Diseases of the cornea and lens are common in captive pinnipeds; environmental factors including water quality and salinity, light intensity, nutrition, and spatial characteristics (eg, orientation of sun on wet and dry areas, depth, exhibit surface color [for reflected light], and animal loading per cubic meter [because of potential water-quality effects]) have been reported as the most likely predominant causes. On the basis of results of a study by Dunn et al,6 most captive pinnipeds are now housed in saltwater rather than freshwater. However, other factors have been more difficult to implicate as direct causes of ocular disease. There are few published studies1–3 that characterize the ocular changes observed in captive pinnipeds. Access to UV-protective shade, early identification and medical management of ocular diseases, and prevention of fighting can limit the frequency or severity of lens-related disease in this population. An extended life span may result from captivity, but this also allows development of pathological changes associated with aging, including cataracts.

Objective—To determine risk factors for lens luxation and cataracts in captive pinnipeds in the United States and the Bahamas.

Design—Cross-sectional study.

Animals—111 pinnipeds (99 California sea lions [Zalophus californianus], 10 harbor seals [Phoca vitulina], and 2 walruses [Odobenus rosmarus]) from 9 facilities.

Procedures—Eyes of each pinniped were examined by a veterinary ophthalmologist for the presence of cataracts or lens luxations and photographed. Information detailing husbandry practices, history, and facilities was collected with a questionnaire, and descriptive statistical analyses were performed for continuous and categorical variables. Odds ratios and associated 95% confidence intervals were estimated from the final model.

Results—Risk factors for lens luxation, cataracts, or both included age ≥15 years, history of fighting, history of ocular disease, and insufficient access to shade.

Conclusions and Clinical Relevance—Diseases of the lens commonly affect captive pinnipeds. Access to UV-protective shade, early identification and medical management of ocular diseases, and prevention of fighting can limit the frequency or severity of lens-related disease in this population. An extended life span may result from captivity, but this also allows development of pathological changes associated with aging, including cataracts.
vitulina], and 2 walruses [Odobenus rosmarus]; age range, 1 to 31 years) from 9 facilities were included in the study. Ophthalmic examinations were performed on all animals by 2 veterinary ophthalmologists (SJG at Denver Zoo and CMHC at all other facilities).

Experiments—A questionnaire was generated by 5 coinvestigators (MSR, JFM, THR, TLS, and PL) to include numerous variables that could potentially contribute to pathological changes of the lens. The questionnaires were completed by 7 coinvestigators (ECN, FK, JCM-F, PL, SPC, BAO, and KT) as well as other trainers and keepers; information contained in the medical records was used for medical history of pinnipeds included in the study. Unfortunately, data were incomplete with regard to some questions, which resulted in variations in the total numbers of animals for different analyses. Variables evaluated included age, sex and reproductive status (sexually intact or neutered), age when neutered (when applicable), weight, place of birth, number of times the pinniped had been relocated, and present location of housing. Other factors assessed included history of ocular or systemic disease (evaluated as yes or no); diet; administration of vitamins or nutraceuticals; water quality (ie, freshwater vs saltwater habitat); shape, color, and depth of pool; show (ie, performing for an audience) or display use of the pinniped; incidental access to live prey; amount of sun exposure; and access to shade.

Statistical analysis—Analysis was performed on data for all pinnipeds in the study, and a separate analysis was also performed for California sea lions. All of the data were entered into a spreadsheet, and descriptive statistics were performed for continuous (age, weight, depth of pool, and age when neutered) and categorical variables (all other variables). Continuous variables were converted into categorical variables to facilitate analysis. The dependent or outcome variable was lens luxation, cataract, or both in any eye (0 = no; 1 = yes). Univariate analysis was carried out by use of descriptive statistics were performed for continuous (age, weight, and depth of pool; show (ie, performing for an audience) or display use of the pinniped; incidental access to live prey; amount of sun exposure; and access to shade.

