Vol. 136: 265–271, 2019
https://doi.org/10.3354/dao03414

DISEASES OF AQUATIC ORGANISMS
Dis Aquat Org

Published online November 14

Renal and vaginal calculi in a free-ranging long-beaked common dolphin *Delphinus capensis*

Kerri Danil[1,*], Sophie Dennison[2], Elyse Wurster[3], Michael M. Garner[4], Jody Lulich[5], Judy St. Leger[6]

[1]Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, CA 92037, USA

[2]TelVet Imaging Solutions, Oakton, VA 22124, USA

[3]Lynker, LLC, Leesburg, VA 20175, USA

[4]Northwest ZooPath, Monroe, WA 98272, USA

[5]Minnesota Urolith Center, St. Paul, MN 55108, USA

[6]Cornell University, Ithaca, NY 14853, USA

ABSTRACT: Bilateral nephrolithiasis with a concurrent vaginal calculus was identified in a stranded free-ranging long-beaked common dolphin *Delphinus capensis*. Necropsy and radiologic examinations of the sexually mature *D. capensis* revealed multiple small irregularly round nephroliths and a 6.4 × 4.1 × 9.2 cm vaginal calculus weighing 182 g. Nephroliths numbered 68 and 71 in the left and right kidneys, respectively, and ranged from 1.7 to 6.9 mm in diameter. Nephroliths were composed of 100% ammonium urate, which has been found in captive dolphin populations. However, the vaginolith consisted of struvite and calcium carbonate suggesting an alternate etiology. The composition of the vaginolith suggests that bacterial vaginitis could have served as the predisposing condition. Renal lesions included chronic tubulointerstitial nephritis with tubular degeneration and loss, likely secondary to the nephroliths. The pathogenesis of ammonium urate nephrolithiasis in managed care is suspected to be linked to diet and age but in this case may be due to metabolic disruption. However, if environmental changes cause a shift in prey species, the risk of nephrolithiasis in free-ranging cetaceans could increase. Careful surveillance for nephroliths in free-ranging populations should be considered by researchers.

KEY WORDS: Nephrolith · Vaginolith · Calculi · Common dolphin · *Delphinus* · Cetacean · Marine mammal

1. INTRODUCTION

Calculi are abnormal concretions occurring in the body and consist of various biogenic minerals such as ammonium urate, struvite, cysteine, calcium oxalate, etc., in combination or alone. A calculus forms when supersaturation of urine allows these mineral solutes to precipitate and form crystals that aggregate and grow (Brown 2016). Calculi typically form within the urinary tract but can form within the vagina, either around a foreign body, or due to the deposition of urinary salts from urine stasis caused by fistulas or partial vaginal obstructions (Bissada & Hanash 1983, Plaire et al. 2000, Kolte et al. 2002).

Reports of renal calculi in free-ranging marine mammals are uncommon and include 8 individuals: 3 species of pinnipeds, a manatee, and 4 species of cetaceans (Ridgway et al. 1975, Stroud 1979, McFee & Osborne 2004, Dennison et al. 2007, Keller et al. 2008, Stimmelmayr et al. 2016, Díaz-Delgado et al. 2018, Mazzariol et al. 2018). However, ammonium urate nephrolithiasis can be highly prevalent in managed populations of bottlenose dolphins *Tursiops truncatus* (Venn-Watson et al. 2010), where age,

*Corresponding author: kerri.danil@noaa.gov

feeding regimes, and purine concentration in the diet appear to be contributing factors (Smith et al. 2013, Ardente et al. 2017). Nephroliths in pinnipeds have consisted of ammonium urate and uric acid; in the manatee, calcium carbonate was the primary component; nephroliths found in a sperm whale and a bowhead whale were composed of ammonium oxalate and calcium oxalate, respectively (Stroud 1979, Dennison et al. 2007, Keller et al. 2008, Stimmelmayr et al. 2016, Mazzariol et al. 2018). These differences likely reflect differing renal physiology in the various taxa. In marine mammals, nephroliths have been reported to cause azotemia, anemia, hematuria, renal atrophy, hydronephrosis, ureteral and urethral obstruction, reduced renal function, and renal failure (Dennison et al. 2007, Keller et al. 2008, Venn-Watson et al. 2008, 2010).

