Factors associated with keratopathy in captive pinnipeds

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OBJECTIVE

To identify factors associated with keratopathy in captive pinnipeds and to provide guidance for preventive measures.

ANIMALS

319 captive pinnipeds (229 otariids [sea lions and fur seals], 74 phocids [true seals], and 16 odobenids [walrus]) from 25 facilities.

PROCEDURES

Descriptive data collected from questionnaires completed by facilities and from medical records and physical examinations of pinnipeds were compiled and evaluated. Variables were assessed with χ^2 tests of homogeneity to determine potential association with keratopathy, and variables with values of $P \leq 0.25$ were inserted into the multivariable logistic regression model.

RESULTS

Results indicated that variables associated with significantly increased odds of keratopathy in captive pinnipeds included lighter or reflective pool color (OR, 2.11; 95% confidence interval [CI], 1.20 to 3.97), pool water salinity < 29 g/L (OR, 3.48; 95% CI, 1.89 to 6.56), and history of eye disease (OR, 3.30; 95% CI, 1.85 to 5.98), trauma (OR, 3.80; 95% CI, 1.72 to 8.89), and having been tested for leptospirosis (OR, 3.83; 95% CI, 1.54 to 10.26). However, odds of keratopathy decreased with UV index ≤ 6 (OR, 0.39; 95% CI, 0.2 to 0.72) and age < 20 years (OR, 0.32; 95% CI, 0.15 to 0.66).

CONCLUSIONS AND CLINICAL RELEVANCE

Findings indicated that odds of keratopathy in pinnipeds could be reduced by maintenance of pool water salinity ≥ 29 g/L and reduction of UV radiation exposure (eg, with adequate shade structures and use of darker, natural colors). Because UV radiation exposure is cumulative, even small attempts to reduce lifetime exposure to it could help control keratopathy in pinnipeds. (*J Am Vet Med Assoc* 2019;255:224–230)

An animal's cornea and skin are exposed to sunlight, which includes UV, visible spectrum, and infrared wavelengths.[1] Pinnipeds have dense fur coats, and their skin, unlike their eyes, does not seem to be affected by chronic exposure to UV radiation. In addition, corneal nerves cannot detect UV radiation, which therefore can injure corneas with suprathreshold and repeated subthreshold UV radiation exposure without any type of warning such as pain.[1] This explains the irreversible keratopathy seen following acute and chronic UV radiation exposure. The cornea, a major filter of UV wavelengths between 200 and 300 nm, absorbs 60% of incident UV-A, 92% of incident UV-B, and 100% of incident UV-C radiation.[2] Although this absorption protects the lens and retina from clinically substantial damage, the cornea becomes jeopardized when excessive UV radiation exposure occurs because such radiation generates a variety of reactive oxygen species that cause cellular and extracellular damage by reacting with DNA, lipids, and proteins.[3] This excess of reactive oxygen species depletes corneal antioxidant enzymes in the anterior aspect of the cornea and leads to apoptotic changes in corneal epithelial cells.[4] These apoptotic changes can result in substantial shedding of corneal epithelial cells, which, combined with the effects of UV radiation on the anterior aspect of the cornea, could explain acute changes (eg, development of corneal ulcer) following lengthening daylight and UV radiation exposure.

ABBREVIATIONS

ORP Oxidative reduction potential

Corneal diseases affect pinnipeds of all species in the wild[5–7] and in managed care,[8] and we believe animals are affected regardless of their geographic location. Initially thought to affect only sea lions,[8] a characteristic corneal disease is, as we have experi-

