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Phacoemulsification cataract surgery in the loggerhead turtle (*Caretta caretta*): surgical technique and outcomes in 10 cases

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Abstract

Cataract removal using phacoemulsification was performed in 10 loggerhead turtles being rehabilitated after stranding. All turtles had significant systemic abnormalities and had cataracts either at the time of rescue or developed them during rehabilitation. Surgical difficulties encountered included an extremely soft globe that did not allow for a partial thickness corneal incision, incomplete topical anesthesia of the ocular surface with proparacaine, inability to dilate the pupil pharmacologically, a markedly shallow anterior chamber, a thick posterior capsular plaque in most cases, and difficulty creating a watertight closure with sutures. Minimal to no intraocular inflammation was seen in all cases following surgery, but all cases in which corneal sutures were used developed a marked inflammatory reaction surrounding the sutures and appeared uncomfortable until sutures were removed or sloughed. All turtles appeared to have improved vision following surgery and were eventually released. Two turtles were re-encountered a year or more after release. Both showed signs of normal growth and the ability to capture prey in the wild. This report documents successful outcomes associated with cataract surgery in loggerhead turtles, but also presents significant surgical challenges that should be taken into account before attempting this procedure in this species.

1 | INTRODUCTION

Loggerhead sea turtles (*Caretta caretta*) are the largest living hard-shelled turtle and are the most abundant sea turtle species found in US coastal waters.[1] However, their numbers have declined dramatically since colonial times and continue to decline.[2-4] They are currently listed by the IUCN Red List of Threatened Species as a species vulnerable to extinction.[5] Loggerheads can be found in temperate and tropical waters of the Atlantic, Pacific, and Indian Oceans, and the Mediterranean Sea, with the second largest nesting assemblage found along the United States' southeast Atlantic coast.[6]

Ocular surface diseases such as heterophilic keratoconjunctivitis and scleritis, blepharitis, and ulcerative keratitis have been reported as common findings in stranded sea turtles with ocular disease.[7,8] However, we are aware of a single case report describing cataracts in a loggerhead turtle[9] and until recently cataracts were considered a rare finding in sea turtles. During the last 3-4 years, there has been a noticeable increase in the number of turtles stranded along the North and South Carolina coast-line diagnosed with cataracts (S. Boylan, C. Harms, personal observations) and a recent survey of cold-stunned turtles in North Carolina revealed approximately 3% of turtles had cataracts.[10] Even though loggerheads use other senses in addition to vision to orient and navigate,[11] vision provides the primary cue used to forage and capture prey.[12] Thus, the visual impairment caused by cataracts is expected to affect a loggerhead turtle's survival adversely.

The purpose of the present report is to describe the surgical removal of cataracts using phacoemulsification, highlighting notable differences to this surgery in mammals, in a series of ten loggerheads (20 eyes) that presented to two rehabilitation centers in North and South Carolina.

2 | ANIMALS

Table 1 describes the characteristics of the turtles in this report. All were found between late May and early August of 2013-2017. Cataracts were diagnosed within 1 month of rescue in four turtles, while in the remaining turtles, cataracts were diagnosed 3 or more months after rescue. Cases 2 and 3 displayed visual deficits prior to the diagnosis of cataracts. In both cases, visual deficits were attributed to central nervous system lesions. Visual deficits gradually improved in both, and then suddenly worsened around the time of cataract diagnosis. All cataracts were mature at the time of diagnosis, except for in cases 8 and 9, in which incipient or immature cataracts were first noticed and progressed to mature cataracts. Intraocular pressure is not routinely measured at the rehabilitation facilities due to a lack of instrumentation, thus intraocular pressure was not recorded. Fundus examination was not performed due the presence of cataracts and the difficulties associated with pharmacologic mydriasis in this species. All turtles exhibited systemic abnormalities at the time of rescue. The most common included anemia, hypoglycemia, and hypoproteinemia consistent with chronic debilitation.[13] In some cases, anemia and hypoglycemia were severe. For example, blood glucose concentration at the time of rescue in case 1 was 1 mg/dL. All were estimated to be juveniles or young adults based on weight and carapace length. Despite surgery being performed an average of 152d following diagnosis of cataracts, no signs of inflammation (aqueous humor flare or cells) were noted on slit lamp biomicroscopy (SL15, Kowa, Japan) in any eye prior to surgery.

