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ANIMAL SCIENCE

Eye morphology of Guiana dolphins (*Sotalia guianensis*) and Clymene dolphins (*Stenella clymene*)

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Abstract: Recent studies showed that vision and hearing in dolphins are mechanisms for perception of the environment, and transmission of information among individuals. Considering that Guiana dolphins (*Sotalia guianensis*) are distributed in costal regions, and Clymene dolphins (*Stenella clymene*) are found in oceanic environments, the objective of this study was to compare the morphology of the eyes of these two species, assessing the differences in eye structures in both environments. Five specimens of *Sotalia guianensis* and four specimens of *Stenella clymene* were analyzed. All the specimens were found stranded in the northeastern coast of Brazil. Samples were fixated in 10% formaldehyde, dissected, photographed, processed, and analyzed by optical microscopy. The inferior palpebral region of the two species showed a granular layer, subcutaneous lymphoid tissue, and innervation. Morphometric values of the eyelid structures and eye bulb were greater in *S. clymene*. The cornea showed four layers in *S. clymene*: anterior epithelium, anterior lamina, stroma, and posterior lamina. The sclera of *S. guianensis* showed more melanocytes and presence of mechanoreceptors next to the Harderian gland. It is possible to suggest that the geographical distribution of these cetaceans determine their eye morphology, which is an adaptation to the intrinsic characteristics of the aquatic environment.

Key words: adaptation, aquatic mammals, cetaceans, eye, ocular structures.

INTRODUCTION

Marine mammals have been studied for decades in terms of physiology, pathology, and behavior (Alonso 2008). However, with time, it became important understand their anatomy in order to better comprehend adaptations related to life in aquatic environments (Griebel & Peichl 2003).

In odontocetes, vision and hearing aids the development of mechanisms for the perception of the environment (Coimbra et al. 2007) and transmission of information among individuals and groups (Hetzel & Lodi 1993). In *Sotalia guianensis* offspring, vision contributes to learning behavioral strategies from adults (Monteiro-Filho 1995, Rautenberg 1999, Neto 2000, Domit 2006) and in *Stenella clymene,* the eyes aid animals in their nocturnal feeding habits (Perrin & Mead 1994).

Cetacean eye anatomy is adapted to the optical properties of the aquatic environment, water density, presence of suspended matter, light dispersion, temperature, and luminosity (Mass et al. 2007). The cornea, sclera, vasculature, and ocular muscles are characteristics that help to protect they eyes from the cold subaquatic temperatures, and minimize the effects of pressure in deep regions and mechanical damage caused by diving (Molina 2007, Mass & Supin 2007, Dawson 1988). Harderian and conjunctival glands help to humidify the cornea and protect the eyes from the salinity of the sea, help to reduce friction during fast movements, have a lubricating role, enable thermal insulation, and protect against impurities of the marine environment (Yablokov et al. 1972, Berta & Sumich 1999).

As Clymene dolphin (*Stenella clymene*) is a marine species that inhabits waters from 250 to 5,000 meters deep (Fertl et al. 2003, Reis et al. 2006), and Guiana dolphin (*Sotalia guianensis*) is an animal found in coastal waters between 15 and 30 meters deep (Jefferson 2008, Batista 2008), the objective of this study was to describe and compare the morphology of the eyes of these two species of odontocetes, in order to provide information and to support future studies on cetacean vision.

MATERIALS AND METHODS

Origin of the samples

Ten eyes of *Sotalia guianensis* (nine adult females and a male offspring) and eight eyes of *Stenella clymene* (six adult females, a juvenile male, and a female offspring) were analyzed. Specimens were found stranded and dead in the coasts of the states of Sergipe, Alagoas, and Bahia (Brazil); their carcasses were adequately preserved when found. Samples were collected by the Aquatic Mammals Foundation. Age was determined by the degree of suture closure and closure of the pulp and alveolar cavity, as described for *Sotalia guianensis* (Alves-Júnior & Monteiro-Neto 1999). Adults presented closed pulp and alveolar cavities, and fusion of the tentorium cerebelli, pterygoid, basioccipital, maxila and premaxilla, mesorostral grove, and palate. Juvenile individuals showed intermediate characteristics, such as initial tentorium cerebelli formation, initial closure of pulp and alveolar cavities, and initial suture closure; offspring did not show either suture closure or pulp and alveolar cavity closure.

Macroscopical analysis

After being removed from the orbits, eyes were fixated in formaldehyde 10%, dissected. Structures were measured using a pachymeter, and photographed in the Animal Anatomy Laboratory at College Pius X. Data obtained for each sample were organized in files with the following information: identification of the animal, characteristics of the eyelids, extraocular muscles, vascularization, Harderian glands, and eye bulb, based on cetacean descriptions by Rodrigues et al. (2014a, b).

In the identification of the animal, information about the origin of the samples, such as species, registration number, side of the eye (left or right), carcass preservation status, age, and total body length were recorded. For the eyelids, the following information was recorded: absence or presence of eyelids, description and /or biometry of palpebral structures, such as palpebral fissure and opening, dorsal and ventral sulci, subcutaneous adipose tissue, and skin.

For extraocular muscles information recorded was: type of tissue adhered to the muscle cone (adipose, connective and/or vascular); types of insertion; distribution of oblique muscles, and other characteristics considered important at the moment of dissection. Width of the tendons and distance from the limbus to the insertion of each muscle were also recorded.

As for vascularization, the presence, absence and/or description of visible blood vessels to the Harderian gland, eyelids, eye bulb, extraocular muscles and sclera were recorded. For the Harderian gland, the shape, distribution, location, and visible openings were recorded.