enced, now recognized across species of pinnipeds. For this reason, the term pinniped keratopathy may be a more proper name for corneal diseases affecting these animals. Clinical signs of pinniped keratopathy vary among species but have 3 progressive stages, with stage 1 being subtle changes, stage 2 usually involving an indolent ulcer that can easily become opportunistically infected, and stage 3 involving an infected corneal ulcer that may also be abscessed.[8,9,a] Sea lions tend to initially have perilimbal corneal edema, a focal gray ulcerated or nonulcerated corneal opacity just dorsotemporal to the flattened plateau, and sometimes hyperemia at the temporal limbus. Fur seals generally have temporal perilimbal edema that is more obvious than in sea lions, but do not have a focal corneal opacity in stage 1. Walrus have an axial corneal opacity that is not usually ulcerated. Although seals have variable clinical signs, corneal edema is a consistent finding in stage 1. In our experience, pinnipeds that have had chronic unrelenting or recurrent keratopathy often develop obvious and progressive cataracts earlier in life than do those without a history of substantial keratopathy, and keratopathy in pinnipeds is commonly uncontrollable when combined with an anteriorly luxated lens that is not promptly surgically removed.

Numerous environmental (eg, light intensity, water salinity and quality, and spatial characteristics) and nutritional factors have been implicated as being associated with corneal diseases in pinnipeds.[10,11] Important spatial characteristics include the number of animals per cubic meter of pool volume, which could potentially affect water quality; enclosure surface color and texture, which affect color and intensity of reflected short wavelength and high-energy UV and blue light; and directional orientation of sunlight on wet and dry spaces, which influences exposure to direct and reflected sunlight. Because UV radiation exposure and other parameters appear to affect clinical onset and severity of pinniped keratopathy, we hypothesized that we could identify factors amenable to adjustment for mitigation of pinniped keratopathy. The objectives of the study presented here were to identify factors associated with keratopathy in captive pinnipeds and to provide guidance for preventive measures.

Materials and Methods

Questionnaire

To help identify factors that could contribute to keratopathy in captive pinnipeds, a questionnaire (**Supplementary Appendix S1**, available at avmajournals.avma.org/doi/suppl/10.2460/javma.255.2.224) was sent in January 2010 to facilities worldwide with captive pinnipeds. To be included in the study, responses to the questionnaire needed to be received before the end of June 2011 (18 months). The questionnaire was modeled after a previously used questionnaire,[12] but requested more details regarding water quality (eg, filtration, sterilization, coliform counts, salinity, and pH) and environmental factors (eg, present housing location, air temperature, water temperature, UV index, day length, amount of accessible shade, and geographical latitude). One questionnaire and a water quality diary for the entire year of 2010 were completed by each participating facility.

Medical records

Medical information on pinnipeds housed at each facility was gathered from respective medical record libraries. Information collected included signalment (ie, species, age, sex, reproductive status [neutered or sexually intact]), body weight at the time of questionnaire, and history (ie, birth location, number of previous facilities in which the animal had been housed, temperament, disease [especially dental, systemic, or ocular diseases], whether tested for leptospirosis, use of vitamins and antioxidant supplements [specifically grapeseed extract and lutein], and oral corticosteroid administration).

Examinations

During the period of the questionnaire data collection, including 6 months before and after receipt of a completed questionnaire from all participating facilities, each pinniped at each facility underwent anterior segment ophthalmic examination and photography of each eye. All ophthalmic examinations and photography were performed by 1 veterinary ophthalmologist (CMHC).

Statistical analysis

Descriptive statistics were compiled. Continuous variables were converted into categorical variables to facilitate analysis. The dependent or outcome variable was corneal opacity or disease in any eye (0 = no; 1 = yes). Independent variables were assessed with χ^2 tests of homogeneity to determine potential association with the outcome (corneal opacity or disease), and variables with values of $P \leq 0.25$ (critical α) were inserted into the multivariable logistic regression model. A backward-stepwise procedure[13] was then used to determine the final model, and variables with values of $P \leq 0.05$ (critical α) were considered significant. From the final model, ORs and 95% confidence intervals were estimated. Analyses were performed with commercially available software.[b]

Results

The questionnaire was sent to 32 facilities worldwide, and 25 (78%) completed questionnaires were received from 11 countries spanning both hemispheres. Descriptive data collected from completed questionnaires and data obtained from medical records and physical examination of pinnipeds were compiled and assessed.