3 | ANESTHESIA

Anesthetic protocols varied among turtles, but most were sedated with intramuscular ketamine (10 mg/kg) and midazolam (0.5-1 mg/kg) for transport from the aquarium to the surgical site. Anesthesia was then induced with dexmedetomidine (30-50 g/kg, IV) and maintained with isoflurane or sevoflurane via an uncuffed endotracheal tube. Hydromorphone (0.15-0.3 mg/kg, IM) was used at induction in two cases (5 and 6), but it resulted in slower recoveries. Respiratory rate was maintained at two breaths per minute. Atipamezole (equal volume and 10× the mg/kg dose of dexmedetomine) was administered intramuscularly at the end of surgery.

TABLE 1 Characteristics of capture, systemic disease, and cataract development in the loggerheads that underwent cataract extraction using phacoemulsification

Case	Weight (kg)	Location and date found		Time to cataract diagnosis (days)	Cataract stage at diagnosis	Systemic disease at presentation
1	80.5	North Myrtle Beach, SC	May 20, 2013	190	Mature	Anemia, epibiota (barnacles), emaciation, hypoglycemia (1 mg/dL)
2	40.24	McClellanville, SC	Jul 20, 2014	136	Mature	Ataxia, dehydration, neurologic abnormalities (hypermetria, trismus, nystagmus)
3	43	South Carolina	Jul 17, 2014	257	Mature	Dehydration, epibiota (barnacles), hypermetria, trismus, trauma to carapace,
4	52.5	Eddingsville Beach, SC	May 27, 2015	2	Mature	Anemia, epibiota (leeches), hypoproteinemia, trauma (boat)
5	58.6	Isle of Palms, SC	May 5, 2015	14	Mature	Anemia, hypoproteinemia, hypoglycemia
6	59.7	Beaufort, SC	Jun 27, 2015	0	Mature	Anemia, hypoglycemia (mild)
7	62.5	Pender County, NC	Aug 6, 2015	31	Mature	Anemia, emaciation, epibiota (barnacle, leech)
8	68	Cape Island, SC	May 16, 2015	108	Incipient (Mature 157 d later)	Anemia, epibiota (barnacle), hypoglycemia, hypoproteinemia
9	56	South Carolina	June, 2016	7	Immature	Anemia, epibiota (barnacle), hypoproteinemia
10	37	Oak Island, NC	Aug, 2017	0	Hypermature	Anemia, epibiota (barnacle), hypoproteinemia

4 | SURGERY

Ocular ultrasound and electroretinography could not be performed awake as even the slightest touch to the eye or eyelids resulted in forceful closure of the eyelids and globe retraction. After induction of anesthesia an ocular ultrasound (10 mHz probe, Aviso-S, Quantel Medical, Bozeman, MT) (cases 1-5, 7-10) and electroretinography (RetiPORT ERG, an-vision, Salt Lake City, UT) (case 7) was performed. Electrical retinal activity was detected and there were no signs of retinal detachment on ultrasound. Electroretinography or ultrasound was not performed in all cases due to the prolongation of anesthesia it required, logistical difficulties, the presence of normal dazzle and pupillary light reflexes in all eyes, and the rarity of retinal degenerative diseases in this species.