Last, for eye bulb macroscopy, the following items were recorded: shape of the cornea;

color and distribution of the tapetum lucidum; position, shape, and color of the lens; and types of tissue adhered to the optical nerve. Biometry of the eye bulb (length, height, and width); of the cornea (height, width, peripheral and central thickness); of the lens (length, height, and width); and optical nerve (diameter of the optical disk) was also carried out.

After all the files were filled in, data were organized in an Excel sheet and arithmetic means of the morphometrical values were calculated for each species, independently of sex, age, or length of the animal.

Microscopic analyses

For optical microscopy analyses, samples of all structures were dehydrated in alcohol solutions of increasing alcoholic concentration (70% to 100%), diaphanized in butanol, and included in histologic paraffin (Paraplast®). Slides were mounted with transversal, 5µm-thick sections, and stained with Hematoxylin-Eosin (HE) and Gomori Trichrome Stain (TG) in the Experimental Ophthalmology Laboratory at the Animal Morphology and Physiology Department at Federal University of Pernambuco. Slides were photographed and analyzed by light microscopy (Leica DM 500), for analysis of microscopic characteristics and validation of the macroscopic descriptions.

RESULTS

Eyelids

The eyelids in both species showed subcutaneous adipose tissue, palpebral fissure, and palpebral opening. Dorsal and ventral sulci were found only in *Stenella clymene*. Greater length of the sulci towards the palpebral fissure were observed three of ten *Sotalia guianensis* eyes, and in all *Stenella clymene* specimens (Fig. 1ab). Palpebral opening was larger in *Stenella clymene* (1.62 cm) than in *Sotalia guianensis* (1.36 cm) (Table I).

The stratified squamous epithelium of the eyelid epidermis in *Stenella clymene* was made up of five layers: stratum basal, stratum spinosum, granular layer, lucid layer, and corneal layer. These layers were constituted of prismatic cells, cuboidal cells, flat polygonal cells with central nuclei, flat cells with eosinophilic cytoplasm, and flat cells without nuclei, respectively (Fig. 1d). In *Sotalia guianensis*, only the stratum basal, stratum spinosum, lucid layer, and corneal layer were observed (Fig. 1c). Melanin accumulation was found all over the epidermis in both species, especially in the epidermal projections (Fig. 1e).

In all samples, the dermis was made up of vascularized loose connective tissue, with the presence of muscle fibers (*Orbicularis oculi*) and mechanoreceptors placed around the palpebral border (Fig. 1e).

In four samples of *Sotalia guianensis* and in two of *Stenella clymene* a set of nerves was observed in the ventromedial region of the lower eyelid (Fig. 2a, b). These four samples of *Sotalia guianensis* showed vascularized lymphoid tissue surrounding the muscle cone and stretching towards the orbit (Fig. 2c, d, e).

The conjunctival membrane showed stratified pavement epithelium and lamina propria made up of vascularized loose connective tissue covering the anterior region of the sclera and the internal surface of the eyelids in the two species.

Table I. Morphometry of eyelid structures in *Sotalia guianensis* (Sg) and *Stenella clymene* (Sc), in centimeters.

EP	SD	SV	FP	AP	TAS	PE
Sg	**	**	1.88	1.36	0.65	0.05
Sc	1.86	1.33	2.11	1.62	0.74	0.09

EP = species; SD = dorsal sulcus; SV = ventral sulcus; FP = palpebral fissure; AP = palpebral opening; TAS = subcutaneous adipose tissue; PE = skin; (**) absent.