Results

Descriptive analysis—One hundred eleven pinnipeds were evaluated: 99 California sea lions, 10 harbor seals, and 2 walruses. Forty-five of the pinnipeds were females (all sexually intact), 45 were sexually intact males, and 21 were neutered males; 89% were California sea lions because this was the most common pinniped species in captivity at the participating facilities (Table 1).

Ages of all pinnipeds ranged from 1 to 31 years (mean ± SD, 12.0 ± 8.65 years). California sea lions were 1 to 30 years old (mean ± SD, 13.0 ± 8.01 years). The pinnipeds were born at various facilities, and many were housed at > 1 facility; 24 were born at SeaWorld San Diego, and 28 were born at SeaWorld Orlando (all California sea lions). Places of birth for the remaining 45 animals born in captivity included the Miami Seaquarium (11 California sea lions), Zoo Atlanta Georgia (2 California sea lions), Marine World Africa (1 California sea lion), Theater of the Sea (2 California sea lions), Denver Zoo (2 harbor seals), Six Flags Vallejo (3 California sea lions and 6 harbor seals), and other locations (16 California sea lions and 2 harbor seals). The 2 walruses were wild animals that were rescued and raised in captivity at SeaWorld Orlando. Origin of 8 California sea lions was unknown, and 4 California sea lions had been beach and rescued.

Results of analyses for all variables contained in the questionnaire were summarized for all pinnipeds and for each species (Table 1). Not all questions were answered for every pinniped, which resulted in some variability in the total number of pinnipeds used in the analyses of different factors. The distribution of lens luxation, cataracts, or apparently normal lenses was evaluated among pinnipeds categorized according to sex (Figure 1). Any white lens opacity was considered a cataract, but nuclear sclerosis without cataract was considered an expected sign of lens aging. Incidence of cataracts was also examined in relationship to age (Figure 2). Six pinnipeds, including 1 California sea lion, did not have access to shade, whereas 66 of 110 (60.0%) pinnipeds, including 63 of 98 (64.3%) California sea lions, had shade available in their enclosure. The enclosures of 8 pinnipeds (4 harbor seals and 4 California sea lions) contained freshwater, and these pinnipeds were given salt PO (as tablets added to fish in the diet); all other enclosures contained saltwater. All but 2 saltwater pools contained chlorinated or ozonated (O3-purified) saltwater. All pinnipeds were given a variety of nutraceuticals and vitamin supplements (with or without added minerals). Most pinnipeds (79/111 [71.2%] overall; 71/99 [71.7%] California sea lions) regularly received ivermectin for parasite control.

Ninety of 107 (84.1%) pinnipeds (including 78/95 [82.1%] California sea lions) were deemed nonaggressive (ie, consistently docile with trainers). Fifty-five of 94 (58.5%) pinnipeds and 47 of 84 (56%) California sea lions had no history of fighting. When evaluated according to sex and reproductive status, 9 of 34 (26.5%) females, 18 of 42 (42.9%) sexually intact males, and 12 of 18 (66.7%) neutered males had a history of fighting. The difference in history of fighting was significant (P = 0.006) among these 3 groups.

Twenty-one of 86 pinnipeds (24.4%; including 16/76 [21.1%] California sea lions) had parents that were known to be blind, although the cause of blindness was unknown. Approximately half of all pinnipeds, including half of the California sea lions, had a history of previous ocular disease, primarily keratitis. Few (10/86 [11.6%] overall; including 9/76 [11.8%] California sea lions) had a history of systemic disease.
Of 111 pinnipeds evaluated, 17 (15.3%) had a dual diagnosis of lens luxation and cataracts, and 38 (34.2%) had cataracts alone. Seven of 45 (15.6%; 6.3% overall) females had lens luxation and cataracts, and 13 of 45 (33.3%; 13.9% overall) had cataracts alone. Seven of 45 (15.6%; 6.3% overall) sexually intact males had lens luxation and cataracts, and 11 of 45 (24.4%; 9.9% overall) males had cataracts alone. Three of 21 (14.3%; 2.7% overall) neutered males had lens luxation and cataracts, and 12 of 21 (57.1%; 10.8% overall) had cataracts alone (Figure 1).