Vaginoliths have been reported in 6 species of cetaceans and observations are notably lacking in other marine mammal orders. Most have been composed of struvite (magnesium ammonium phosphate), with a few composed of calcium phosphate or fetal bones (Sawyer & Walker 1977, Benirschke et al. 1984, Woodhouse & Rennie 1991, Van Bressem et al. 2000, McFee & Osborne 2004, Norman et al. 2011). Struvite stones commonly form in response to urease-producing bacterial infections such as *Proteus* or *Staphylococcus* spp. Urea is the main nitrogenous breakdown product of protein metabolism and is excreted in urine, where it is abundant. Urease cleaves urea into ammonium and bicarbonate molecules. The ammonium ions become available to combine with magnesium and phosphate to form magnesium ammonium phosphate (struvite) crystals. Additionally, bicarbonate increases the urine pH, decreasing the solubility of the struvite crystals (Ettinger & Feldman 2009). This metabolic activity of the bacteria can change the pH from acidic to alkaline, initiating the formation of calculi (Gleeson & Griffith 1993, Brown 2016).

We present the first description of nephrolithiasis in a free-ranging long-beaked common dolphin *Delphinus capensis*, with a concurrent vaginolith and lumbar lesions.

2. MATERIALS AND METHODS

On 13 April 2017, an adult female long-beaked common dolphin *Delphinus capensis* stranded alive on Carlsbad State Beach, San Diego, CA (33.115° N, 117.323° W), and subsequently died. The carcass was taken immediately for computed tomography (CT) and magnetic resonance imaging (MRI) scans, and was refrigerated at 4°C until necropsy the following morning. The CT scan was completed using a Toshiba Aquilion 64 slice set at 120 kV with effective mAs set at 176. The dolphin was placed in sternal recumbency within the gantry and the cranial portion of the dolphin was scanned with 1 mm slices and the caudal portion was scanned with 2 mm slices, using both bone and soft tissue reconstruction algorithms. An MRI was acquired with a 3T Discovery GE750 scanner using both fast spin echo and gradient echo sequences, with the specimen placed in sternal recumbency within the gantry and acquired in 1 acquisition.

Gross examination consisted of examination and collection of tissues from the adrenals, bladder, bone marrow, brain, colon, esophagus, eye, heart, kidneys, liver, lung, lymph nodes, mammary gland, ovary, pancreas, rib, skeletal muscle, skin, spinal cord, spleen, uterus, vagina, and vulva. Tissues were fixed in 10% neutral-buffered formalin, embedded in paraffin, sectioned, stained with hematoxylin and eosin (H&E), and examined microscopically. Morbillivirus testing was performed using the universal morbillivirus primers directed against the phosphoprotein (P) gene (Barrett et al. 1993) followed by nested primers specific for morbillivirus. Brucella testing was performed via PCR as described by Colegrove et al. (2016). Domoic acid and saxitoxin were tested via ELISA as described by Lefebvre et al. (2016). Renal and vaginal calculi were submitted to the University of Minnesota Veterinary Diagnostic Laboratory for core culture and to the Minnesota Urolith Center for mineral composition using polarization microscopy and infrared spectroscopy. Age was determined by examining growth layers in the teeth following the methods outlined by Danil & Chivers (2007).

3. RESULTS

3.1. Radiology (CT and MRI)

Multifocal fascial plane edema, mild pleural effusion, vaginolith, bilateral nephroliths, and lytic and sclerotic lesions with concurrent fusion of spinous processes of L4 and L5 vertebrae were identified on CT scans (Fig. 1). The lytic region of the vertebral lesion measured approximately 3.4 × 1.8 × 1.1 cm and was surrounded by sclerosis. The maximal dimensions to the margins of the sclerosis were approximately 2.7 × 4 × 3 cm. This equates to the lysis