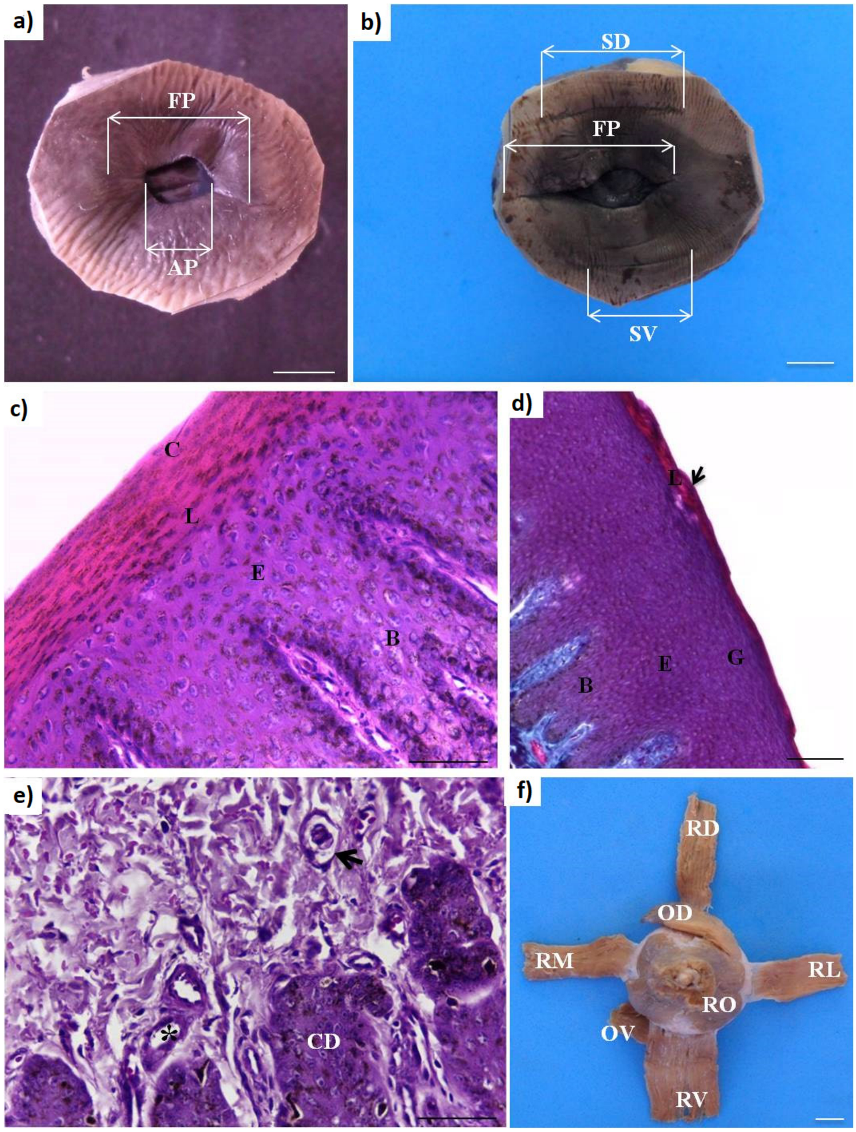

Figure 1. a) and **b)** Lateral view of the eyelid of *Sotalia guianensis* and *Stenella clymene*, respectively. FP – Palpebral fissure; AP –palpebral opening; SD – dorsal sulcus; SV – ventral sulcus. Bars: 1 cm. **c)** and **d)** Strata of the eyelid epidermis of *Sotalia guianensis* and *Stenella clymene*, respectively. C – cornea; L – lucid layer; G – granular layer; E – stratum spinosum; B – stratum basal. Bars: 50 µm and 100 µm. HE and Gomori Trichrome stain, respectively. **e)** Vascularized dermis with mechanoreceptor (arrow) near the dermal projections (CD). Bar: 50 µm. HE. **f)** Extraocular muscles in *Stenella clymene*. RM – Medial Rectus; RL –lateral rectus; RD –dorsal rectus; RV –ventral rectus; RO – *retractor bulbi*; OV –ventral oblique; OD –dorsal oblique. Bar: 1 cm.

Extraocular muscles

The eyes analyzed were made up of seven, partially fused, extraocular muscles (four recti, two oblique muscles, and a retractor muscle) that surrounded the posterior pole of the eye bulb and stretched toward the orbit, forming a cone. These muscles showed laminar insertions on the sclera. Lateral and medial recti were symmetrical in relation to the eye bulb, both anteriorly and posteriorly. At the insertion, these muscles were wider in *Stenella clymene* than in *Sotalia guianensis*, ranging from 1.01 to 1.84 cm and 0.69 to 1.13 cm, respectively (Table II).

In both species, the ventral rectum was inserted anteriorly to the equator of the eye bulb by means of two tendons. The ventral oblique muscle was inserted between these tendons. The dorsal oblique muscle stretched forward to the dorsomedial wall of the orbit before going around some dense connective tissue (similar to the trochlear cartilage), and ended on the dorsolateral face of the eye bulb, below the tendon of the dorsal rectum (Fig. 1f). The

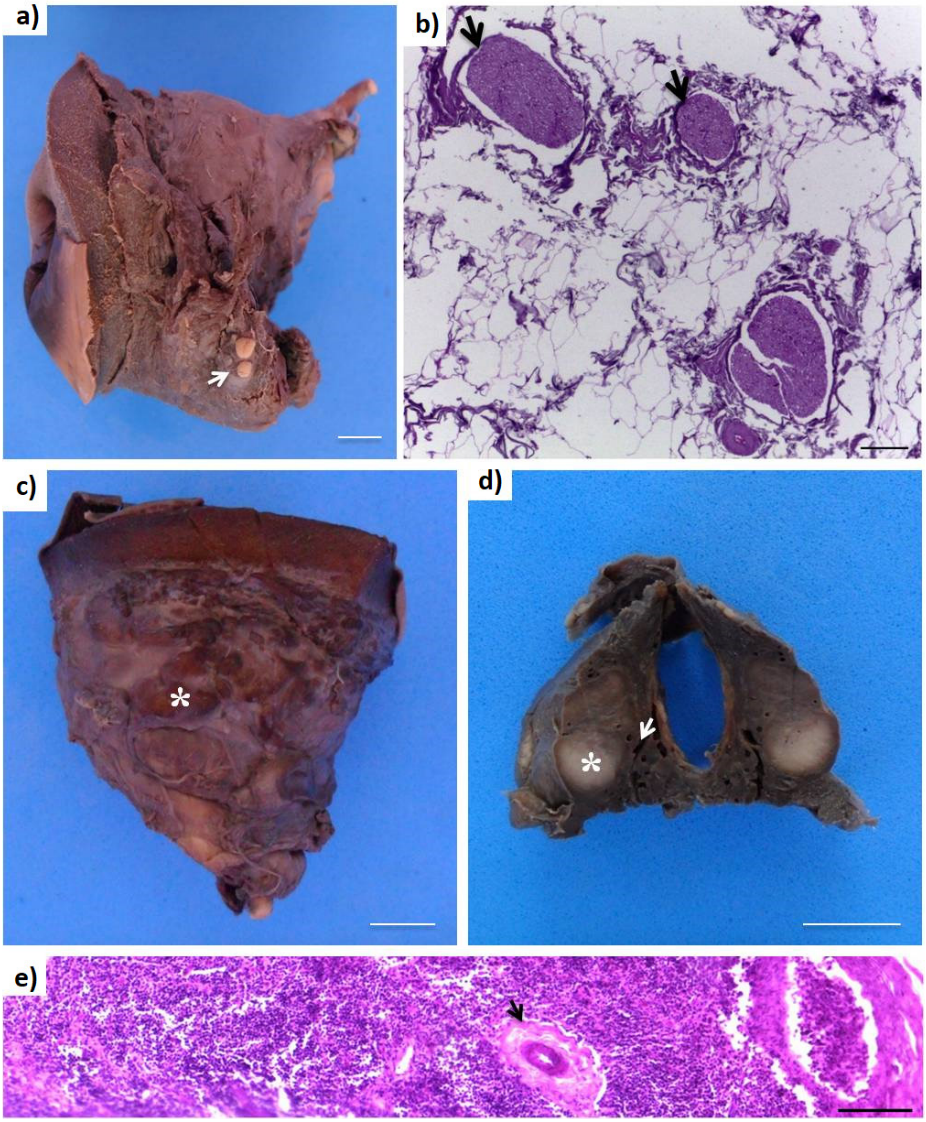

Figure 2. a) and **b)** Medial view of the nerves (arrows) located in the ventromedial region of the lower palpebra of *Sotalia guianensis*. Bars: 1.9 cm and 100 µm. **c), d)** and **e)** Dorsal view of the lymphoid tissue (asterisk) vascularized (arrow) on the base of the muscle cone. Bars: 1 cm and 100 µm, respectively.