Animals

Housed in the 25 respondent facilities between January 1, 2010, and January 1, 2011, were 319 pinnipeds: 229 (71.8%) otariids, 74 (23.2%) phocids, and 16 (5.0%) odobenids **(Supplementary Table S1**, available at avmajournals.avma.org/doi/suppl/10.2460/javma.255.2.224). Fifteen of the animals (7 otariids and 8 phocids) had also been included in a previous study[9] of factors that influence cataracts in pinnipeds. Of the 319 pinnipeds, 179 (56.1%) were sexually intact females and 140 (43.9%) were males (112 sexually intact males and 28 neutered males). Mean ± SD age was 15.73 ± 8.75 years (range, 1 to 40 years). Keratopathy was not identified in 138 (43.3%) of the pinnipeds, but was identified in 181 (56.7%), with both eyes affected in 164 (51.4%), only the left eye affected in 11 (3.4%), and only the right eye affected in 6 (1.9%). Concurrent lens disease defined as having cataracts with or without lens instability or luxation was identified in 179 (56.1%) of the pinnipeds with (110/179 [61.5%]) and without (69/179 [38.5%]) keratopathy; however, no cataracts were identified in 140 of 319 (43.9%) pinnipeds with (65/140 [46.4%]) and without (75/140 [53.6%]) keratopathy. Lens disease was identified in right eyes of 175 (54.9%) pinnipeds with (113/175 [64.6%]) and without (62/175 [35.4%]) keratopathy and in left eyes of 173 (54.2%) pinnipeds with (115/173 [66.5%]) and without (58/173 [33.5%]) keratopathy.

When grouped by age, 237 of 319 (74.3%) pinnipeds with (114/237 [48.1%]) and without (123/237 [51.9%]) keratopathy were ≤ 20 years old (range, 1 to 20 years), whereas 82 (25.7%) pinnipeds with (49/82 [59.8%]) and without (33/82 [40.2%]) keratopathy were > 20 years old (range, 21 to 40 years; **Table 1**). Pinnipeds ≤ 20 years old were significantly (OR, 0.32; $P = 0.002$) less likely to have had keratopathy than were those > 20 years old **(Table 2)**.

Associations were identified between medical history factors and the presence of keratopathy in pinnipeds during the study period. For instance, 125 of 319 (39.2%) pinnipeds with (64/125 [51.2%]) and without (61/125 [48.8%]) keratopathy did not have a history of any eye disease, whereas 194 (60.8%) pinnipeds with (130/194 [67.0%]) and without (64/194 [33.0%]) keratopathy had a history of eye disease (Table 1). Pinnipeds with a history of eye disease were significantly (OR, 3.30; $P < 0.001$) more likely to have had keratopathy than were those without a history of eye disease (Table 2). In addition, 271 (85.0%) pinnipeds with (137/271 [50.6%]) and without (134/271 [49.4%]) keratopathy had no history of trauma, whereas 48 (15.0%) pinnipeds with (36/48 [75.0%]) and without (12/48 [25.0%]) keratopathy had a history of trauma. Pinnipeds with a history of trauma were significantly (OR, 3.80; $P < 0.001$) more likely to have had corneal disease than were pinnipeds with no history of trauma. Further, 273 (85.6%) pinnipeds with (148/273 [54.2%]) and without (125/273 [45.8%]) keratopathy had not been tested previously for leptospirosis, whereas 46 (14.4%) pinnipeds with (35/46 [76.1%]) and without (11/46 [23.9%]) keratopathy had been tested previously for leptospirosis, and all results were negative. Pinnipeds with a history of having been tested for leptospirosis were significantly (OR, 3.83; $P = 0.003$) more likely to have had keratopathy than were pinnipeds with no history of having been tested for leptospirosis. No meaningful associations with keratopathy in pinnipeds were detected for other animal-based variables, such as temperament; histories of receiving vitamins, antioxidant supplements, or corticosteroids; or having had

Table 1—Results of logistic regression analysis to identify variables associated with keratopathy in 319 captive pinnipeds (229 otariids [sea lions and fur seals], 74 phocids [true seals], and 16 odobenids [walrus]) housed at 25 facilities from 11 countries between January 1, 2010, and January 1, 2011.