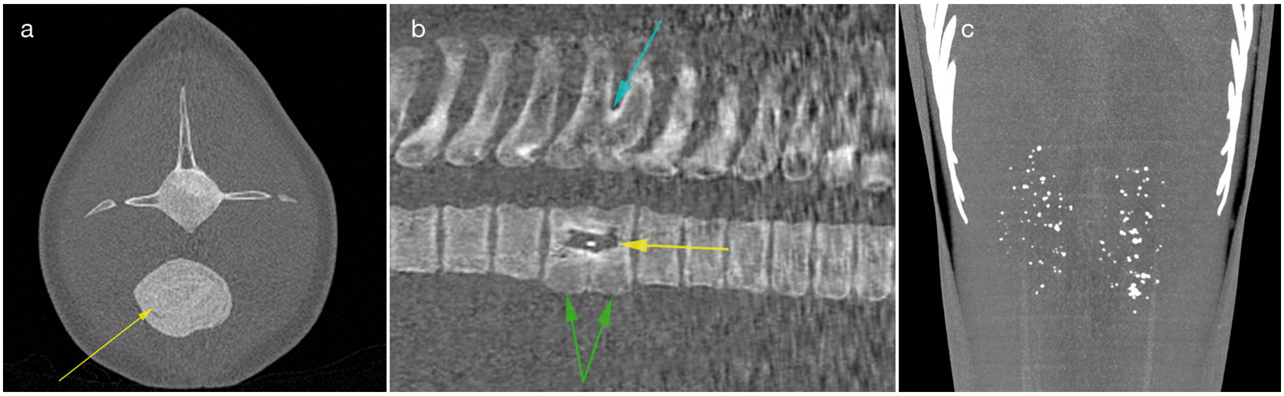

Fig. 1. *Delphinus capensis*. CT images of (a) vaginolith (→), (b) lumbar lesions (→ fusion of spinous processes; → deviated margins of vertebrae; → lucent area crossing L4 and L5), and (c) nephroliths

effacing approximately 25 to 30% of the vertebrae and the combination of lysis and sclerosis effaced approximately 75 to 80% of the vertebrae. The vaginolith measured 6.4 × 4.1 × 9.2 cm. In the left and right kidneys, 68 and 71 nephroliths, respectively, were identified using maximum intensity projection (MIP) slab reconstructions to help ensure that nephroliths were only counted once. Nephroliths ranged from 1.7 to 6.9 mm (mean = 3.2 mm). Mean size of nephroliths did not vary between kidneys (t = 34.9238, $p < 0.0001$). MRI identified fluid in the airways and lungs.

3.2. Gross examination

External examination of the 206.2 cm long, 78.5 kg dolphin revealed good nutritional condition (Body Condition Score 3; Joblon et al. 2014), green mucus in both eyes, froth in the blowhole, and 1.0 cm diameter bilaterally symmetrical vulvar ulcers (Fig. 2).

Internally, fascial edema and subscapular subcutaneous emphysema were observed. The forestomach was empty and contained multiple ulcers associated with nematodes. A 182.1 g hard vaginolith was present and 3 irregularly round nephroliths (2.0 to 4.0 mm) were dissected from 3 separate reniculi (Fig. 2). Grossly, the vaginal mucosa varied from regionally diffuse green to more extensive irregularly shaped deep pink to purple foci. The endometrium of both uterine horns was deep purple to black. In the right ovary, a 14.2 × 8.6 × 10.9 mm fluid-filled cyst was present. The left and right ovaries contained 9 and 3 corpora albicantia, respectively, indicating that this dolphin was sexually mature and likely had a prior series of pregnancies. The bladder was empty. The spinal lesions were not identified until after gross exam and thus were only studied via CT images. Examination of growth layers in the teeth indicated the dolphin was approximately 21 yr of age.