Immediately following ocular ultrasound and electroretinography, turtles were positioned so that the palpebral fissure of one eye was parallel to the ceiling. Because neck rotation alone could not achieve this ocular position while the turtle lay flat on the table, one side of the plastron was elevated so the body of the turtle rested at an angle. The neck was then rotated to achieve the final head position. The ocular surface was cleansed routinely with dilute povidone iodine and physiologic saline. The thick, viscous secretions of the salt gland required multiple fluid flushes and cotton tipped applicator wipes to remove completely.

For early cases, topical anesthesia was attempted with proparacaine (two drops, two minutes apart, up to five times). However, topical anesthesia was incomplete, as evidenced by immediate globe retraction when the conjunctiva was grasped with forceps. This response persisted even when the turtle was in a deep plane of anesthesia. Subconjunctival injections of 2% lidocaine (0.1 mL, LidoJect, Henry Schein Animal Health, Dublin, OH) or a lidocaine bupivacaine mixture were required in order to provide enough anesthesia for the conjunctiva to be grasped during surgery. This resulted in immediate, complete anesthesia of the conjunctiva in the area of the injection.

Pupillary dilation was attempted with intracameral atracurium (0.1 mL, 1:10 dilution in balanced salt solution, atracurium besylate, 10 mg/mL, AuroMedics, NJ) with epinephrine (1 mg/mL, UniAmp, Hospira) in one case (#1) and intracameral atracurium alone in another (#7). There was no obvious increase in pupillary diameter. In another case (#8), alternating topical drops of 0.4% vecuronium (Mylan, Canonsburg, PA) and phenylephrine[14] (phenylephrine hydrochloride ophthalmic solution 2.5%, Akorn, Lake Forest, IL) were administered prior to surgery, with similar lack of appreciable effect.

A two-step corneal incision was attempted in early cases. However, in all cases, due to a lack of back pressure, which allowed the cornea to indent into the anterior chamber under the pressure of the blade, presumably because of low intraocular pressure, it was not possible to perform a partial thickness corneal incision with a 6400 Beaver™ blade (Beaver-Visitec, Waltham, MA). A full thickness, 2.85 mm (cases 1-7 and 9) or 2 mm (case 8 and 10) stab incision was made with a keratome (Cases 1-7 and 9) or a diamond knife (case 8 and 10). Hyaluronic acid (I-visc Vet 1.8%, Imed Animal Health, Quebec, Canada) was injected into the anterior chamber using a 30 g hypodermic needle prior to the corneal incision in cases 1-6 and 9, to facilitate creation of the incision. The injection had to be performed with great care, as the anterior chamber was extremely shallow, with the iris and lens apex appearing to nearly contact the corneal endothelium.

Following the corneal incision, the anterior chamber was filled with a viscoelastic device (2.2% hyaluronic acid, an-bfh 2.2%, an-vision, Salt Lake City, UT or I-visc Vet 1.8%, Imed Animal Health, Quebec, Canada), which resulted in enough pupillary dilation to visualize the anterior lens capsule and perform the capsulotomy. A routine continuous curvilinear capsulorrhexis using Utrata forceps was performed in cases 1-6 and 9. In cases 7, 8, and 10 a high frequency capsulotomy probe (Alexos, an-vision, Salt Lake City, UT) was used to create a circular capsular opening. Because of the smaller corneal incision in case 8 and 10, a capsulorrhexis gripper (Acrivet, Bausch and Lomb, Berlin, Germany) was used to remove the capsular fragments. Cortical material was removed routinely using phacoemusification. An AMO Sovereign phacoemulsification system equipped with a 19 g, straight needle with a 45° tip was used in cases 1-6 and 9, while in cases 7, 8, and 10 an Alexos™ phacoemulsification system (an-vision, Salt Lake City, UT) equipped with an avian needle was used. Cataracts were soft in all cases and removed using mostly aspiration with only short pulses of phacoemulsification power. Automated irrigation and aspiration was used to remove remaining cortical material. Due to poor pupillary dilation, this had to be performed without visualization of the instrument tip behind the iris.