Of 222 eyes evaluated, 104 (46.8%) had lens luxation, cataracts, or both. Among the eyes of California sea lions, 84 of 198 (42.4%) had lens luxation, cataracts, or both.

When data were grouped in 5-year increments according to the ages of pinnipeds, cataracts were not detected among pinnipeds younger than 10 years of age (A, 0 to 5 years [14]; B, 6 to 10 years [14]; C, 11 to 15 years [12]; D, 16 to 20 years [32]; E, 21 to 25 years [16]; F, 26 to 30 years [7]; and G, > 30 years [2]).
results of interest for lens luxation, cataracts, or both in 111 captive adult pinnipeds described in Table 1.

Table 2—Results of multivariate logistic regression analysis of variables of interest for lens luxation, cataracts, or both in 111 captive adult pinnipeds described in Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>&lt; 15</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>≥ 15</td>
<td>Reference</td>
</tr>
<tr>
<td>Weight (kg [lb])</td>
<td>&lt; 108.2 (238)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>≥ 108.2 (238)</td>
<td>Reference</td>
</tr>
<tr>
<td>Reproductive status</td>
<td>Not neutered</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td>Neutered</td>
<td>Reference</td>
</tr>
<tr>
<td>Place of birth</td>
<td>Sea World San Diego</td>
<td>0.056</td>
</tr>
<tr>
<td></td>
<td>Sea World Orlando</td>
<td>&lt; 0.003</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>Reference</td>
</tr>
<tr>
<td>Born in captivity</td>
<td>No</td>
<td>0.171</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Reference</td>
</tr>
<tr>
<td>No. of housing facilities*</td>
<td>0</td>
<td>0.465</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>&lt; 0.017</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Reference</td>
</tr>
<tr>
<td>Access to shade</td>
<td>None</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>Some type of shade</td>
<td>Reference</td>
</tr>
<tr>
<td>Treatment against parasites</td>
<td>No</td>
<td>0.203</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Reference</td>
</tr>
<tr>
<td>History of fighting</td>
<td>No</td>
<td>&lt; 0.022</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Reference</td>
</tr>
<tr>
<td>History of ocular disease</td>
<td>No</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Reference</td>
</tr>
</tbody>
</table>

*For data to be used in statistical analysis, animals that were never moved were assigned a value of 0; those moved 1 or 2 times were assigned a value of 1, and those moved 3 to 6 times were assigned a value of 2.

Table 3—Results of final multivariate logistic regression analysis for data obtained from 111 captive adult pinnipeds described in Table 1.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Category</th>
<th>Odds ratios (95% confidence intervals)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td></td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Age (y)</td>
<td>&lt; 15</td>
<td>0.08 (0.0–0.29)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>≥ 15</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>Access to shade</td>
<td>No</td>
<td>9.66 (1.56–78.06)</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>History of fighting</td>
<td>No</td>
<td>0.08 (0.01–0.41)</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>History of ocular disease</td>
<td>No</td>
<td>0.11 (0.03–0.42)</td>
<td>&lt; 0.002</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Reference</td>
<td></td>
</tr>
</tbody>
</table>

Variables were used in a backward stepwise multivariate logistic regression model, and results of the final analysis were summarized (Table 3).