Orbicularis oculi was found next to the internal surface of the eyelid and was permeated by dense connective tissue.

Although not found in humans, and described as an incomplete muscle cone in some mammals, the *Retractor bulbi* was inserted posterior to the equator of the eye bulb and formed a muscle cone around the optical nerve. The cone was made up of four muscle bundles, except in one *Sotalia guianensis* specimen, which showed three bundles. The largest bundle was found in the dorsal region, but it could also be found in the ventral region in *Stenella clymene* (Fig. 1f). In the optical foramen region, the lateral and medial bundles could be partially fused in *Sotalia guianensis*.

Glands

The conjunctival gland was flat and surrounded by the upper and lower eyelids (Fig. 3b) in both species. In *Sotalia guianensis* specimens, the Harderian gland emerged in four different regions (Fig. 3a), and in *Stenella clymene*, it emerged in only one region (Fig. 3b).

Table II. Length of extraocular muscles at their insertions, in centimeters.

EP	LT						DL					
	MRD	MRV	MRM	MRL	MOD	MOV	MRD	MRV	MRM	MRL	MOD	MOV
Sg	0.77	1.08	0.69	0.75	1.13	0.92	0.51	0.50	0.39	0.33	0.66	0.54
Sc	1.27	1.84	1.05	1.01	1.31	1.29	0.73	0.87	0.63	0.57	0.90	0.78

Sg = *Sotalia guianensis*; Sc = *Stenella clymene*; EP = species; LT = width of the tendons in insertion in the sclera; DL = Distance from the limbus to the insertion in the sclera; MRD = dorsal rectum; MRV = ventral rectum; MRM = medial rectum; MRL = lateral rectum; MOD = dorsal oblique; MOV = ventral oblique.

The conjunctival gland was made up of serous cells, and the Harderian gland was made up of mucous cells in both species. Gland lobes were separated by septa made up of connective tissue from the capsule. Septa contained nerve fibers, collecting ducts, blood and lymph vessels. In spite of these similarities, only *Sotalia guianensis* showed mechanoreceptors in the connective tissue surrounding the Harderian gland (Fig. 3c).

General characteristics of the eye bulb

All the samples analyzed showed eye bulbs made up of three tunics (fibrous, vascular, and nervous tunics) (Fig. 4), anterior chamber, posterior chamber, and lens. Morphometry of the eye bulb structures in *Stenella clymene* showed they were larger than those of *Sotalia guianensis*, ranging from 2.20 to 3.34 cm and 1.73 to 2.50 cm, respectively (Table III). Due to the small number of samples, it was not possible to draw a conclusion on the proportion between the size of the animal and the size of the eye bulb in these species.

Nervous tunic

The nervous tunic (retina) was vascularized and represented an extension of the optical nerve. It was irrigated by branches of the central retinal artery in both species. Microscopically, it was made up of ten layers: pigmented epithelium, layer of rods and cones, outer limiting membrane, outer nuclear layer, outer plexiform layer, inner nuclear layer, inner plexiform layer, ganglionic layer, layer of nerve fibers, and inner limiting membrane (Fig. 4b).

Vascular tunic

All samples showed a vascular tunic made up of the choroid, ciliary body, and iris. The choroid was made up of the *lamina suprachorioidea* with melanocytes spread over a net of connective tissue; the *lamina vasculosa*; the tapetum lucidum; and the capillary plexus with capillaries distributed over a single plane (Fig. 5c), stretching from the ring around the optical nerve to the ciliary body (Fig 6b). Although not quantified, it seemed that, in2 the offspring, there were more vessels in this layer in both species, when compared to older animals.

In the two species, the tapetum lucidum took around 2/3 of the fundus. In *Sotalia guianensis*, it was greenish blue (Fig. 5b) and in *Stenella clymene*, it was blue (Fig. 5a). In both species, the tapetum lucidum was rich in collagen fibers and was located between the choroidal capillary plexus and the *lamina vasculosa* (Fig. 5c).

The ciliary body projected ciliary crests (ciliary processes) (Fig. 5e), was covered by pigmented epithelium (Fig. 5d), and its stroma presented melanocytes and capillaries spread over loose connective tissue (Fig. 5d) in all samples. The ciliary muscle was absent in both species.