In all cases, except for in the left eye of case 1 and both eyes of case 9, a large posterior polar capsular plaque was present and a planned posterior capsulotomy was performed to remove the plaque.

The corneal incision was closed in a simple interrupted or cruciate pattern in six cases (using 8-0 polyglactin 910 in cases 1 and 4-7 or 8-0 nylon in case 2), while in the remaining four cases (3 and 8-10) the incision was not closed. In cases 4-6, it was not possible to create a watertight closure and aqueous humor was noted escaping through the incision.

All turtles recovered slowly, but uneventfully, from anesthesia and were "dry-docked" for at least 1 day. Then they were "wet-docked" (partially submerged, with water below the level of the eyes) for 1-2 days, with most turtles returning to their tanks within 48 hours.

Postoperative medications consisted of a topical broad spectrum antibiotic (ciprofloxacin, ofloxacin, or neomycin/

polymixin) and a topical anti-inflammatory medication (prednisolone acetate, dexamethasone, or flurbiprofen) applied two to three times a day to each eye. Medications were discontinued 3-7 weeks after surgery. Case 9 did not receive any postoperative medications for three days following surgery due to a hurricane that prompted the evacuation of the aquarium staff. Minimal to no intraocular inflammation was seen immediately following surgery. After 3 weeks, no turtles had any signs of intraocular inflammation.

All turtles that had corneal sutures placed developed marked mucopurulent discharge accumulation surrounding the suture material (Figure 1) in at least one eye. This was accompanied by various degrees of blepharospasm and globe retraction and marked corneal vascularization surrounding the suture material. Some turtles were observed rubbing the eye with a front flipper. These signs were less severe in the case in which nylon was used to close the corneal incision. These symptoms all resolved upon removal, or sloughing of the sutures. Suture removal required short general anesthesia in all cases and occurred 7-61d after surgery. In the one eye in which sutures were allowed to slough spontaneously (case 7), sloughing occurred approximately 59d after surgery. Cases that did not have corneal sutures did not develop discharge, did not show any globe retraction or blepharospasm, and developed minimal corneal vascularization.

5 | FINAL OUTCOME

All were able to track and catch live food within days following surgery, which in all cases was considered by handlers to be a marked improvement. All turtles have been released. Average time to release following cataract surgery was 168 days (range 72-504 days). Flipper tags and passive integrated transponders were placed in all cases to allow for identification during future encounters. Case 1 restranded and was encountered by a sea turtle rescue group approximately 2 years following release. The turtle had a large carapace laceration that appeared to be due to a boat strike. This was estimated to have occurred 1 month prior to recapture. The turtle had lost 10 kg of body weight compared to its release weight. Carapace length was not measured. Radiographs of the gastrointestinal tract showed there were crabs and clams ingested prior to capture. An ophthalmic exam was normal except for aphakia and the turtle was able to track food within its enclosure. Following 11 months of rehabilitation for the carapace injury, it was again released. Case 3 was encountered by a surveying crew 13 months following release. At that time, carapace length had increased approximately 2% while bodyweight had decreased by 9% compared to prior to release. The increase in size, even in the face of weight loss, is consistent with normal growth for some period prior to events leading to stranding.

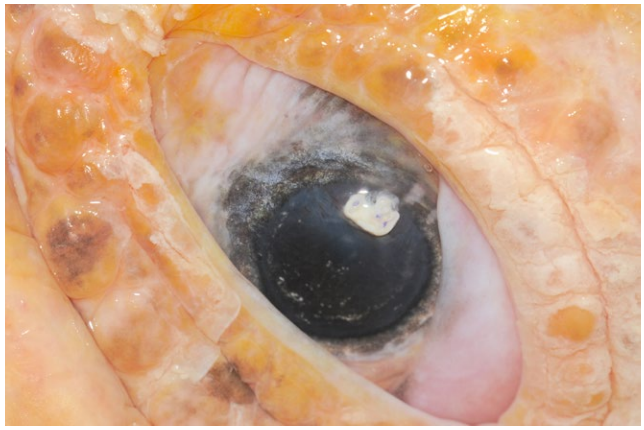

FIGURE 1 Copious mucopurulent discharge surrounding polyglactin 910 corneal sutures in a loggerhead following cataract removal surgery using phacoemulsification. Corneal vessels can also be seen coursing toward the sutured incision