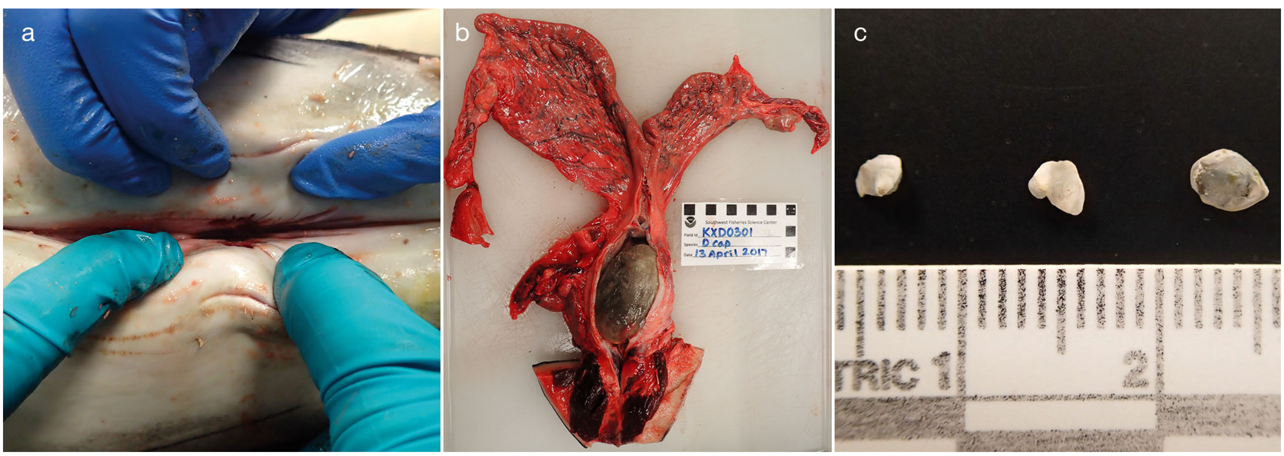

Fig. 2. *Delphinus capensis*. (a) Vulvar lesions, (b) vaginolith *in situ*, and (c) extracted nephroliths

3.3. Histologic findings

The vulvar lesions were foci of mucosal erosion and ulceration associated with bacterial colonization and an infiltrate of moderate numbers of neutrophils, lymphocytes, and plasma cells in the superficial submucosa and at the mucosal interface. Some mild edema was noted in the cytoplasm of epithelial cells beneath eroded areas. No inclusions were seen. Vaginal mucous membranes had mild to moderate, perivascular to lichenoid, lymphocytic inflammation with erosions and focal ulceration. Kidneys demonstrated moderate to severe multifocal and coalescing chronic tubulointerstitial nephritis with tubular loss, replacement fibrosis, tubular hyaline to granular casts, and tubular mineralization (Fig. 3). The pancreas had marked diffuse fibrosis of the interstitium, associated with disruption of acinar structures. Coalescing foci of suppurative inflammation and necrosis with microabscess formation were observed in a lymph node. Within this foci, Grocott methenamine stain (GMS) identified fungal elements morphologically consistent with mucormycetes.

No discrete uroliths were identified within the renicular pelvices, or within the tissues submitted for histologic exam. The character and distribution of the foci of renal mineralization in the radiographic images were highly correlated with the distribution of the mineralized tubules.

3.4. Microbiology, calculi analysis, and biotoxins

PCR tests on cerebellum and lung were negative for *Morbillivirus* sp. The cerebellum was also negative for *Brucella* sp. via PCR. Bacterial cultures yielded *Shingomonas paucimobilis* in eye exudate, *Edwardsiella tarda* in cerebrospinal fluid, and *Staphylococcus warneri* and *E. tarda* in both uterine horns. Bacterial cultures of vulvar lesions were not available. Renal and vaginal core calculi cultures yielded no organisms. Nephroliths were composed of 100% ammonium urate. The single, laminar vaginolith was primarily magnesium ammonium phosphate (struvite) (Fig. 4). Domoic acid and saxitoxin concentrations in feces were 4.8 ng g^{-1} and below detection limit, respectively.

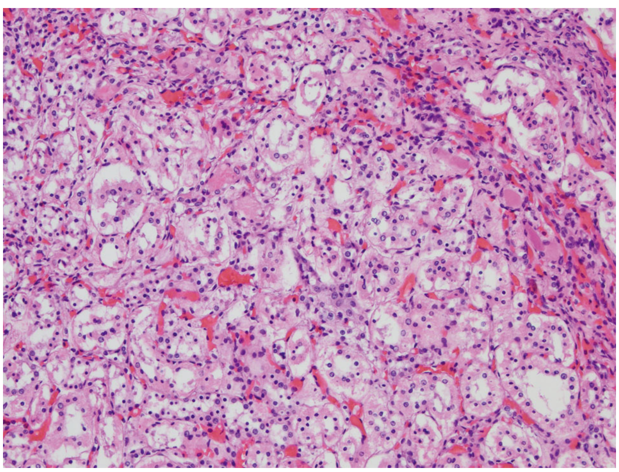

Fig. 3. *Delphinus capensis*. Severely affected reniculus with extensive tubular loss, fibrosis, and inflammation (200× magnification)