The iris was a plane ring suspended between the cornea and the crystalline, in both species. It was covered by pigmented epithelium and, internally, it was made up of blood vessels,

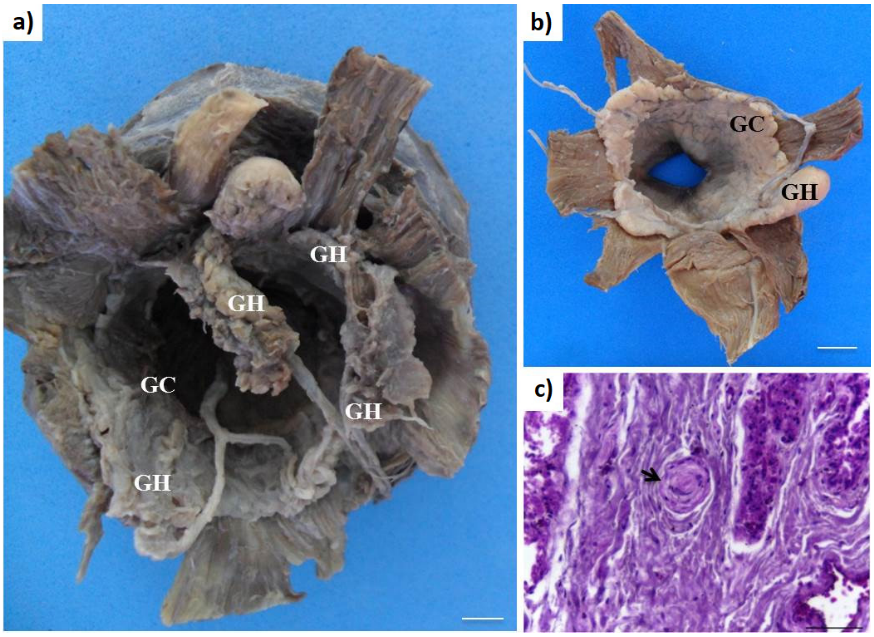

Figura 3. a) Caudal view of the Harderian gland (GH) and conjunctival gland (GC) in *Sotalia guianensis*. Bar: 1 cm. **b)** Conjunctival gland (GC) and Harderian gland in (GH) *Stenella clymene*. Bar: 1 cm. **c)** Mechanoreceptor (arrow) immersed in connective tissue of the Harderian gland in Guiana dolphin. Bar: 50 µm. HE.

Table III. Morphometry of the eye bulb, in centimeters.

EP	GO			CO				LE			ES		NO
	CC	AL	LR	AL	LR	ESP	ESC	CC	AL	LR	MAE	MEE	DI
Sg	1.73	2.36	2.50	1.35	1.56	0.13	0.04	0.66	0.71	0.68	0.31	0.08	0.17
Sc	2.20	3.02	3.34	1.84	2.20	0.12	0.03	0.80	0.92	0.90	0.37	0.05	0.29

Sg = *Sotalia guianensis*; Sc = *Stenella clymene;* EP = species; GO = eye bulb; CO = Cornea; LE = Lens; ES = sclera; NO = optic nerve; CC = length (lateromedial); AL = height (dorsoventral); LR = width (anteroposterior); ESP = peripheral thickness; ESC = central thickness; MAE = maximum thickness; MEE = minimum thickness; DI = diameter.

nerves, melanocytes, and the iris dilator muscle (Fig. 5f). All structures were immersed in loose connective tissue.

Fibrous tunic

In the samples analyzed, the fibrous tunic was composed by the sclera and the cornea, which were united in the limbus. In both species, the cornea was oval and convex (Fig. 6a) and in *Stenella clymene*, it was formed by four regions: anterior epithelium, anterior lamina, stroma, and posterior lamina (Fig. 6c, d). The anterior epithelium was stratified pavement epithelium; the anterior lamina was a thick homogenous layer; the stroma was made up of collagen fibers distributed in parallel, from one layer to the other; the posterior lamina was made up of collagen fibrils. In *Sotalia guianensis*, the only regions observed were the anterior epithelium, anterior lamina, and stroma. The posterior epithelium was not observed in any of the species.

In the eye bulb region, the sclera surrounded the optical nerve in both species (Fig. 6b). In the anterior region of the eye bulb, it was covered by stratified squamous epithelium (Fig. 6f). In *Sotalia guianensis*, the Tenon capsule was observed (Fig. 6e). Mechanoreceptors and melanocytes were found in the vascularized lamina propria of *Stenella clymene*, and were absent in *Sotalia guianensis* (Fig. 6f). The stroma was made up of a net of dense connective tissue