Pinnipeds < 15 years old were significantly (P < 0.001) less likely to develop lens luxation, cataracts, or both, compared with pinnipeds ≥ 15 years old (Table 2). Pinnipeds that had no history of fighting were significantly (P = 0.022) less likely to develop lens luxation, cataracts, or both, compared with pinnipeds that had a history of fighting; those that had no history of ocular disease were significantly (P < 0.002) less likely to develop lens luxation, cataracts, or both, compared with those that did have a history of ocular disease. However, pinnipeds that did not have access to any shade were almost 10 times as likely (odds ratio, 9.66; P = 0.033) to develop lens luxation, cataracts, or both, as were pinnipeds that had access to shade. The Hosmer-Lemeshow statistic (P = 0.486) suggested a good fit between the actual observations and the expected observations.

Discussion

Results of the study reported here indicated that there are risk factors for the development of lens luxations, cataracts, or both among captive pinnipeds, including increasing age, insufficient access to shade, history of fighting, and history of ocular disease.

The lens is a unique structure because it is transparent and has no direct vascular or nerve supply, yet it grows throughout life. Cataract is an opacity of the lens that has cataracts, but 0.5% of 765 California sea lions examined had ocular disease that included cataracts. It is estimated that 5% of wild pinnipeds have cataracts, but this has not been evaluated objectively to the authors’ knowledge. It is estimated that 5% of wild pinnipeds have cataracts, but this has not been evaluated objectively to the authors’ knowledge. One study that evaluated stranded pinnipeds during a 6-year period found cataracts in animals of all ages, including pups. Unfortunately, the data were not assessed on the basis of numbers of pinnipeds in each age group that had cataracts, but 0.5% of 765 California sea lions examined had ocular disease that included cataracts. Specific causes were not investigated; however, suspected causes included congenital anomalies, nutritional excesses or deficiencies, trauma, and senility. Another large-scale study evaluated > 1,700 wild northern fur seals (Callorhinus ursinus). Of 1,501 subadult males (2 to 5 years old), 23 had unilateral cataracts; the other adult pinnipeds did not have obvious cataracts, although 40 adult harem bulls had severe unilateral corneal scarring that precluded evaluation of the lens.
Cataracts are commonly seen in older humans and nonhuman animals; they are often classified as senile (ie, age-related) cataracts if no other antecedent cause is apparent and the animal or person is of advanced age. It is estimated\(^9\)\(^{10}\) that age-related cataracts affect 5% of humans aged 65 years and up to 50% of humans ≥75 years old. The exact pathogenesis of age-related cataracts in any species is unknown, but numerous changes that contribute to the multifactorial development of cataracts occur within the lens. These include oxidation of protein residues such as glutathione, an important endogenous antioxidant; denaturation and aggregation of soluble lens proteins including crystallins; protein cross-linking; and a high amount of cholesterol in the lens fiber cell membranes, which increases rigidity.\(^1\)\(^1\) The 1 major risk factor for cataracts in humans is aging.\(^1\)\(^1\) A recent large-scale study\(^1\)\(^2\) in dogs also showed an increase in the incidence of cataracts with increasing age; signs of cataracts developed in different breeds at different ages because of variations in longevity. Those investigators also commented on similar findings in horses\(^1\)\(^3\) and cats.\(^1\)\(^4\) Much of the speculation regarding the pathogenesis of age-related cataracts in humans focuses on photooxidative injury to the lens, the consequence of decades of exposure to ambient solar radiation and UV wavelengths of radiation.\(^1\)\(^4\) Ultraviolet radiation–related cataracts are not unique to older animals; in fact, young humans and nonhuman animals develop cataracts directly from excessive exposure to this oxidative stress,\(^1\)\(^5\) with an increasing incidence attributed to ozone depletion.\(^1\)\(^6\)

