) and 100 young adults (80.6%) showing signs of periodontitis. Similarly, the proportion of male and female polar bears affected was nearly identical, with 102 males (80.9%) and 76 females (81.7%). Thus, there was no significant difference in prevalence based on age ($P = 0.8745$) or sex ($P = 1.0$). Overall, stage 3 periodontitis was most common (94.7%), followed by stage 2 (3.1%) and stage 4 (2.1%). The mandibular incisor teeth accounted for the vast majority of cases of periodontitis (86.4%); 76.4% of all mandibular incisor alveoli were scored as having at least mild periodontitis (Fig. 4). Aside from the mandibular incisor teeth, the right and left maxillary first molar teeth were the most common location at which periodontal hard tissue lesions were observed. Of the 498 maxillary first molar alveoli examined, 51 (10.2%) exhibited vertical or horizontal bone loss consistent with stage 3 or 4 periodontitis, with 20 of these alveoli affected by fenestration and 13 affected by dehiscence (Fig. 5). Of the 33 (13.3%) specimens with varying degrees of periodontitis affecting the left and/or right maxillary first molar teeth, 54.5% were affected bilaterally and 45.5% were affected unilaterally.

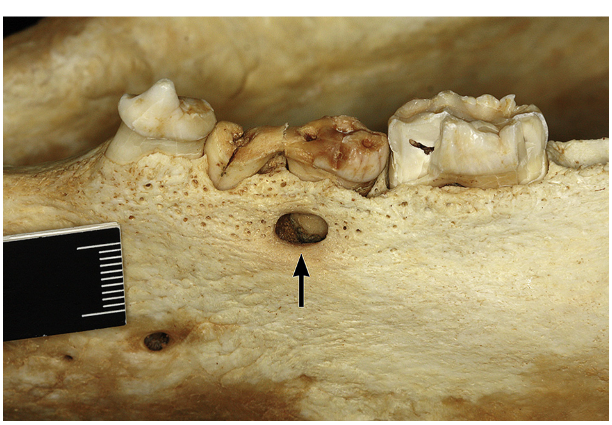

Fig. 3. Complicated crown-root fracture of the left mandibular first molar tooth in an adult male specimen, with an associated periapical lesion (arrow). Bar, 1 cm.

Enamel Hypoplasia

One young adult polar bear of unknown sex had a left maxillary canine tooth affected by focal enamel hypoplasia.

Temporomandibular Joint Pathology

Lesions consistent with TMJ-OA were found in 23 specimens, accounting for 9.2% of the total number of polar bears. In these 23 specimens, a total of 34 different lesion sites were found (affecting a combination of the right mandibular head and/or left mandibular head and/or right mandibular fossa of the temporal bone and/or left mandibular fossa of the temporal bone). Overall, mild TMJ-OA was most common (Fig. 6), accounting for 52.9% of all articular surfaces affected by TMJ-OA, followed by moderate TMJ-OA (41.2%) and severe TMJ-OA (5.9%). None of the 246 complete skull specimens displayed gross TMJ-OA lesions on all four articular surfaces. There were 12 specimens with a form of moderate TMJ-OA resembling osteochondritis dissecans (Fig. 7), more commonly encountered on the mandibular heads (71.4%) and less commonly located on the fossae (28.6%). One specimen had grade 3 TMJ-OA of the left mandibular head and mandibular fossa, suggestive of septic arthritis due