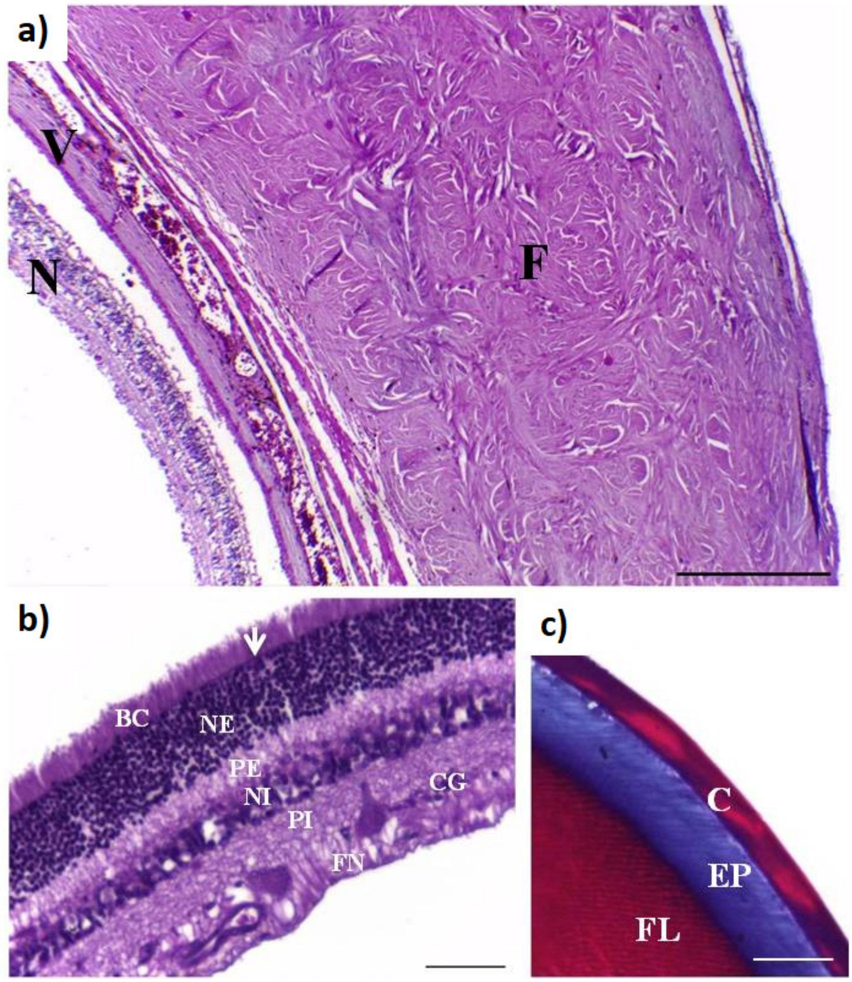

Figure 4. a) Tunics of the eye in *Sotalia guianensis*: fibrous (F), vascular (V) and neural (N). **b)** Retinal layers: rod and cone layer (BC), outer limiting membrane (arrow), outer nuclear layer (NE), outer plexiform layer (PE), inner nuclear layer (NI), inner plexiform layer (PI), ganglionic layer (CG), and nerve fiber layer (FN). Bar: 50 µm. HE. **c)** Lens capsule (C), lens epithelium (EP), lens fibers (FL). Bar: 100 µm. TG.

with melanin accumulation in some regions. In *Sotalia guianensis*, melanin accumulation was more intense (Fig. 6g, h).

Lens

The lens (Fig. 6b) was shaped like an ellipse and made up of three layers: capsule, epithelium, and fibers of the lens, in both species (Fig. 4c). The capsule was acellular, homogeneous, and had a hyaline lining; epithelium was simple, cuboid, and fibers were parallel to each other, perpendicular to the surface of the lens.

Anterior and posterior chambers

In *Sotalia guianensis* and *Stenella clymene*, the anterior chamber (between the cornea and iris) and the posterior chamber (between the iris and the crystalline) communicated through the pupil and were filled by aqueous humor. The vitreous chamber, located between the lens and the retina, was filled by transparent and gelatinous vitreous humor.

Optical nerve

The optical nerve exited the sclera in the optical disk towards the external region of the eye bulb (Fig. 6b), falling upon the orbit in all samples. The area of a longitudinal section of the optical disk in *Sotalia guianensis* measured around 0.17 cm and in *Stenella clymene*, 0.29 cm (Table III). In both species, the nerve went in a retroocular direction and entered the adipose tissue of the orbit. It was characterized by the presence of myelinated fibers surrounded by loose

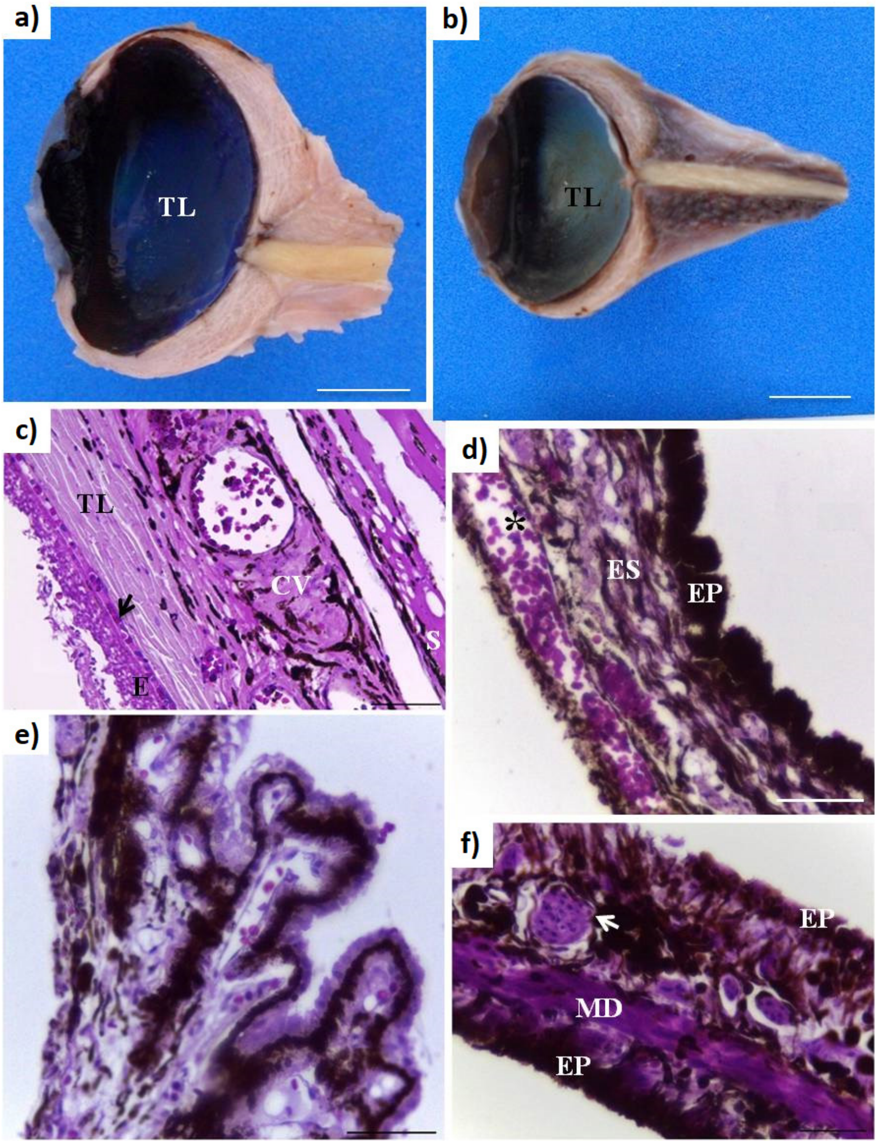

Figure 5. a) and **b)** Median section for the visualization of the tapetum lucidum in *Stenella clymene* and *Sotalia guianensis*, respectively. Bars: 1 cm. **c)** *Lamina suprachorioidea* (S), *lamina vasculosa* (CV), tapetum lucidum (TL), capillary plexus (arrow), and pigment epithelium (E). Bar: 100 µm. HE. **d)** Pigment epithelium (EP) and vascularized (asterisk) stroma (ES) of the ciliary body. Bar: 50 µm. HE. **e)** Ciliary processes. **f)** *Dilator pupilae* (MD), iris pigment epithelium (EP) and innervation (arrow). Bar: 50 µm. HE.