Variable	No. (%) of pinnipeds	No. (%) of pinnipeds with variable and keratopathy	*P* value*
Ultraviolet index			0.003
≤ 6	198 (62.1)	96 (48.5)	
> 6	121 (37.9)	71 (58.7)	
Pool color			0.01
Light or reflective	165 (51.7)	99 (60.0)	
Dark or natural	154 (48.3)	75 (48.7)	
Water salinity (g/L)			< 0.001
< 29	114 (35.7)	73 (64.0)	
≥ 29	205 (64.3)	108 (52.7)	
Age			0.002
≤ 20 y	237 (74.3)	114 (48.1)	
> 20 y	82 (25.7)	49 (59.8)	
History of ocular disease			< 0.001
No	125 (39.2)	64 (51.2)	
Yes	194 (60.8)	130 (67.0)	
History of trauma or injury			0.001
No	271 (85.0)	137 (50.6)	
Yes	48 (15.0)	36 (75.0)	
Tested for leptospirosis			0.003
No	273 (85.6)	148 (54.2)	
Yes	46 (14.4)	35 (76.1)	

*Variables with values of $P \leq 0.25$ were inserted into the multivariable logistic regression model.

A compilation of additional descriptive data collected, but with values of $P > 0.25$, is available online (Supplementary Table S1, available at avmajournals.avma.org/doi/suppl/10.2460/javma.255.2.224).

Table 2—Results of final logistic regression analysis to identify variables associated with keratopathy in the pinnipeds described in Table 1.

Variables	OR (95% confidence interval)	*P* value
UV index ≤ 6	0.39 (0.20–0.72)	0.003
Pool salinity < 29 g/L	3.48 (1.89–6.56)	< 0.001
Age ≤ 20 y	0.32 (0.15–0.66)	0.002
Pool paint color light or reflective	2.11 (1.20–3.97)	0.010
Previous eye disease	3.30 (1.85–5.98)	< 0.001
Previous trauma	3.80 (1.72–8.89)	0.001
Previous test for leptospirosis	3.83 (1.54–10.26)	0.003

previous systemic or dental disease. Interestingly, 39 of the 66 (59%) pinnipeds noted as receiving grapeseed extract and lutein also had keratopathy, whereas 27 (49%) did not have keratopathy (Supplementary Table S1).

Water

Of the 319 pinnipeds, 222 (69.6%) with (118/222 [53.2%]) and without (104/222 [46.8%]) keratopathy lived in natural saltwater habitats, 81 (25.4%) with (49/81 [60.5%]) and without (32/81 [40.0%]) keratopathy lived in synthetic saltwater habitats, and 16 (5.0%) with (12) and without (4) keratopathy lived in freshwater habitats (Supplementary Table S1). Of the 319 pinnipeds, 114 (35.7%) with (73/114 [64.0%]) and without (41/114 [36.0%]) keratopathy lived in pools with water salinity < 29 g/L, compared with 205 (64.3%) pinnipeds with (108/205 [52.7%]) and without (97/205 [47.3%]) keratopathy that lived in pools with water salinity ≥ 29 g/L (Table 1). Pinnipeds in pools with water salinity < 29 g/L were significantly (OR, 3.48; $P < 0.001$) more likely to have had corneal disease than were those in pools with water salinity ≥ 29 g/L (Table 2).

Water pH was reported for pools in which 269 pinnipeds lived (Supplementary Table S1). No meaningful association between water pH and keratopathy was identified; however, the prevalence of keratopathy was higher in pinnipeds that lived in pools with water pH > 7.6 (42/61[68.9%]), compared with that in pinnipeds that lived in pools with water pH ≤ 7.6 (110/208 [52.9%]).

Oxidation reduction potential of pools was divided into 4 categories: 0 to 225 mV, 226 to 450 mV, 451 to 600 mV, and > 600 mV (Supplementary Table S1). No meaningful association was identified between ORP category and corneal disease in pinnipeds; however, the prevalence of keratopathy was lower in pinnipeds that lived in pools with ORP between 451 and 600 mV (7/24 [29.2%]), compared with pinnipeds in pools with ORP between 0 and 255 mV (96/180 [53.3%]), ORP between 226 and 450 mV (47/81 [58.0%]), or ORP > 600 mV (22/34 [64.7%]).