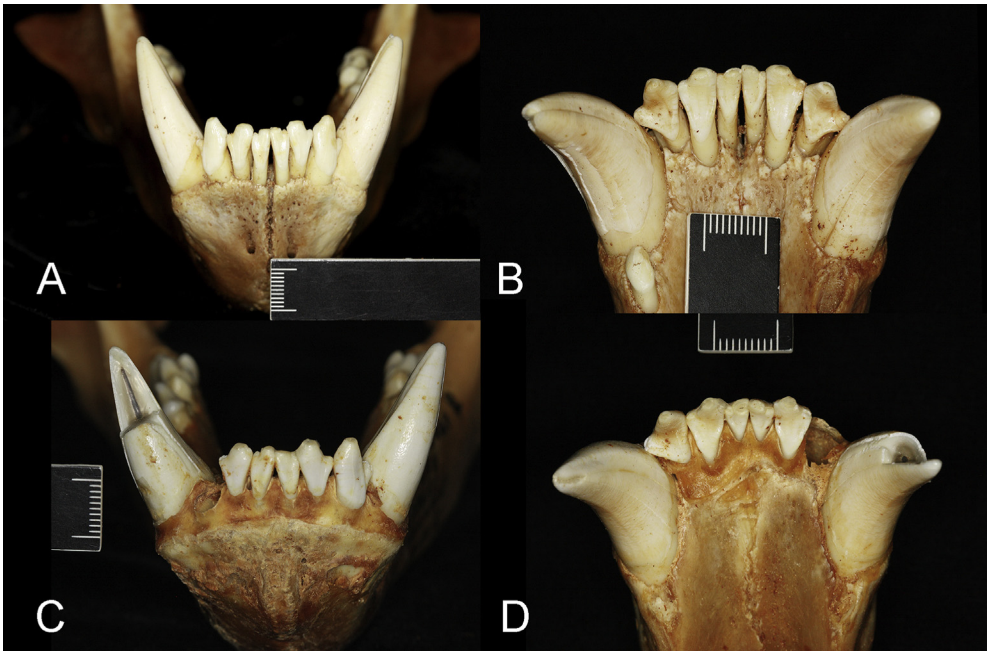

Fig. 4. (A, B) Stage 3 periodontitis of the mandibular incisor teeth in an adult male specimen. (C, D) The skull of a young adult female was prepared in such a way that residual gingival tissue was dried around the mandibular incisor teeth, with no evidence of periodontitis. Bar, 1 cm.

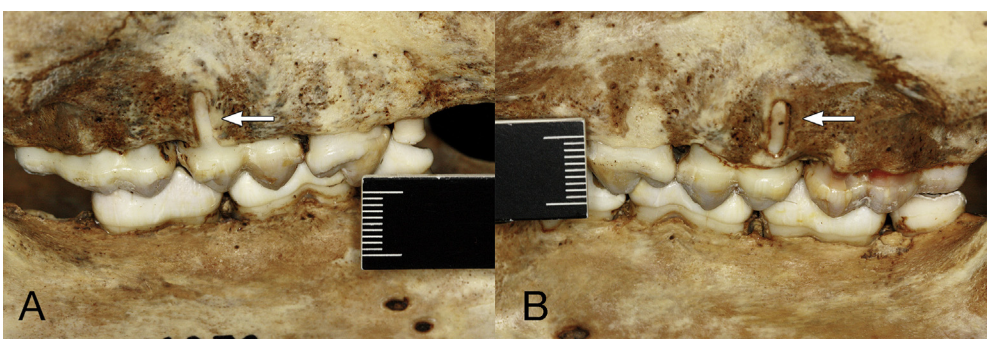

Fig. 5. Periodontitis stage 4 of the right and left maxillary first molar teeth in a young adult specimen. (A) Dehiscence of the first molar alveolus (arrow); (B) fenestration of the first molar alveolus (arrow). Bar, 1 cm.

to the severe subchondral bone lysis and osteophytosis (Fig. 8). There was a significant difference between the proportion of adult and young adult specimens exhibiting TMJ-OA ($n = 14$ versus $n = 2$, respectively; 11.2% of all adult specimens versus 1.6% of young adults; $P = 0.0031$). A significantly greater proportion of males than females were affected by TMJ-OA ($n = 16$ versus $n = 2$, respectively; 12.7% of all males versus 8.6% of females; $P = 0.0052$).

Other Findings

There were three specimens with mandibular fractures (two adult males and one young adult female), as well as an adult female specimen with bilaterally fractured maxillae and mandibles. It was impossible to distinguish if these fractures were the cause of mortality or if they were acquired *post mortem*. A young adult female specimen possessed diastemata interproximally between the left and right mandibular fourth premolar and first molar teeth (Fig. 9).