connective tissue and branches of the internal and external ophthalmic artery.

Vascularization

A neurovascular plexus separated the recti and oblique muscles from the *retractor bulbi*, and penetrated the conjunctival gland in the eyelid in four different regions, vascularizing the Harderian gland and the muscles of the eyes in all samples. Branches of the external ophthalmic artery to the eye bulb penetrated the sclera, originating the long posterior ciliary and anterior ciliary arteries (Fig. 6a).

DISCUSSION

Sotalia guianensis is a species of coastal habits, found in bays, coves, estuaries, and areas close to mangroves. It is found from the Northern coast of Honduras, in the Caribbean, to the state of Santa Catarina, in Brazil (Silva & Best 1996, Simões-Lopes 1988, Carr & Bonde 2000, Torres & Beasley 2003). Differently, *Stenella clymene* is an oceanic

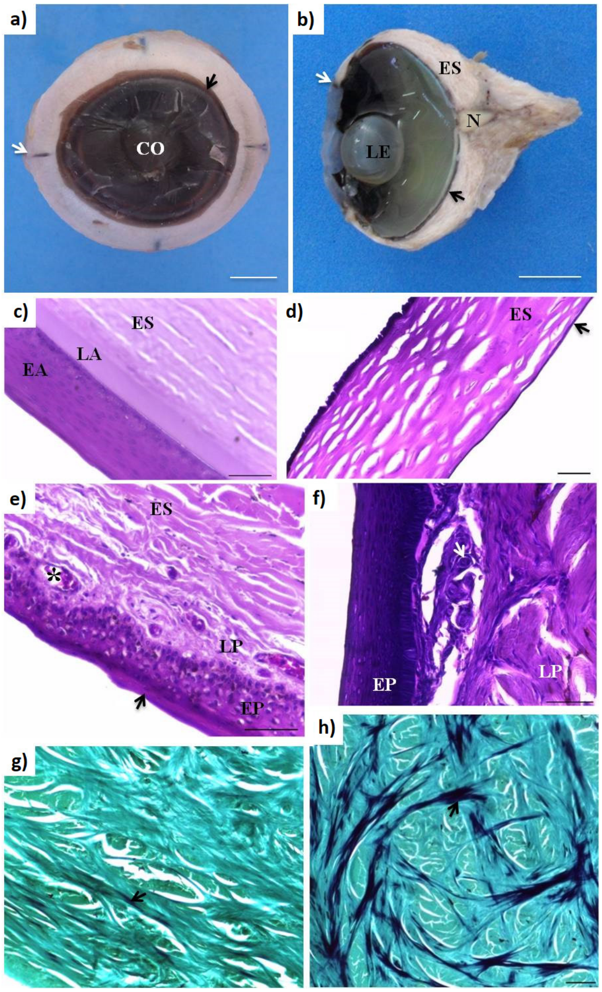

Figure 6. a) Dorsal, ventral, rostral and caudal vascularization (white arrow) of the cornea (CO) in the limbus region (black arrow). Bar: 1 cm. **b)** Median section for the visualization of the internal structures of the eye. LE – lens; ES – sclera; N – optical nerve; black arrow – choroid; white arrow– limbus. Bar: 1 cm. **c)** anterior epithelium (EA), anterior lamina (LA), and stroma (ES) of the cornea. Bar: 50 μm. HE. **d)** Stroma (ES) and posterior lamina (arrow) of the cornea in *Stenella clymene*. Bar: 50 μm. HE. **e)** Tenon capsule (arrow), squamous epithelium (EP), vascularized (asterisk) lamina propria (LP) and stroma (ES) of the sclera in Guiana dolphin. Bar: 50 μm. HE. **f)** Presence of mechanoreceptors (arrow) in the lamina propria (LP) of the sclera in *Stenella clymene*. EP – epithelium. Bar: 50 μm. HE. **g)** and **h)** Stroma of the sclera in *Sotalia guianensis* and *Stenella clymene* with melanin accumulation (arrow), respectively. Bar: 100 μm. TG.

dolphin that is found in hot, temperate waters in the South and North Atlantic (Fertl et al. 2003).

In these regions, *Stenella clymene* is subjected to the wide thermal amplitude (Pinto & Netto 2008) and, in cetaceans, the dimensions of the eyes may be related to protection and thermal insulation (Mass & Supin 2007). Considering these characteristics, and the fact that morphometric results for the eye bulb, width of extraocular muscles, and eyelid structures in *Stenella clymene* were greater than those of *Sotalia guianensis*, it may be suggested that these differences result from adaptations to the environment where these animals live. However, some authors suggest that the size of the eyes is directly related to visual acuity and sensitivity, once larger eyes have greater areas for reception of light in the retina (Prince 1960, Walls 1967, Carpenter 1977).