6 | DISCUSSION

This report describes the successful removal of cataracts in 10 loggerheads using phacoemulsification. All turtles appeared to have improved visual function following surgery and all have been released. Notable differences found in this series of turtles, as compared to the same surgery in mammals, were difficulty in performing a two-step corneal incision, inability to dilate the pupils pharmacologically, lack of response to topical anesthesia with proparacaine, a consistently present posterior capsular plaque, and a marked inflammatory response to corneal sutures.

A two-step corneal incision allows for easy apposition and for a wide margin of water-tightness.[15] Because of these benefits, it was initially attempted by both surgeons. However, there was insufficient back-pressure on the cornea to create a partial thickness incision. When attempted, there was only severe corneal indentation without a resultant incision. This occurred presumably due to low intraocular pressure, although it wasn't measured at the time of surgery. This low intraocular pressure could be due to low grade uveitis, incited by the cataracts, even though no overt clinical signs were noted. However, it is more likely this extremely low intraocular pressure is normal in loggerhead turtles. A study evaluating the intraocular pressure of normal juvenile loggerhead turtles using applanation tonometry found the average intraocular pressure in turtles was 5 mm Hg.[16]

A recent report evaluating corneal sensitivity in Kemp's ridley sea turtles found that the application of a single drop of 0.5% proparacaine resulted in the abolishment of all corneal sensation within 1 minute in 17 out of 18 eyes tested.[17] However, that was not reflected in the experience of the surgeons with the loggerheads described in the current report. Even after multiple applications of proparacaine, grasping of the conjunctiva resulted in an obvious response in all cases. It seems unlikely there are such marked differences in nerve physiology that proparacaine is completely ineffective in loggerheads. Most likely, grasping of the conjunctiva with forceps is a much stronger stimulus than that provoked by a corneal esthesiometer. Regardless, a subconjunctival injection of lidocaine in the area to be manipulated resulted in the surgeon being able to grasp the conjunctiva without any appreciable response from the turtle.

Pupillary dilation is essential during cataract surgery in order to visualize the entire lens and avoid inadvertent damage to the lens capsule. The use of intracameral atracurium during phacoemulsification-assisted cataract surgery in a loggerhead has been previously reported.[9] However, that report does not state whether its use resulted in clinically useful pupillary dilation. The authors of the current report did not observe any notable effect on pupil diameter with the use of intracameral atracurium. Alternating drops of vecuronium and phenylephrine, as previously described in the red-eared slider turtle,[14] were attempted in one case. Again, no appreciable, and definitely no clinically useful, pupillary dilation resulted. It is possible that both of these strategies (intracameral atracurium or topical vecuronium/phenylephrine) do actually result in some marginal increase in pupillary diameter. Pupil diameter in the red eared slider turtle increased from 2.6 to 3.2 mm after application of the vecuronium/phenylephrine combination.[14] Even though this represents a 35% increase in pupil diameter, it corresponds to only a 0.6 mm increase. It is possible pupil diameter did increase in the loggerheads in the current report but the magnitude was not enough to be noticeable without precise measurements of the pupil. Regardless, in the authors' opinion, none of the reported strategies to dilate the pupil pharmacologically in a loggerhead result in clinically relevant effects. A much more effective strategy was to dilate the pupil physically with a viscosurgical device. It is possible that other neuromuscular blocking agents, such as rocuronium, would result in more marked pupillary dilation.[18]