Discussion

Examination of a sizable collection of specimens enabled characterization of the nature and prevalence of dental pathology and TMJ lesions in the polar bear. Some skulls and teeth possessed defects clearly attributable to post-mortem trauma or preparation artefacts; however, these defects were discounted and did not impinge on the evaluation of true pathology. Investigating lesion variability over

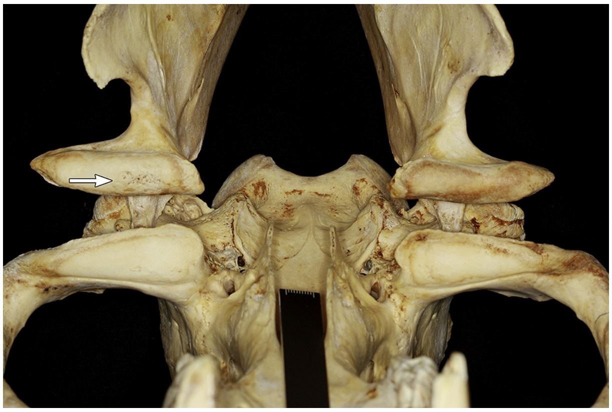

Fig. 6. Mild TMJ-OA of the left mandibular head (arrow) in an adult specimen of unknown sex. Note the increased porosity and irregular texture of the articular surface, with minimal subchondral bone change. Bar, 1 cm.

Fig. 7. Moderate TMJ-OA of the left mandibular head in a young adult specimen of unknown sex. Note the moderately irregular texture along the periphery of the articular surface, with subchondral bone destruction resembling an osteochondritis dissecans lesion. Bar, 1 cm.

the 105-year collection period was problematic because specimen procurement was erratic, with inconsistent numbers and ages of specimens collected over time. Therefore, no obvious trends correlating to chronology could be identified.

Congenital lesions were consistently infrequent in this sample of polar bears, although of the developmental abnormalities, congenitally absent teeth were most common, accounting for 13.4% of teeth. In this group of polar bears, the second and third premolar teeth were most often absent congenitally. Studies of other bear species have found that premolar teeth are consistently absent congenitally: a study of 22 free-ranging brown bears (*U. arctos*) revealed that all individuals were missing one or more premolar teeth (Strömquist *et al.*, 2009) and an older study (Miles and Grigson, 1990) found that only 2% of 159 examined American black bear (*Ursus americanus*) skulls had a full complement of premolar teeth. In small domestic animals with hypodontia, the premolar teeth are most often missing; one cause of this condition is an autosomal recessive genetic abnormality (Harvey and Orr, 1990).

Only one of the specimens in the present population was affected by enamel hypoplasia. To our knowledge, the prevalence of this condition has not been studied previously in the polar bear; however, in a study that examined 22 free-ranging brown bears, 15 were noted to have this condition (Strömquist *et al.*, 2009).

Certain acquired lesions, such as acquired tooth loss, periapical disease and TMJ-OA, were encountered rarely. Less than 1% of teeth were lost *ante mortem*, a finding consistent with a previous *Ursus* spp. study in which 1.7% of teeth were deemed absent due to acquired loss in a collection of 53 skulls derived

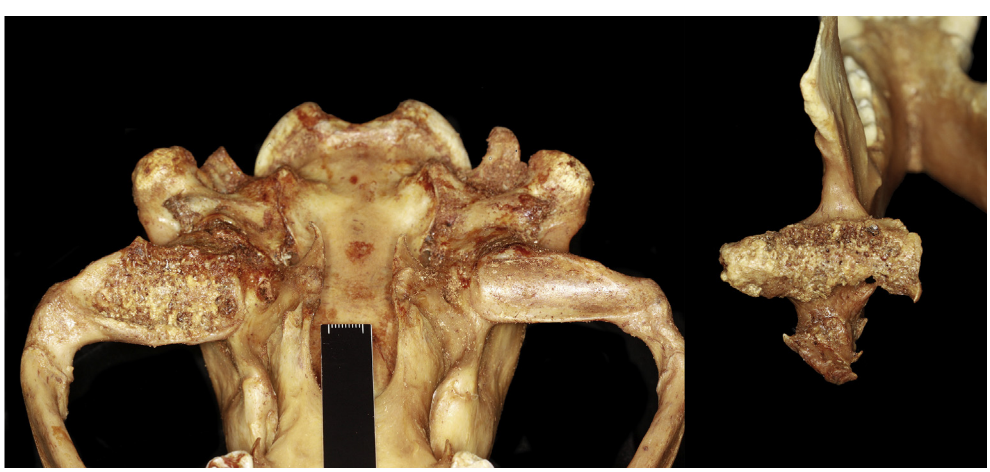

Fig. 8. Severe TMJ-OA of the left mandibular head and fossa in an adult female specimen, suggestive of septic arthritis. Note the pronounced periarticular new bone formation/osteophytes and marked subchondral bone destruction. Bar, 1 cm.