Sunlight

No meaningful associations with keratopathy were detected for factors such as day length, geographic latitude, or accessible shade (Supplementary Table S1). However, odds of having had keratopathy were significantly (OR, 0.39; $P = 0.003$) lower for pinnipeds in areas with a UV index ≤ 6 (96/198 [48.5%]), compared with those in areas with a UV index > 6 (71/121 [58.7%]; Tables 1 and 2). Similarly, the odds of having had keratopathy were significantly (OR, 2.11; $P = 0.010$) lower for pinnipeds living in darker or natural-colored pools (75/154 [48.7%]), compared with those living in pools with lighter or reflective colors (99/165 [60.0%]). Pinnipeds living in exhibits with lighter or reflective colors on surrounding exhibit walls or floors were not meaningfully more likely to have had keratopathy than were pinnipeds living in exhibits with dark or natural colors on surrounding exhibit walls and floors.

Discussion

Results of the present study indicated that many risk factors could predispose captive pinnipeds to keratopathy. In fact, many risk factors (eg, greater UV radiation exposure, being older, having had previous eye disease, and having had previous trauma) were similar to those that are associated with lens diseases in pinnipeds.[12]

The cornea is a unique structure because it is transparent and lacks vascularization but has a nerve supply and, like skin, is exposed to environmental oxidative stressors at all times. Pinnipeds in the wild and in captivity appear susceptible to ophthalmologic abnormalities, especially affecting the cornea. Results of the present study indicated that captive pinnipeds also had these corneal diseases, including corneal ulceration, corneal perforation, and corneal edema, thought to be related to trauma and possibly nutrition as well as a previously characterized[8] keratopathy that appeared to be related to environmental and natural factors, such as aging.

Results of the present study indicated that UV index was a major factor associated with pinniped keratopathy. The UV index, according to the US Environmental Protection Agency and conforming to guidelines established by the World Health Organization, "provides a forecast of the expected risk of overexposure to UV radiation from the sun."[14] A UV index of 6 to 7 means that, in humans, there is a high risk of damage from UV radiation unless protection, such as UV-blocking sunglasses and a wide-brimmed hat, is used.[14] The higher the UV index, the less time it takes for UV radiation to damage eyes and skin. Although UV indices < 6 can contribute to corneal disease, findings in the present study indicated that the prevalence of keratopathy was substantially lower in pinnipeds in areas with UV indices ≤ 6, compared with that in pinnipeds from areas with UV indices > 6. Pinniped housing facilities located near the equator can have UV indices as high as 10 or 11, with the same limited amount of shade or inadequately dark or natural pool colors as facilities located elsewhere, and we believe that such UV radiation exposure of the pinnipeds housed in these regions will affect their eyes over time.

Lack of shade increases the likelihood of cataracts in pinnipeds by almost 10 times (OR, 9.66)[12]; however, access to shade was not meaningfully associated with keratopathy in the present study. This difference could have been attributed to several facilities changing their pool walls and floors to darker or natural colors and thus diminishing reflected UV radiation since the previous study.[12] The prevalence of keratopathy in pinnipeds from pools with darker or natural colors was lower than in pinnipeds from pools with lighter, more reflective colors in the pres-

ent study. Therefore, we suggest that an overall goal to help mitigate keratopathy in captive pinnipeds is for all facilities to use darker or natural colors on pinniped pool walls and floors as well as use protective shade structures that further diminish UV radiation exposure. These changes would also help protect pinnipeds' eyes even when other seasonal factors (eg, longer day lengths and higher UV radiation intensity during spring and summer) occur.