The primary target cell of UV-B (295 to 315 nm) irradiation is the LEC. Exposure of LECs to UV-B radiation can cause DNA damage, unscheduled DNA synthesis, and decreased concentrations of reduced glutathione; it may also impair membrane pumps and deactivate several metabolic enzymes.\(^1\)\(^7\) The LECs can also be damaged by UV-A radiation. One mechanism of UV-A-induced injury is oxidation of the protective antioxidant enzyme catalase by singlet oxygen species (\(1^\text{O}_2\)); NADPH is concentrated in LECs and is the major absorber of UV-A radiation. Singlet oxygen species generated by this reaction contribute to lipid peroxidation and cross-link lens proteins.\(^1\)\(^8\) Effects of UV-A radiation include delayed cell growth, enhanced apoptosis, reduced ATP concentrations, actin and tubulin damage, and inhibition of Na\(^+\),K\(^+\)-ATPase and catalase activities.\(^1\)\(^9\) Therefore, UV-A and UV-B exposures are cumulatively cataractogenic.\(^1\)\(^8\)

The specific types of DNA damage in LECs caused by chronic UV-B radiation exposure include DNA-DNA cross-linking and the formation of pyrimidine dimers and thymine glycols.\(^1\)\(^4\) Any of these mechanisms lead to LEC damage and cataract formation; the posterior aspect of the lens can also be affected by UV-B radiation as age increases.\(^1\)\(^0\) In a study\(^1\)\(^1\) in humans, investigators found that subjects exposed to the sun on a professional basis (eg, through fishing, working on the beach, oyster farming, or construction) had a higher incidence of posterior subcapsular cataracts. Mice exposed to both UV-B radiation also developed posterior cortical cataracts.\(^2\)\(^1\) It is not clear what mechanisms are involved in this type of cataract formation, but photooxidation is likely a component. The direct and indirect effects of UV radiation–induced damage are mediated by UV radiation–activated intermediates (ie, free radicals).\(^2\)\(^3\) These free radicals include superoxide anion, hydroxyl radicals, and peroxides. It is also likely that exposure to UV-B radiation may be synergistic, wherein it increases the rate of cataract formation or adds to other oxidative insults to surpass a threshold for cataract development.\(^2\)\(^4\)

The age of onset at which a change in lens opacity would be considered age related is arbitrary and varies among species or breeds. Nuclear or lenticular sclerosis is an aging change in which the nucleus of the lens initially becomes apparent and is seen as a bluish haze secondary to continual compression of the lens fibers with time. This change can be detected at approximately 6 years of age in most dogs, 60 years of age in humans, and 15 years of age in horses.\(^1\)\(^6\) A critical study\(^1\)\(^2\) of changes in canine lens opacities showed that 50% of 2,000 dogs evaluated in the study had nuclear sclerosis by approximately 9.6 years of age. Nuclear sclerosis does not typically affect sight until late in life when the nucleus becomes very opaque and other defects (eg, cortical or capsular opacities) are often present. These advanced changes in older pinnipeds are termed cataracts when they affect sight or the examiner’s ability to visualize the ocular fundus. Cataracts in younger animals have numerous etiologies that include genetic predisposition, uveitis, exposure to toxins, diabetes mellitus, blunt or sharp trauma, exposure to UV light, or a combination of any of these.\(^2\)\(^5\)

In the study reported here, the authors identified age as a risk factor for cataracts, lens luxation, or both in pinnipeds. Any white lens opacity was considered a cataract, and nuclear sclerosis without cataract was considered an expected sign of lens aging. In the authors’ experience, California sea lions in captivity typically live for 20 to 30 years; therefore, nuclear sclerosis detected at approximately 15 to 20 years of age would be similar to the onset of nuclear sclerosis in humans and dogs at similar life stages. However, cataractous changes of the lens were found in all age groups >5 years, with 3 of 14 pinnipeds in the 6- to 10-year-old category (all ≥7 years old) affected. The observation of cataracts in pinnipeds at this relatively young age suggests a role for other factors in addition to UV radiation exposure. The 3 affected pinnipeds <11 years old had parents in which cataracts were diagnosed in the present study. Thus, genetic predisposition is a possibility, although the fact that the parents had cataracts could also be a reflection of the high incidence of lens diseases in captive pinnipeds with longer life spans. Unfortunately, the sight status of many pinnipeds’ parents was unknown, and statistical analysis could not be performed for this important variable. The incidence of lens luxation, cataracts, or both increased substantially in the 11- to 20-year-old group. Nine of the pinnipeds in this category had parents that were blind, presumably as a result of cataracts, but specific details were not recorded. All pinnipeds >26 years old had cataracts. It is likely that, similar to human lenses, the lenses of pinnipeds and other species have diminished antioxidant capacity with increasing age, further contributing to the typical changes reported for this type of cataract.\(^1\)\(^9\) All
of the pinnipeds in the present study were administered various vitamin products, but none of these preparations included antioxidants that have been shown to protect the lens, such as lutein and zeaxanthin. Lutein and its coexistent isomer, zeaxanthin, are carotenoids that protect ocular tissue against photooxidative stress; they filter blue light, quench and scavenge UV radiation–induced reactive oxygen species, and inhibit lipid peroxidation.