Fig. 9. Diastemata interproximally between the left and right mandibular fourth premolar and first molar teeth in a young adult female specimen (the right side more pronounced). Bar, 1 cm.

from captive brown bears and 1% of teeth were lost during life in a group of 14 skulls from free-ranging Alaskan grizzly bears (*U. arctos horribilis*) (Wenker *et al.*, 1999).

Periapical lesions were observed in only 8.4% of the specimen population, affecting 0.23% of teeth. Periapical lesions typically result from pulp exposure and subsequent pulp necrosis. As lesions are only overtly obvious on skull specimens when severe and dramatic, it is probable that this pathology was underdetected; dental radiographic examination would have likely revealed smaller, subtler lesions beyond those noted during macroscopic examination. Periapical lesions typically cause considerable discomfort and pain, leading to decreased function.

Other acquired lesions, such as attrition/abrasion, dental fractures and periodontitis, were more common in this sample of polar bears. Attrition/abrasion was encountered in essentially one-sixth of specimens, most often affecting the incisor teeth. This finding is corroborated by previous studies that also documented the incisor teeth to be the most common location for attrition/abrasion in brown bears (Strömquist *et al.*, 2009), Alaskan grizzly bears (Wenker *et al.*, 1999) and polar bears (Sonne *et al.*, 2007). Sonne *et al.* (2007) suggested that the feeding behaviour of polar bears might explain the incisor wear; these authors observed that polar bears utilize their incisor teeth when tearing blubber and muscle from seal carcasses. As long as abrasion remains mild and is slower than the rate of tertiary dentine formation, it should not contribute to morbidity or mortality.

There were few teeth with dental fractures, but one in five polar bears had at least one fractured tooth, the most common of which was the canine. Previous ursid studies have also noted the canine teeth to be most susceptible to fracture (Sonne *et al.*, 2007; Strömquist *et al.*, 2009). In a study examining the skulls of various carnivore species, the canine teeth were fractured with the highest frequency, the proposed reason being that due to their shape and function, the canine teeth have a greater bending stress than other teeth (Van Valkenburgh, 1988). In bears, specifically, it has been suggested that the canine teeth suffer fractures due to the shape and function of these teeth, diet, intraspecies exchanges and predator—prey interactions (Strömquist *et al.*, 2009). In this collection of specimens, there were more male polar bears with fractured canine teeth than females; however, this trend was not significant. A previous study of polar bear skulls found that the incidence of fractured canine teeth was not influenced by sex (Sonne *et al.*, 2007). Dental fractures are acutely painful. If the fracture is complicated (i.e. exposing the pulp), then the periapical tissues are at risk for abscess formation, which is a considerable source of pain and decreased function. Disruption to the integrity of the crown may also affect the function of that tooth.

Alveolar bony changes consistent with periodontitis were observed in the majority of specimens (79.9%), affecting the minority of their teeth (12.6%). Just over three-quarters of mandibular incisor alveoli had at least mild periodontal disease, while periodontal disease was relatively rare elsewhere. Diagnosis of periodontal lesions from dry skulls is fundamentally flawed because soft tissue lesions, crucial in pathogenesis, are unavailable for study. However, an increase in vascular foramina and alveolar bone loss are signs of periodontal disease. In the present sample, there was no significant difference in the prevalence of periodontitis between age groups and sexes. In a previous study of polar bear skulls, there was no difference in frequency of periodontitis between males and females, although incidence increased with age (Sonne *et al.*, 2007). Periodontitis is typically not a painful process and is unlikely to have impacted these bears substantially.

Lesions consistent with TMJ-OA were observed in 9.2% of the total number of polar bear specimens. The reason for TMJ pathology in the polar bear remains unknown, especially considering that polar bears feed almost exclusively on soft blubber and flesh, which requires little or no mastication prior to swallowing (Slater *et al.*, 2010). When present, TMJ-OA may cause pain and dysfunction, resulting in reduced food consumption and masticatory disability (Arzi *et al.*, 2013a). Further studies characterizing the TMJ of the Ursidae and documenting potential clinical consequences of TMJ degeneration in these species are needed.

Attrition/abrasion, dental fractures and TMJ-OA were more prevalent in adult specimens than in young adult specimens, as expected. This is not surprising, as with advancing age there is increased exposure to inciting causes of acquired dental pathology and likelihood of chronic lesions developing (Winer *et al.*, 2013). In part because of our robust sample size, differences in prevalence of these lesions by age group were significant. Additionally, attrition/abrasion and TMJ-OA were more prevalent in male specimens than those from females, with statistical significance. The aetiology and clinical significance of this sex difference is unknown.