4. DISCUSSION

4.1. Lumbar lesion

Scoliosis concurrent with vaginal and/or renal calculi has been noted in 2 other marine mammal case studies (Stroud 1979, McFee & Osborne 2004); spinal cord injury is a risk factor for both metabolic and infection-based stone formation in humans via immobilization hypercalciuria or urinary tract infections from bladder dysfunction (Chen et al. 2000, Matlaga et al. 2006, Welk et al. 2012). However, there was no evidence of a healed or chronic fracture of the spinous processes at the site of fusion. Additionally, there was no asymmetry to the soft tissues that would suggest an alteration to the spinal cord or nerve roots. The lumbar observations in the CT images may be related to the mucormycosis identified in a lymph node. Mucormycosis is known to cause bone infections and can cause osteolytic lesions (Taj-Aldeen et al. 2017). However, no histology nor cultures were performed on this section of spinal column or the associated cord and nerve roots to confirm this. Al-

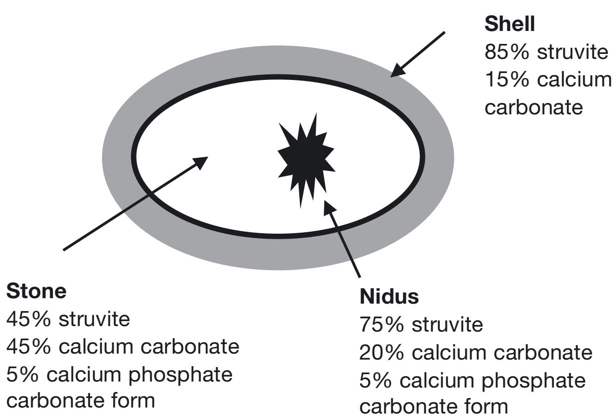

Fig. 4. *Delphinus capensis*. Schematic of vaginolith and qualitative mineral analysis of layers

though the mucormycosis may have played a role in the death of this dolphin, it is likely incidental to the observed renal and vaginal calculi.

4.2. Nephroliths

The total number of macroscopic nephroliths present in this case (n = 159) was much higher than the mean (n = 31.8) and maximum number (n = 64) of nephroliths found in a managed population of bottlenose dolphins *Tursiops truncatus* (Venn-Watson et al. 2010, Smith et al. 2013). This may be partially due to the superior ability of CT to provide accurate stone counts compared to the ultrasound that was used in those studies (Smith et al. 2013) or simply due to the nature of this case. Nonetheless, the number of nephroliths found in this study was high and likely caused urinary tract damage and consequently reduced renal function. Histologic examination revealed medullary and cortical tubular degeneration and loss attributed to the nephrolithiasis. As with animals in managed care, the stones were composed of 100% ammonium urate.

Risk factors for uric acid calculi include low urinary volume, persistent low urinary pH, and hyperuricosuria, which can be facilitated by a high protein diet rich in purines. Additionally, gene mutations in urate transporters have been identified in humans with renal hypouricaemia and nephrolithiasis (Rodgers 2010). One or some of these factors could have been present in the specimen of this case study, leading to ammonium urate nephrolithiasis.

While the nutritional condition of the animal was normal, the marked pancreatic fibrosis may have been associated with digestive abnormalities. The exocrine pancreas secretes numerous (at least 22) digestive enzymes that become activated in the duodenal lumen (Slack 1995). Altered secretion of digestive enzymes may have created a disruption to the metabolism of the diet consumed by this dolphin, and consequently changed the systemic physiochemistry to one favorable for the formation of ammonium urate renal stones.