Although length of day, latitude, access to shade, and having an indoor enclosure did not have a meaningful association with keratopathy in pinnipeds of the present study, we have observed acute onset of keratopathy in pinnipeds of all areas of the world when days become longer. Longer days, even with lower UV indices, affect pinniped eyes, although not as intensely as with higher UV indices, and when exposed on a daily basis, UV radiation damage is cumulative. With repeated exposure to UV radiation, mice and rabbits develop increased corneal thickness (ie, edema),[15] and mice also develop decreased stromal keratocytes, which can result in corneal stromal thinning, corneal fibrosis and vascularization, corneal perforation, and phthisis bulbi.[16] Except for vascularization, all of these corneal changes are also seen in corneas of pinnipeds continually exposed to sunlight without adequate shade or other mechanisms to lower the cumulative UV radiation exposure.

Ocean salinity is 33 to 35 g/L with a natural mixture of salt and other minerals, and the single water-quality parameter that was identified as protective for keratopathy in pinnipeds of the present study was water salinity ≥ 29 g/L. The finding that this was the only water quality factor identified to have had a meaningful association with keratopathy in pinnipeds conflicted with our clinical experience because we have elsewhere observed clinical corneal edema and blepharospasm in pinnipeds when other water-quality parameters changed. In addition, natural occurrences, including excessive rain, may lower the salinity of bodies of water along with changes in other parameters, including pH and temperature. Although we suspected that other water-quality parameters could have been associated with keratopathy, the finding regarding salinity highlighted the importance of suitable life support standards for pinniped pools so that ocular health and overall health are not jeopardized.

Pinnipeds born in and housed in freshwater pools may have clinically normal eyes for many years, until an imbalance in water quality occurs. Animals maintained in fresh water are usually given nutritional salt supplementation and exposure to smaller saltwater pools to prevent direct damage. In our experience, once keratopathy begins, an affected cornea will never return to clinically normal, and the keratopathy is much more difficult to control in pinnipeds housed in fresh water. The importance of maintaining pinnipeds in salt water has been known for a long time, and one of the most important beneficial changes made in captive pinniped environments has been a switch from freshwater to saltwater enclosures, although some freshwater enclosures remain.[10]

We recognize that saltwater habitats are expensive to maintain and that it is often difficult or expensive to dispose of dirty salt water; therefore, there are strong economic incentives to reuse salt water for extended periods of time. Soluble wastes and disinfection byproducts not removed can build to concentrations in pool water that may affect sensitive tissues such as corneas. Properly designed systems should maintain water that contains no greater amounts of harmful products than the original water.

An interesting finding, although not meaningfully associated with keratopathy, was that pinnipeds from pools with ORP between 451 and 600 mV had the lowest prevalence of keratopathy, compared with that in other ranges of ORP. When the variables for types of life support systems (eg, open, semiclosed, and closed systems) were evaluated, again, no meaningful association with keratopathy was identified in the present study, possibly because of the wide variety of life support systems and operator skills involved.

In general, healthy corneas rarely develop infections. Adequate tear film and the health of the corneal epithelium are barriers to bacterial and fungal keratitis.[17] However, the chemicals used to disinfect enclosures and disinfection byproducts may affect the preocular tear film and corneal epithelium, thus predisposing corneas to ulceration and secondary infections. This is an area in need of further research.

Results of the present study indicated that pinnipeds ≤ 20 years old were less likely to have had keratopathy than were those > 20 years old. Similarly, natural aging is a risk factor for cataracts in all species, and youth protects against keratopathy and cataracts, unless there is an underlying chronic level of oxidative stress. Cataracts have been associated with keratopathy in pinnipeds,[12] and findings in the present study indicated a direct association between aging and keratopathy. In addition to the association between cataracts and keratopathy, we have noticed that pinnipeds with poorly controlled, chronic keratopathy will develop rapidly progressive cataracts at younger ages than will pinnipeds without keratopathy or with milder or controlled keratopathy.