The presence of dorsal and ventral sulci observed in *Stenella clymene* was also identified in bowhead whales (*Balaena mysticetus*) (Zhu et al. 2001), southern right whales (*Eubalaena australis*) (Buono et al. 2012), and humpback whales (*Megaptera novaeangliae*) (Rodrigues et al. 2014b). According to Dawson (1988) and Kroger & Kirschfeld (1994), eyelid thickness may serve as thermal insulation and aid in the protection of the cornea against the pressure exerted by swimming. Findings of the present study suggest that the sulci and the caudal extension of the palpebral fissures found in *Stenella clymene* may serve as thermal insulation against wide variations in temperature.

Spearman (1972, 1964) reported the absence of a granular layer in the epidermis of cetaceans. This author also states that the loss of this layer is related to the absence of pilous follicles in these animals, and that the transition between the stratum spinosum and the corneal layer is more gradual in cetaceans than in other mammals. However, in the present study, and in the study by Rodrigues et al. (2014b) in humpback whales, this layer was observed in the epidermis of the eyelid.

Melanin acts in photoprotection, absorbing most of the ultraviolet radiation (UV) and protecting the epidermis from sunburn and DNA damage (Lin & Fisher 2007). It was observed, in the present study, that *Sotalia guianensis* showed more melanin accumulation in the sclera than *Stenella clymene*. This difference may be related to the coastal habits of the *Sotalia guianensis*, which increases the probability that the animal is closer to the surface of the water and receives more UV radiation due to lower atmospheric refraction.

In most terrestrial mammals, the dorsal oblique extraocular muscle changes direction near a cartilage. However, it was absent in the specimens analyzed in the present study, as well as in bowhead whales (*Balaena mysticetus*). In this latter species, dense connective tissue derived from the musculature is found in place of the cartilage and has the same role, according to Zhu et al. (2000).

In the present study, it was observed that branches of the external ophthalmic artery to the eye bulb penetrated the sclera, originating the long posterior ciliary and anterior ciliary arteries. Superficial, macroscopic vascularization may be related to protection against pathogens (Molina 2007, Bauer et al. 2003). According to Samuelson et al. (1994, 1997), this vascularization may negatively affect vision, which generates discussions on differences of visual capacity in aquatic mammals.

In vertebrates, the tapetum lucidum shows diverse structure, color, organization and composition. It may vary according to the species, breed, age color and amount of pigment in the eyes and skin (Ollivier et al. 2004). This structure is found in all cetaceans (Mass & Supin 2007, Miller et al. 2013), and may be spread all over the fundus (Waller 1984), or only in two thirds of it (Dawson 1988, Rodrigues et al. 2014a), as observed in *Sotalia guianensis* and in *Stenella clymene*. As *Sotalia guianensis* is an animal of coastal and estuarine habits (Jefferson 2008), where waters are more turbid and incidence of light is considerably lower than in the ocean, it is suggested that the distribution of this structure is larger in *Stenella clymene* to increase retinal sensitivity. According to Mass & Supin (2007), in spite of the differences, the tapetum lucidum acts as a reflexive layer that works at low levels of luminosity. Therefore, when it is found all over the fundus, it is an indication that the eye bulb is highly sensitive to light (Griebel & Peichl 2003) or that it aids in the visualization of the tridimensional environment in which these aquatic mammals live (Ollivier et al. 2004).

The layers of collagen fibers in the tapetum lucidum reflect light to the retina, and they are thicker in the posterior extremity in Dall's porpoises (*Phocoenoides dalli*) (Mass & Supin 2007, Murayama et al. 1995). In cetaceans, the tapetum lucidum is fibrous, as observed in the present study; differently, in pinnipeds, the tapetum lucidum is a cellular structure (Bjerager et al. 2003, Miller et al. 2010, Ollivier et al. 2004, Gatesy et al. 1999).

The presence of mechanoreceptors observed in the eyes of *Sotalia guianensis* and *Stenella clymene* was also reported by Wickham (1980), Miller et al. (2010, 2013), and Rodrigues et al. (2014b) in different cetacean species. Although their role is uncertain (Hatfield et al. 2003, Wickham 1980, Vrabec 1972), it is suggested that these nerve endings act as receptors to maintains intraocular pressure stable in the aquatic environment (Hatfield et al. 2003, Wickham 1980, Vrabec 1972). Wickham (1980) observed that the location of these structures in the eyes of odontocetes vary according to the species. Rodrigues et al. (2014b) observed these structures in the eyelids of humpback whales, similar to the findings of the present study, which found mechanoreceptors in eyelids, glands, and sclera. Miller et al. (2013) reported that these structures were absent in northern right whale dolphins (*Lissodelphis borealis*), long-beaked common dolphins (*Delphinus capensis*), and rough-toothed dolphins (*Steno bredanensis*). However, the presence of these nerve endings cannot be ruled out in other parts of the eye bulb, as only one region was analyzed.

CONCLUSIONS

The exposure of *Stenella clymene* to wide thermal amplitudes in the temperate zone, when compared to the exclusively tropical habits of *Sotalia guianensis,* may explain the larger dimensions of their eyes and palpebral sulci (which increase eyelid thickness), showing a role in thermal insulation.

Coastal habits of *Sotalia guianensis* justify greater accumulation of melanin in the sclera, as these animals receive greater amounts of UV radiation in coastal regions with their shallow waters compared to the oceanic regions inhabited by *Stenella clymene*.

Therefore, in the present study, the evaluation of eye structures of *Sotalia guianensis* and *Stenella clymene* showed that these structures may be influenced by several factors, such as thermal amplitude, thermal insulation, water turbidity, and reception of UV radiation in shallow waters.

Given the importance of investigating adaptations in order to better understand these animals, it is necessary to identify the function of structures observed in the present study that were not seen in other cetaceans, such as subcutaneous lymphoid and nervous tissues (located in the lower palpebral region), granular palpebral layers, and mechanoreceptors close to the Harderian gland.

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