The prevalence of ammonium urate nephrolithiasis in managed vs. free-ranging populations of *T. truncatus* has been attributed to age and a diet higher in purines (Smith et al. 2013, Ardente et al. 2017). North Pacific common dolphins can live to approximately 30 yr (Ferrero & Walker 1995, Chivers et al. 2016) and the specimen in this study at 21 yr would be of advanced age for this species. In regards to diet, 3 species of prey tested for purines (Ardente et al. 2017) are documented prey items of long-beaked common dolphins *Delphinus capensis*: Pacific mackerel *Scomber japonicas*, Pacific sardine *Sardinops sagax*, and squid *Loligo* spp. (Osnes-Erie 1999). *S. japonicas* and *S. sagax* are high in purines but do not occur frequently in the diet of *D. capensis*, whereas *Loligo* spp. are low in purines and frequently consumed. This, in combination with the lack of nephrolithiasis reported in *D. capensis*, suggests that the risk of nephrolithiasis due to diet is low for this species in general. However, if prey species shift in response to oceanographic changes (e.g. climate change, ocean acidification), this risk could increase, particularly if more fish with a metallic sheen are consumed. These fish types have higher purine content due to the guanine crystals that reflect light to camouflage the fish (Levy-Lior et al. 2008, Kaneko et al. 2014). Additionally, Kaplan et al. (2013) showed squid reared under elevated carbon dioxide concentrations, and therefore a more acidic environment, showed significant developmental and physiological changes that could directly impact squid survival and behavior, and thereby lead to a decrease in consumption by cetaceans as ocean acidification reaches future projected levels.

Despite the large number of nephroliths enumerated via the CT images that were analyzed after necropsy, none of the nephroliths were observed during routine sectioning of the kidneys during the necropsy. Although uric acid stones are typically radiolucent in plain radiographs, they appeared faintly opaque in images of sub-sampled kidney and these images were used to locate and extract nephroliths for analysis. Considering the difficulty in locating nephroliths macroscopically, it is likely that nephroliths may be overlooked during routine gross exams and that their presence may be underestimated in free-ranging marine mammal populations. This highlights the importance of advanced imaging, such as CT scans, in necropsy investigations.

4.3. Vaginolith

Vaginoliths can either be primary or secondary, forming as a result of urine pooling in the vagina or crystallization of inorganic salts around a foreign object, respectively. The differential for primary vaginoliths includes urogenital tract abnormality, neurogenic bladder, or partial vaginal outlet obstruction (Plaire et al. 2000, Castellan et al. 2017, Kassem 2017). Gross and CT examination of the vaginolith combined with the mineral composition analysis indicated this was a primary struvite vaginal calculus. Although previously reported vaginoliths in common dolphins have been linked with fetal remains, this case is more similar to struvite vaginoliths reported in other species (Sawyer & Walker 1977, Benirschke et al. 1984, Woodhouse & Rennie 1991, McFee & Osborne 2004, Norman et al. 2011). *Staphylococcus warneri* was isolated from the uterus and urease-producing *Staphylococcus* spp. have been associated with formation of struvite calculi (Osborne et al. 1981).

The culture of *Staphylococcus* spp. suggests that bacterial vaginitis could have served as the predisposing condition for vaginolith formation. In addition, the ulcerative vulvitis could have been a source for the urease-producing *Staphylococcus* spp. Alternatively, the vaginolith could have formed in response to urease-producing bacteria that may have been present in urine that leaked or pooled in the vagina.

4.4. Summary

Albeit rare, nephroliths do occur in free-ranging cetaceans and those observed in this study were similar in composition to those that occur in captive populations due to age and purine-rich diets. Although age is likely a factor, the risk of nephrolithiasis in *D. capensis* due to diet appears to be low when documented prey are considered. In this case, a metabolic disruption, perhaps due to altered digestive enzyme secretion, may have led to the formation of these renal stones. A concurrent primary struvite vaginolith was also described that likely formed due to urease-producing *Staphylococcus* spp.

Acknowledgements. Thank you to Keiko Sherman, Holly Baijnuth, and Alexa Kownacki for assistance with the necropsy examination; and Katie Colegrove, David Gasper, Tracey Goldstein, Kathi Lefebvre, Victoria Palmer, Sarena Sunico, and Lisa Ulrich for diagnostic services. Hill's Pet Nutrition provided financial support for calculi composition analyses.