Lutein and zeaxanthin are the only xanthophyll carotenoids that have been detected in human, frog, quail, and dog lenses (in the authors’ experience in collaboration with another investigator). A study that evaluated lutein in cataractous human lenses found that newer epithelium and peripheral cortex had 3-fold increases in the amounts of lutein, compared with findings in the older, more interior cortical lens fibers. It was recently shown that pinnipeds are capable of absorbing orally ingested lutein; therefore, it is possible that their lenses would also accumulate this important antioxidant.

Preliminary histologic evaluation of pinniped cataract samples evaluated following cataract removal (CMHC; data not shown) revealed cellular and capsular characteristics identical to those seen in cataracts from other species. Most of the lenses from older seals and California sea lions are typically slightly or obviously brunescent (ie, characterized by amber discoloration of the lens). Development of this color change is attributed to photooxidation of lens proteins. Brunescence is more frequently seen in humans who work outdoors with chronic exposure to sunlight and is also found in chronic cataracts in dogs; it is 1 characteristic commonly used to grade cataract progression in human lenses.

Although the clinical appearance and rate of progression of age-related cataracts can vary in all species, they are often detected initially as an increase in light refraction with punctate to linear opacification in the adult nucleus of the lens and generally develop concurrently with or subsequent to dense nuclear sclerosis. The rate of progression of age-related cataracts is often slow and gradual in humans and dogs; however, severity of nuclear and cortical opacities increases nonlinearly with age in humans, and this is likely true in other species as well. Pinnipeds spend a substantial amount of time outdoors with exposure to direct and indirect sunlight; this indicates that photooxidative mechanisms contribute to cataractogenesis in these species, although this finding alone may not explain the lens luxation component of the phenotype. The lens is held in place by zonules made of fibrilin proteins in humans and most other species. Pinniped lenses are held in position by zonules as well as by direct attachment to the ciliary processes. Therefore, the attachment in pinnipeds may be a fibrilin-rich adhesion. Matrix metalloproteinases are enzymes that degrade components of extracellular matrix. Exposure to UV radiation induces expression of MMP-2, MMP-9, MMP-12, MMP-13, and MMP-14, which are all capable of cleaving the proline-rich and carboxy-terminus regions of fibrillin-1 and the glycine-rich region of fibrillin-2. It is possible that chronic exposure to UV radiation could cause degradation of the zonulalike, fibrilin-rich structures that adhere the ciliary processes to the lens, resulting in lens instability and eventual luxation. Results of a study in cats revealed high concentrations of MMP-9 in the ciliary bodies of eyes with lens luxations. Amounts of MMPs were increased in the aqueous humor of human eyes with anterior uveitis, compared with those that underwent elective cataract surgery; similarly, MMP values were increased in rabbit eyes with experimentally induced anterior uveitis, compared with sham-treated contralateral eyes in the same rabbits. Activity of MMP-9 was increased in cataractous LEKC in humans, especially in those with cortical cataracts, and MMP-9 activity also increased with age (irrespective of cataract type) in humans.