Sutureless clear corneal incisions have become the standard of care in routine cataract surgery in humans.[19] However, for various reasons, sutured incision closure is still the norm in veterinary species. Polyglactin 910 sutures were used to close the incisions in 5/10 turtles in this series. The surgeons' choice to use polyglactin 910 was based on availability and comfort level with that multifilament suture in terrestrial patients. This resulted in copious mucopurulent discharge that adhered to the sutures and clear signs of discomfort in all turtles. All of these resolved once the sutures were removed or sloughed. Nylon sutures were placed in one of the cases to see if a different, monofilament suture material resulted in less of a response. Nylon did elicit less of a response, but still required surgical removal of the sutures under anesthesia. In contrast, the four turtles that did not have any sutures placed to close the corneal incision did not show any signs of discomfort and did not develop discharge. The sutureless incisions healed uneventfully. A study comparing tissue reactions to chromic gut, polyglyconate, polyglactin 910, and polyglecaprone used to close skin incisions in loggerhead turtles detected a slightly greater reaction to polyglactin 910 than to the other sutures, but a marked reaction in all.[20] Additionally, environmental temperatures lower than 37°C increase breakdown time for sutures degraded by hydrolysis,[21] explaining the prolonged time required for spontaneous suture sloughing in case 7. Taken together, the authors' experience suggests that there is significantly less morbidity associated with sutureless corneal incisions in loggerhead turtles and corneal incisions that do not require sutures should be created if at all possible.

All turtles appeared to have improved visual function following cataract surgery according to their handlers. This was manifested as an ability to catch live food and track objects crossing their visual field. Interestingly, this improvement was seen even without the placement of an intraocular lens in any of the turtles. Because of a relatively flat cornea, the lens is the major refractive structure in sea turtles while out of water. When under water, due to the similarity in refractive indices between water and cornea, the lens is the only refractive structure.[22] Therefore, after lens removal, and while the turtle is underwater, light rays reach the retina essentially unrefracted. The first consequence of this situation is a markedly defocused image upon the retina. The second consequence is that the image presented to the retina is upright, instead of inverted as it would be in a phakic eye. Thus, immediately after lens removal, the turtle would see the world as upside down compared to previous experience. In now famous experiments using upside-down goggles, humans adapted to a non-inverted retinal image in a matter of days.[23] If, how, or in what time period these adaptations occur in turtles is not known. What does seem apparent, based on the turtles encountered after release in this series, is they are able to function well enough to feed and survive. It is possible visual acuity is improved by the "pinhole" effect caused by the small pupillary opening present in this species, allowing for image formation in the absence of any refractive structures, as is seen in the nautilus.[24]

It is tempting to associate the presence of cataracts with the systemic abnormalities present at the time of rescue. The severe hypoglycemia seen in some of the turtles could theoretically result in the formation of cataracts.[25,26] However, two of the authors (Boylan and Harms) have overseen hundreds of turtles that have been rescued and treated at the two centers. The systemic abnormalities present in the turtles of this series do not represent a marked deviation from what is typically observed. Additionally, the therapies used to treat the systemic abnormalities have been in place for years, making it unlikely that they are associated with the formation of cataracts. Another possible etiology that could account for the systemic disease and the formation of cataracts is heavy spirorchiid infestation.[27,28] Parasitic infections causing cataracts are common in rabbits[29] and have been associated with cataracts in humans.[30] In turtles, the spirorchiid trematode can infest a variety of organ systems[27] and is an important cause of stranding and mortality. It has also been associated with neurological disease.[28] However, the characteristics of the neurological deficits reported are quite different from those seen in the current series. To the authors' knowledge, this parasite has not been associated with the formation of cataracts. Nevertheless, this may be an interesting area for further investigation. Other etiologies potentially responsible for cataract formation include environmental,[31] nutritional,[32] and genetic factors.[33] The first two are difficult to investigate considering the extensive migration and foraging habits these turtles exhibit. The latter seems unlikely since affected animals are likely to face significant negative selection pressure, making them unlikely to survive to breeding age.