LITERATURE CITED

Ardente AJ, Garrett TJ, Colee J, Vagt BJ and others (2017) Differences in purine metabolite concentrations in the diet of managed and free-ranging common bottlenose dolphins (*Tursiops truncatus*). Aquat Mamm 43:618–628

Barrett T, Visser I, Mamaev L, Goatley L, Van Bressem MF, Osterhaus A (1993) Dolphin and porpoise morbilliviruses are genetically distinct from phocine distemper virus. Virology 193:1010–1012

Benirschke K, Henderson JR, Sweeney JC (1984) A vaginal mass, containing fetal bones, in a common dolphin, *Delphinus delphis*. Rep Int Whaling Comm Spec Issue 6: 457–458

Bissada NK, Hanash KA (1983) Primary vaginal stones. Urology 21:512–513

Brown SA (2016) Urolithiasis in small animals. In: Aiello SE, Moses MA (eds) The Merck veterinary manual, 11th edn https://www.merckvetmanual.com (accessed 10 May 2019)

Castellan P, Nicolai M, De Francesco P, Di Tizio L and others (2017) Primary vaginal calculus in a woman with disability: case report and literature review. J Endourol Case Rep 3:182–185

Chen Y, DeVivo M, Roseman J (2000) Current trend and risk factors for kidney stones in persons with spinal cord injury: a longitudinal study. Spinal Cord 38:346–353

Chivers SJ, Perryman WL, Lynn MS, Gerrodette T and others (2016) Comparison of reproductive parameters for populations of eastern North Pacific common dolphins: *Delphinus capensis* and *D. delphis*. Mar Mamm Sci 32: 57–85

Colegrove KM, Venn-Watson S, Litz J, Kinsel MJ and others (2016) Fetal distress and *in utero* pneumonia in perinatal dolphins during the Northern Gulf of Mexico unusual mortality event. Dis Aquat Org 119:1–16

Danil K, Chivers SJ (2007) Growth and reproduction of female short-beaked common dolphins, *Delphinus delphis*, in the eastern tropical Pacific. Can J Zool 85: 108–121

Dennison S, Gulland F, Haulena M, De Morais H, Colegrove K (2007) Urate nephrolithiasis in a northern elephant seal (*Mirounga angustirostris*), and a California sea lion (*Zalophus californianus*). J Zoo Wildl Med 38:114–120

Díaz-Delgado J, Fernández A, Sierra E, Sacchini S and others (2018) Pathologic findings and causes of death of stranded cetaceans in the Canary Islands (2006–2012). PLOS ONE 13:e0204444

Ettinger SJ, Feldman EC (2009) Textbook of veterinary internal medicine. Elsevier Health Sciences, St. Louis, MO

Ferrero RC, Walker WA (1995) Growth and reproduction of the common dolphin, *Delphinus delphis*, in the offshore waters of the North Pacific Ocean. Fish Bull 93:483–494

Gleeson MJ, Griffith DP (1993) Struvite calculi. Br J Urol 71: 503–511

Joblon MJ, Pokras MA, Morse B, Harry CT and others (2014) Body condition scoring system for delphinids based on short-beaked common dolphins (*Delphinus delphis*). J Mar Anim Ecol 7:5–13

Kaneko K, Aoyagi Y, Fukuuchi T, Inazawa K, Yamaoka N (2014) Total purine and purine base content of common foodstuffs for facilitating nutritional therapy for gout and hyperuricemia. Biol Pharm Bull 37:709–721

Kaplan MB, Mooney TA, McCorkle DC, Cohen AL (2013) Adverse effects of ocean acidification on early development of squid (*Doryteuthis pealeii*). PLOS ONE 8:e63714

Kassem TW (2017) Large primary vaginal stone secondary to vesico-vaginal fistula in a 63-year-old woman. Egypt J Radiol Nucl Med 48:303–305

Keller M, Moliner JL, Vásquez G, Cruz D and others (2008) Nephrolithiasis and pyelonephritis in two West Indian manatees (*Trichechus manatus* spp.). J Wildl Dis 44: 707–711

Kolte S, Choube S, Phulare S, Joharapurkar S (2002) Primary vaginoliths. Indian J Radiol Imaging 12:511–512

Lefebvre KA, Quakenbush L, Frame E, Huntington KB and others (2016) Prevalence of algal toxins in Alaskan marine mammals foraging in a changing arctic and subarctic environment. Harmful Algae 55:13–24