A limitation of this study is that only hard tissues were available for macroscopic examination, which could lead to underdiagnosis of pathologies such as periodontal disease (i.e. subtle periapical lesions and gingivitis could not be detected) or overdiagnosis, as at times it can be difficult to differentiate true pathology from artefacts secondary to specimen preparation or variations of normal anatomy. It is important to note, given the substantial prevalence of teeth deemed absent congenitally (13.4% of teeth), that the differentiation between congenitally absent teeth versus acquired tooth loss can be challenging. For example, if a tooth was lost many years prior to death, the vacated alveolus may have had enough time to completely remodel to the point that it appears a tooth was never there at all. Therefore, the true prevalence of congenitally absent teeth may be lower, while the true prevalence of acquired tooth loss may be higher. The prevalence of periodontitis affecting the mandibular incisor teeth may be inflated in this study. It is unlikely (but not impossible) that our data accurately reflect the actual prevalence of incisor periodontitis, and it is more likely that we scored a variation of normal as a form of pathology. Studies conducted on live polar bears are needed to better understand and classify polar bear periodontitis.

In conclusion, a diversity of dental and TMJ lesions and abnormalities was discovered in the present study. Animals exhibiting pronounced periapical disease, dental fractures and advanced TMJ-OA likely suffered morbidity and possibly mortality secondary to these lesions. Understanding the dental pathology of polar bears may aid in the development of good husbandry practices for these animals when in captivity (Sinai *et al.*, 2014). In a previous study, it was noted that the second most frequent reason for surgical intervention under general anaesthesia in captive bears was the treatment of dental disease (Wenker *et al.*, 1999). Documenting the prevalence of the various dental lesions present in the polar bear contributes to a better understanding of their overall health and strengthens the foundation for advancing the understanding of dental diseases in this species.

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References

Aalderink MT, Nguyen HP, Kass PH, Arzi B, Verstraete FJM (2015a) Dental and temporomandibular joint pathology of the northern fur seal (*Callorhinus ursinus*). *Journal of Comparative Pathology*, **152**, 325–334.

Aalderink MT, Nguyen HP, Kass PH, Arzi B, Verstraete FJM (2015b) Dental and temporomandibular joint pathology of the Eastern Pacific harbour seal (*Phoca vitulina richardii*). *Journal of Comparative Pathology*, **152**, 335–344.

Aars J, Andersen M, Brenière, Blanc S (2015) White-beaked dolphins trapped in the ice and eaten by polar bears. *Polar Research*, **34**, 26612.

Abbott C, Verstraete FJM (2005) The dental pathology of northern elephant seals (*Mirounga angustirostris*). *Journal of Comparative Pathology*, **132**, 169–178.

Amstrup SC (2003) Polar bear, *Ursus maritimus*. In: *Wild Mammals of North America: Biology, Management, and Conservation*, GA Feldhamer, BC Thompson, JA Chapman, Eds., Johns Hopkins University Press, Baltimore, pp. 587–610.

Arzi B, Cissell DD, Verstraete FJ, Kass PH, Duraine GD *et al*. (2013a) Computed tomographic findings in dogs and cats with temporomandibular joint disorders: 58 cases (2006–2011). *Journal of the American Veterinary Medical Association*, **242**, 69–75.

Arzi B, Leale DM, Sinai NL, Kass PH, Lin A *et al*. (2015) The temporomandibular joint of California sea lions (*Zalophus californianus*): part 2 – osteoarthritic changes. *Archives of Oral Biology*, **60**, 216–222.

Arzi B, Winer JN, Kass PH, Verstraete FJM (2013b) Osteoarthritis of the temporomandibular joint in southern sea otters (*Enhydra lutris nereis*). *Journal of Comparative Pathology*, **149**, 486–494.

Atwood TC, Marcot BG, Douglas DC, Amstrup SC, Rode KD *et al*. (2015)*Evaluating and Ranking Threats to the Long-term Persistence of Polar Bears: US Geological Survey Open-file Report 2014: 1254*, p. 114. http://dx.doi.org/10.3133/ofr20141254, (accessed 26.04.16).

Cowan DF (2002) Pathology. In: *Encyclopedia of Marine Mammals*, WF Perrin, B Wursig, JGM Thewissen, Eds., Academic Press, San Diego, pp. 883–890.