Pinnipeds in the present study with a history of previous or concurrent eye disease were more likely to have keratopathy than were those without such a history. Numerous endogenous and exogenous factors (eg, trauma, systemic disease, vaccinosis reactions, and lens diseases) can contribute to ophthalmologic issues, especially keratopathy in pinnipeds. For instance, cataracts cause intraocular inflammation that may cause corneal edema, and inflammation related to keratopathy causes further reflex uveitis. Uncontrolled chronic anterior uveitis can cause progression of cataracts; degradation of the zonules, leading to lens instability and luxation; and predisposition of

affected individuals to secondary glaucoma.[18] Anterior lens luxation immediately damages the corneal endothelium, and if the lens is not removed from the eye in a relatively short time period, the cornea will continue to sustain further damage, resulting in diffuse corneal edema, signs of pain, bullae, permanent fibrosis, and, in some cases, ulceration and perforation. Although less likely in pinnipeds, we have also observed secondary glaucoma following lens luxation in a few pinnipeds. Corneal edema in some animals is severe, and the sequela of corneal endothelial damage and resulting edema is formation of subepithelial bullae that may rupture, causing moderate to severe clinical signs of pain. Ruptured bullae of any size are predisposed to secondary infections that can then progress to deeper stromal ulcers, descemetoceles, and perforations. Outside of the present study, we have observed loss of the lens through a corneal perforation in some pinnipeds. Surgical repair of the corneal perforation with concurrent lensectomy has been successful in retaining the globe and, sometimes, sight in 3 pinnipeds.[c]

Regarding systemic disease, an interesting and unexpected factor identified as associated with keratopathy in pinnipeds in the present study was having been tested previously for leptospirosis. Pinnipeds that had been tested for leptospirosis lived at only 3 facilities in the present study, and reasons for testing included having been stranded, living in an area endemic for leptospirosis, or being in a facility where stranded animals are often brought. Although many stranded pinnipeds placed in aquaria or zoos have cataracts, corneal ulcers, or scarring at the time,[d] it has been our observation that, thus far, no wild pinniped has been identified to have had the characteristic changes consistent with what we suggest should be called pinniped keratopathy; however, wild pinnipeds have developed keratopathy after coming under human care.

In addition, vaccinations may cause vaccinosis reactions in pinnipeds. Although vaccines are not commonly used in pinnipeds, harbor seals may be vaccinated for West Nile Virus. Endotheliitis, a vaccinosis also known as blue eye, has not been documented in marine mammal literature; however, we suspect that occurrences may have gone undiagnosed. Nutritional deficiencies (eg, of vitamin A or zinc) could also predispose pinnipeds to corneal disease,[19–21] and the questionnaire used in the present study asked facilities about use of oral antioxidants that have been shown to protect against various kinds of oxidative stress[22] and UV radiation.[e] In the present study, 39 of the 66 (59%) pinnipeds that were being given grapeseed extract and lutein also had keratopathy, although this finding was not considered to be meaningfully associated with keratopathy. However, the use of antioxidants was implemented often after the animals developed keratopathy, and thus a lack of obvious effect was not unexpected. Anecdotally, pinnipeds given these and other antioxidants appear to stabilize and have fewer recurrences of keratopathy.[f,g] Over time, data about how these supplements affect the prevalence, incidence, and progression of keratopathy and cataracts in pinnipeds may become available from facilities that give these antioxidants daily to pinnipeds under their care.

A limitation of the present study was the wide variety of life support systems and operator skills involved in maintaining pools of pinnipeds. This made evaluation of variables related to types of life support systems difficult and may have confounded findings regarding water quality parameters.

On the basis of findings in the present study, we developed recommendations for preventive measures to reduce the odds of keratopathy in pinnipeds. Implementing methods to lower total UV radiation exposure, such as the use of darker or natural colors for shade structures, pool walls and floors, and elsewhere in enclosures, may diminish the odds of captive pinnipeds developing keratopathy and may enhance control of active keratopathy. Maintaining pool water salinity ≥ 29 g/L would be optimal. Although results of the present study did not identify meaningful associations between other water quality parameters (eg, pH, chlorine concentration, and ORP), we believe these factors are important and should be appropriately maintained to optimize pinniped health. Although natural aging (ie, ≤ 20 years of age vs > 20 years of age) was the only meaningfully associated factor that cannot be controlled, limiting lifetime exposure to UV radiation and other forms of oxidative stress could potentially reduce the odds of developing keratopathy in pinnipeds. In addition, prevention of fighting and trauma could potentially help mitigate ocular and systemic issues that might contribute to keratopathy in pinnipeds.

Footnotes

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