Levy-Lior A, Pokroy B, Levavi-Sivan B, Leiserowitz L, Weiner S, Addadi L (2008) Biogenic guanine crystals from the skin of fish may be designed to enhance light reflectance. Cryst Growth Des 8:507–511

Matlaga BR, Kim SC, Watkins SL, Kuo RL, Munch LC, Lingeman JE (2006) Changing composition of renal calculi in patients with neurogenic bladder. J Urol 175: 1716–1719

Mazzariol S, Centelleghe C, Cozzi B, Povinelli M and others (2018) Multidisciplinary studies on a sick-leader syndrome-associated mass stranding of sperm whales (*Physeter macrocephalus*) along the Adriatic coast of Italy. Sci Rep 8:11577

McFee WE, Osborne CA (2004) Struvite calculus in the vagina of a bottlenose dolphin (*Tursiops truncatus*). J Wildl Dis 40:125–128

Norman SA, Garner MM, Berta S, Dubpernell S, Klope M (2011) Vaginal calculi in a juvenile harbor porpoise (*Phocoena phocoena*). J Zoo Wildl Med 42:335–337

Osborne CA, Klausner JS, Krawiec DR, Griffith DP (1981) Canine struvite urolithiasis: problems and their dissolution. J Am Vet Med Assoc 179:239–244

Osnes-Erie L (1999) Food habits of common dolphin (*Delphinus delphis* and *D. capensis*) off California. MSc thesis, San Jose State University, CA

Plaire JC, Snodgrass WT, Grady RW, Mitchell ME (2000) Vaginal calculi secondary to partial vaginal outlet obstruction in pediatric patients. J Urol 164:132–133

Ridgway S, Geraci J, Medway W (1975) Diseases of pinnipeds. Rapp P-V Reun Cons Int Explor Mer 169:327–337

Rodgers A (2010) Pathogenesis of stones: summary of current concepts. In: Rao NP, Preminger GM, Kavanagh JP (eds) Urinary tract stone disease. Springer, London, p 151–156

Sawyer JE, Walker WA (1977) Vaginal calculi in the dolphin. J Wildl Dis 13:346–348

Slack JM (1995) Developmental biology of the pancreas. Development 121:1569–1580

Smith CR, Venn-Watson S, Wells RS, Johnson SP and others (2013) Comparison of nephrolithiasis prevalence in two bottlenose dolphin (*Tursiops truncatus*) populations. Front Endocrinol 4:145

Stimmelmayr R, Rexford C, Brower H (2016) Calcium oxalate urolithiasis in a bowhead whale: A case report. In: Lee J, Yasumiishi E (eds) Alaska Marine Science Symposium, January 25–29, 2016, Anchorage, AK, p 174

Stroud RK (1979) Nephrolithiasis in a harbor seal. J Am Vet Med Assoc 175:924–925

Taj-Aldeen SJ, Gamaletsou MN, Rammaert B, Sipsas NV and others (2017) Bone and joint infections caused by mucormycetes: A challenging osteoarticular mycosis of the twenty-first century. Med Mycol 55:691–704

Van Bressem MF, Van Waerebeek K, Siebert U, Wünschmann A, Chávez-Lisambart L, Reyes J (2000) Genital diseases in the Peruvian dusky dolphin (*Lagenorhynchus obscurus*). J Comp Pathol 122:266–277

Venn-Watson S, Smith CR, Dold C, Ridgway SH (2008) Use of a serum based glomerular filtration rate prediction equation to assess renal function by age, sex, fasting, and health status in bottlenose dolphins (*Tursiops truncatus*). Mar Mamm Sci 24:71–80

Venn-Watson S, Smith CR, Johnson S, Daniels R, Townsend F (2010) Clinical relevance of urate nephrolithiasis in bottlenose dolphins *Tursiops truncatus.* Dis Aquat Org 89:167–177

Welk B, Fuller A, Razvi H, Denstedt J (2012) Renal stone disease in spinal-cord–injured patients. J Endourol 26: 954–959

Woodhouse CD, Rennie CJ III (1991) Observations of vaginal calculi in dolphins. J Wildl Dis 27:421–427

Editorial responsibility: Stephen Raverty, Abbotsford, British Columbia, Canada

Submitted: July 12, 2019; Accepted: August 23, 2019
Proofs received from author(s): November 7, 2019