In summary, cataract removal using phacoemulsification can be performed in loggerhead turtles and results in improvements in vision even if left aphakic. This vision, based on two cases with follow-up, appears to be sufficient for survival and feeding. Important differences in surgical technique were encountered in the current report and surgeons attempting cataract surgery in loggerhead turtles should be prepared to account for these differences.

REFERENCES

1. NOAA F. Loggerhead Turtle (*Caretta caretta*) [Internet]. [cited 2017 Nov 2]. Available from: http://www.nmfs.noaa.gov/pr/species/turtles/loggerhead.html.
2. Ernst CH, Lovich JE. Loggerhead Seaturtles. In: Ernst CH, Lovich JE eds. *In Turtles of the United States and Canada*. 2nd ed. Baltimore: John Hopkins University Press; 2009: 37–55.
3. Witherington B, Kubilis P, Brost B, Meylan A. Decreasing annual nest counts in a globally important loggerhead sea turtle population. *Ecol Appl*. 2009;19(1):30–54.
4. National Marine Fisheries Service and U.S. Fish and Wildlife Service. *Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtle (*Caretta caretta*), Second Revision*. Silver Spring, MD: National Marine Fisheries Service; 2008.
5. The IUCN Red List of Threatened Species [Internet]. Version 2015–4. [cited 2016 Jun 8]. Available from: www.iucnredlist.org.
6. Hawkes LA, Witt MJ, Broderick AC, et al. Home on the range: Spatial ecology of loggerhead turtles in Atlantic waters of the USA. *Divers Distrib*. 2011;17(4):624–640.
7. Orós J, Torrent A, Calabuig P, Déniz S. Diseases and causes of mortality among sea turtles stranded in the Canary Islands, Spain (1998–2001). *Dis Aquat Organ*. 2005;63(1):13–24.
8. İşler CT, Altuğ M, Cantekİn Z, Özsoy ŞY, Yurtal Z, Devecİ M. Evaluation of the eye diseases seen in Loggerhead Sea turtle (*Caretta caretta*). *Revue Méd Vét*. 2014;165:258–262.
9. Kelly TR, Walton W, Nadelstein B, Lewbart GA. Phacoemulsification of bilateral cataracts in a loggerhead sea turtle (*Caretta caretta*). *Veterinary Record*. 2005;156(24): 774–777.
10. Lively MJ, Westermeyer HD, Harms CA, Christiansen EF.Survey of ophthalmic changes in a population of cold-stunned sea turtles (Chelonia mydas, Lepidochelys kempii, *Caretta caretta*). In: 49th annual conference of the American College of Veterinary Ophthalmologists. Minneapolis, MN; 2018.
11. Avens L, Lohmann KJ. Use of multiple orientation cues by juvenile loggerhead sea turtles *Caretta caretta*. *The Journal of Experimental Biology*. 2003;206(Pt 23):4317–4325.
12. Narazaki T, Sato K, Abernathy KJ, Marshall GJ, Miyazaki N. Loggerhead turtles (*Caretta caretta*) use vision to forage on gelatinous prey in mid-water. *PLoS ONE*. 2013;8(6):1–10.
13. Manire C, Stacy N, Norton T. Chronic debilitation. In: Manire C, Norton T, Stacy B, Innis C, Harms C, eds. *Sea Turtle Health & Rehabilitation*. Florida: Ross Publishing, Plantation; 2017:707–724.
14. Dearworth JR, Cooper LJ. Sympathetic influence on the pupillary light response in three red-eared slider turtles (Trachemys scripta elegans). *Veterinary Ophthalmology*. 2008;11(5):306–313.
15. Eisner G. *Eye Surgery*. 2nd ed. New York: Springer-Verlag; 1990. p. 162.
16. Chittick B, Harms C. Intraocular pressure of juvenile loggerhead sea turtles (*Caretta caretta*) held in different positions. *Vet Rec*. 1954;2001(149):587–589.
17. Gornik KR, Pirie CG, Marrion RM, Wocial JN, Innis CJ, Reptile D. Baseline corneal sensitivity and duration of action of proparacaine in rehabilitated juvenile Kemp's Ridley Sea Turtles (*Lepidochelys kempii*). *Journal of Herpetological Medicine and Surgery*. 2015;25(3):2011–2016.
18. Petritz OA, Sanches-Migallon Guzman D, Gustavsen K, et al. Evaluation of the mydriatic effects of topical administration of rocuronium bromide in Hispaniolan Amazon parrots (Amazona ventralis). *Journal of American Veterinary Medical Association*. 2016;248(1):67–71.
19. Matossian C, Makari S, Potvin R. Cataract surgery and methods of wound closure : a review. *Clinical Ophthalmology*. 2015;9:921–928.
20. Govett PD, Harms CA, Linder KE, Marsh JC, Wyneken J. Effect of four different suture materials on the surgical wound healing of loggerhead sea turtles (*Caretta caretta*). *Journal of Herpetological Medicine and Surgery*. 2004;14(4):6–11.
21. Cannizzo SA, Roe SC, Harms CA, Stoskopf MK. Effect of water temperature on the hydrolysis of two absorbable sutures used in fish surgery. *Facets*. 2016;1:44–54.
22. Northmore D, Granda AM. Ocular dimensions and schematic eyes of freshwater and sea turtles. *Vis Neurosci*. 1991;7:627–635.
23. Stratton GM. Some preliminary experiments on vision without inversion of the retinal image. *Psychol Rev*. 1896;3(6):611–617.
24. Hurley AC, Lange GD, Hartline PH. The adjustable "pinhole camera" eye of Nautilus. *J Exp Zool*. 1978;205(1):37–43.