To date, the authors have not detected measurable concentrations of MMP-2 or MMP-9 in aqueous humor samples from the eyes of pinnipeds (unpublished data), but have not yet performed zymography or immunohistochemical staining for these proteins in the lens or uvea.

The typical clinical characteristic of progressing cataracts and lens instability in pinnipeds is variable in onset. In at least 6 of approximately 30 California sea lions, 1 of the authors (CMHC) noticed that the lens, with variable cataract formation, often luxated anteriorly at nightfall to reveal a completely white opacity just behind the cornea; with the onset of daylight, the lens repositioned behind the iris, leaving a small, diffuse white corneal opacity axially with variable blepharospasm. After a few weeks, the lens typically remained anteriorly luxated, which caused uveitis with blepharospasm and epiphora and sometimes resulted in secondary glaucoma and severe keratitis, with or without bullous keratopathy.

Pinnipeds in the present study that had anterior lens luxations and relatively clear cornes did not have any pigment evident on the lens periphery, which strongly suggested degradation of normal zonulalike structures (possibly by MMPs). This has been detected clinically in sea lions and seals > 17 years of age by 1 of the authors (CMHC). Less often, the lens fell posteriorly into the vitreous humor, thereby not causing obvious signs of pain and possibly improving sight; however, this could still cause chronic progressive problems including chronic uveitis, secondary glaucoma, and retinal detachment. It has not been definitively established whether the cataracts or the lens instability develops first in these populations, although minimally cataractous lenses can become luxated, in the authors’ experience. Lens instability results in cataract development, and chronic cataracts with lens-induced uveitis can result in lens instability. In the authors’ clinical practice, intracapsular lens extraction with appropriate perioperative and postoperative medical management results in pain relief and improved vision in pinnipeds with lens luxation and cataracts.

Seals and sea lions rely primarily on sight for hunting underwater, whereas walruses rely more on touch via their sensitive mystacial vibrissae with little use of sight. Under water, the cornea is almost ineffective as a result of the nearly identical refractive index of water and aqueous humor. However, because pinnipeds live on land and in the water, they have developed optical adaptations to accommodate to both environments. Seals have a flattened area in the medial paraxial region...
of the cornea that is in the shape of a stripe in the vertical meridian. In sea lions and walruses, a flat circular region approximately 6.5 mm in diameter is also located along the nasal aspect of the horizontal meridian. Pinnipeds can constrict their pupils to a pinpoint shape that aligns with this flattened surface, providing an emmetropic window that allows refraction to remain almost constant in both air and underwater (although the lens is not used substantially on land). To maximize vision sensitivity under low light conditions, pinnipeds evolved with large eyes, a highly developed tapetum lucidum, large ganglion cells, and a predominance of rods in the retina. The combination of the constricted pupil with flattened corneal surface and highly developed posterior segment structures provides these species with optimal vision on land and in the ocean. Living conditions for pinnipeds in the wild, where they primarily sleep on land and open their eyes to hunt and swim, are in contrast to conditions in some facilities that house with natural ocean-bottomed pools, compared with a larger number that were in blue-colored pools. Some facilities had changed pool color to a tan or brown color just prior to the beginning of the study reported here; this may have been too short a period to notice ocular improvements or a slowdown in progression of cataracts. Tan is a less reflective color, compared with blue, and animals raised in tan-colored pools and enclosures anecdotally have fewer eye problems.

This study identified insufficient access to shade, history of fighting, previous ocular disease, and increasing age as important risk factors for lens diseases in captive pinnipeds. We conclude that shade to protect against UV radiation, early identification and medical management of ocular disease, and limiting fighting may delay the onset of pathological changes in the lens. Increased life span of pinnipeds is a benefit of living in captivity, but it also reveals a gradual inability to repair damage by oxidative stress in all cell systems including the eye.

References