Derocher AE, Wiig Ø, Andersen M (2002) Diet composition of polar bears in Svalbard and the western Barents Sea. *Marine Mammal Science*, **25**, 448–452.

Galicia MP, Thiemann GW, Dyck MG, Ferguson SH (2015) Characterization of polar bear (*Ursus maritimus*) diets in the Canadian High Arctic. *Polar Biology*, **38**, 1983–1992.

Gulland FM (1999) Stranded seals: important sentinels. *Journal of the American Veterinary Medical Association*, **214**, 1191–1192.

Harvey CE, Orr HS (1990) In: *BSAVA Manual of Small Animal Dentistry*, CE Harvey, HS Orr, Eds., British Small Animal Veterinary Association, Cheltenham, p. 37, 85.

Kiliaan HPL, Stirling I (1978) Observations on overwintering walruses in the eastern Canadian High Arctic. *Journal of Mammalogy*, **59**, 197–200.

Kurtén B (1964) The evolution of the polar bear, *Ursus maritimus* Phipps. *Acta Zoologica Fennica*, **108**, 3–30.

Lowry LF, Burns JJ, Nelson RR (1987) Polar bear, *Ursus maritimus*, predation on belugas, *Delphinapterus leucas*, in the Bering and Chukchi seas. *The Canadian Field Naturalist*, **101**, 141–146.

Miles AEW, Grigson C (1990). In: *Colyer's Variations and Diseases of the Teeth of Animals*, 2nd Edit., AEW Miles, C Grigson, Eds., Cambridge University Press, Cambridge, pp. 77–437-438.

Sacco T, Van Valkenburgh B (2004) Ecomorphological indicators of feeding behavior in the bears (Carnivora: Ursidae). *Journal of Zoology*, **263**, 41–54.

Sinai NL, Dadaian RH, Kass PH, Verstraete FJM (2014) Dental pathology of the California sea lion (*Zalophus californianus*). *Journal of Comparative Pathology*, **151**, 113–121.

Slater GJ, Figueirido B, Louis L, Yang P, Van Valkenburgh B (2010) Biomechanical consequences of rapid evolution in the polar bear lineage. *PLoS One*, **5**, e13870.

Smith TG, Sjare B (1990) Predation of belugas and narwhals by polar bears in nearshore areas of the Canadian High Arctic. *Arctic*, **43**, 99–102.

Sonne C, Rigét FF, Dietz R, Wiig Ø, Kirkegaard M *et al*. (2007) Skull pathology in East Greenland and Svalbard polar bears (*Ursus maritimus*) during 1892 to 2002 in relation to organochlorine pollution. *Science of the Total Environment*, **372**, 554–561.

Strömquist A, Fahlman A, Arnemo JM, Pettersson A (2009) Dental and periodontal health in free-ranging Swedish brown bears (*Ursus arctos*). *Journal of Comparative Pathology*, **141**, 170–176.

Van Valkenburgh B (1988) Incidence of tooth breakage among large, predatory mammals. *American Naturalist*, **131**, 291–302.

Verstraete FJM (2003) Dental pathology and microbiology. In: *Textbook of Small Animal, Surgery*, Vol. 2, DH Slatter, Ed., WB Saunders, Philadelphia, pp. 2638–2651.

Verstraete FJM, van Aarde RJ, Nieuwoudt BA, Mauer E, Kass PH (1996a) The dental pathology of feral cats on Marion Island, part I: congenital, developmental, and traumatic abnormalities. *Journal of Comparative Pathology*, **115**, 265–282.

Verstraete FJM, van Aarde RJ, Nieuwoudt BA, Mauer E, Kass PH (1996b) The dental pathology of feral cats on Marion Island, part II: periodontitis, external odontoclastic resorption lesions and mandibular thickening. *Journal of Comparative Pathology*, **115**, 283–297.

Wenker CJ, Stich H, Muller M, Lussi A (1999) A retrospective study of dental conditions of captive brown bears (*Ursus arctos* spp.) compared with free-ranging Alaskan grizzlies (*Ursus arctos horribilis*). *Journal of Zoo and Wildlife Medicine*, **30**, 208–221.

Winer JN, Liong SM, Verstraete FJM (2013) The dental pathology of southern sea otters (*Enhydra lutris nereis*). *Journal of Comparative Pathology*, **149**, 346–355.

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