25. Hull D. Cataract associated with metabolic disorder in infancy. *Proc R Soc Med*. 1969;62(July):694–696.
26. Fagerholm P. Regional sensitivity to hypoglycemia within the rabbit lens epithelium. *Acta Ophthalmol (Copenh)*. 1989;67(1):13–20.
27. Stacy BA, Foley AM, Greiner E, et al. Spirorchiidiasis in stranded loggerhead *Caretta caretta* and green turtles *Chelonia mydas* in Florida (USA): Host pathology and significance. *Dis Aquat Organ*. 2010;89(3):237–259.
28. Jacobson ER, Homer BL, Stacy BA, et al. Neurological disease in wild loggerhead sea turtles *Caretta caretta*. *Dis Aquat Organ*. 2006;70(1–2):139–154.
29. Felchle LM, Sigler RL. Phacoemulsification for the management of Encephalitozoon cuniculi-induced phacoclastic uveitis in a rabbit. *Veterinary Ophthalmology*. 2002;5(3):211–215.
30. Labib MA, Moussa AH, Shalash BA, El-Antably S. Soft cataract in relation to hypoproteinaemia and anaemia. *Bulletin of the Ophthalmologic Society of Egypt*. 1970;63:295–303.
31. Colitz C, Saville W, Renner MS, et al. Risk factors associated with cataracts and lens luxations in captive pinnipeds in the United States and the Bahamas. *J Am Vet Med Assoc*. 2010;237(4):429–436.
32. Waagboø R, Tröße C, Koppe W, Fontanillas R, Breck O. Dietary histidine supplementation prevents cataract development in adult Atlantic salmon, *Salmo salar* L., in seawater. *Br J Nutr*. 2010;104(10):1460–1470.
33. Mellersh CS, Pettitt L, Forman OP, Vaudin M, Barnett KC. Identification of mutations in HSF4 in dogs of three different breeds with hereditary cataracts. *Veterinary Ophthalmology*. 2006;9(5):369–378.

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