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ORIGINAL ARTICLE

Clinical findings and normative ocular data for free-living Anna's (*Calypte anna*) and Black-chinned (*Archilochus alexandri*) Hummingbirds

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Abstract

Objective: To estimate the prevalence of ocular disease and obtain normative ocular data for free-living hummingbirds.

Animals studied: Two hundred and sixty-three free-living, adult Hummingbirds from coastal and inland central California were studied, including Anna's (*Calypte anna*, n = 186) and Black-chinned (*Archilochus alexandri*; n = 77) hummingbirds.

Procedures: Slit lamp biomicroscopy and indirect ophthalmoscopy were performed on all individuals. Rebound tonometry, measurement of horizontal palpebral fissure length, and streak retinoscopy were performed on select individuals. Five conscious Anna's Hummingbirds underwent ocular imaging including fundus photography, digital slit lamp photography, and anterior segment and retinal optical coherence tomography.

Results: The prevalence of ocular disease in this population was 2.28%. Ocular imaging revealed a thin cornea, shallow anterior chamber, large lens, and a single central, deep convexiclvate fovea. Mean $\pm$ SD intraocular pressure was 11.21 ± 2.23 mm Hg. Mean $\pm$ SD eyelid length was 2.59 ± 0.19 mm. All eyes were emmetropic or mildly hyperopic with a mean (range) $\pm$ SD refractive error of $+0.32$ (-0.25 to $+1$) ± 0.33 diopters.

Conclusions: Consistent with previous reports, these data suggest that hummingbirds have visual characteristics found in predatory and prey species, as well as a low prevalence of spontaneous ocular disease. This work provides a set of reference values and clinical findings that can be used in the future research on hummingbird vision and ocular disease. It also provides representative diagnostic images of normal birds and demonstrates that advanced ocular imaging can be performed on manually restrained hummingbirds without pharmacologic dilation.

KEYWORDS

avian, bird, eye, fovea, poxvirus

1 | INTRODUCTION

Hummingbirds are small birds that have received considerable attention in part because they are the only group of birds that use hovering flight.^{1,2} The intricate flight behavior and maneuverability of hummingbirds during flight have led to an interest in hummingbird vision, although studies of the ocular anatomy and physiology of the hummingbird eye are limited to a few descriptions of retinal architecture and spectral sensitivity,^{3,4} visual fields (LP Tyrrell, personal communication), and central vision.⁵⁻¹¹ Hummingbirds were initially reported to possess two foveae in each retina,¹² although recent studies on retinal architecture suggest that hummingbirds have a single central fovea and a temporal area centralis (LP Tyrrell, personal communication).⁴ Hummingbirds have a well-developed visual system enabling successful performance of a number of visually demanding tasks such as precision foraging,^{1,13,14} high-velocity, agile flight,^{2,13,15} and intraspecies communication.^{3,14,16,17} Given their visually dominated lifestyle, their survival is likely critically dependent on their ability to process visual information at a high level and increased mortality might be expected in visually compromised individuals.

General disease prevalence in free-living hummingbirds is infrequently reported.¹⁸ In one report of 27 000 wild-caught hummingbirds, systemic evaluation revealed an extremely low incidence of abnormalities (0.1%), with the most common physical abnormalities being proliferative lesions suspected to be related to avian poxvirus (16 individuals) and various bill injuries (11 individuals).¹⁴ Avian poxvirus is known to result in ocular and periocular lesions and has been isolated in Anna's Hummingbirds, but its morbidity and mortality, and overall impact on migratory and stationary populations, is unknown.^{19,20} Mites and other external parasites are commonly detected in free-living hummingbird populations¹⁴ and can also have ocular consequences (eg, chorioretinal atrophy),²¹ but typically have little effect on general health. To the authors' knowledge, the prevalence of ocular disease in hummingbirds has not been reported. This may be because visual compromise results in rapid removal of individuals from the population through metabolic demise and/or predation, or because of limited expertise with and access to specialized ophthalmic equipment at wildlife rehabilitation centers. The limited number of clinical ocular diagnoses may also result in few eyes for these birds being submitted for histopathologic examination.

Although an important tool for studying naturally occurring ocular disease, clinical surveys of ocular disease in free-living avian populations are rarely reported.^{22,23} More frequently, reports of ophthalmic findings in wild birds

describe those presented to veterinary clinics and rehabilitation centers,²⁴⁻²⁷ or selected so as to describe specific disease conditions.²⁸ However, findings of such studies are likely not representative of ocular disease prevalence in free-living avian populations.

The goals of this study were to perform a survey of the prevalence of ocular lesions in free-living hummingbirds in Northern California, to provide normative ocular findings and values for the hummingbird eye, and to conduct a pilot study assessing the utility of advanced imaging techniques in manually restrained hummingbirds without the use of sedation, anesthesia, or pharmacologic pupil dilation. Results provide a reference for examining hummingbirds which may guide future studies in clinical ophthalmology and visual ecology of hummingbird species.

2 | MATERIALS AND METHODS

Anna's (*Calypte anna*) and Black-chinned Hummingbirds (*Archilochus alexandri*) ranging in body weight from 4-4.5 to 2.3-4.9 g, respectively, were chosen for this study due to their calm demeanor during handling and their relative abundance and distribution across the Pacific coast of California.^{14,29} A total of 263 hatch-year and after-hatch-year hummingbirds (186 Anna's and 77 Black-chinned Hummingbirds) were captured using Hall traps at feeders set at the University of California, Davis arboretum teaching nursery (38°31'49.6"N 121°76'20.2"W) or two urban backyard locations in coastal (Inverness; 38°04'40.5"N 122°45'42.3"W) and inland (Winters, 38°32'03"N, 121°50'37"W) central California. All capture, handling, and ophthalmic procedures were approved by the institutional animal care and use committee of the University of California-Davis and were conducted under authorization of federal and state scientific permits (LAT; USGS BBL Permit #23947, US Fish and Wildlife Permit MB55944B-2 and California Department of Fish and Wildlife SC-013066). Birds were aged according to the presence/absence of beak corrugations, secondary remige shape, and the presence/absence of buffy feathers.³⁰ Females and males of both species were distinguished by color dimorphism when obvious, or by color of outer tail retrices.^{14,31}

All hummingbirds were briefly examined for the presence of identification bands and for signs of obvious physical distress or illness (eg, distended coelom, open-beak breathing, emaciation, feather loss, etc.). Only animals considered well-conditioned and capable of being safely examined were evaluated further; all others were immediately released. Each hummingbird was restrained inside a 1-inch

piece of foam pipe insulation that was cut so as to safely contain birds of this size and allow for ophthalmic examination and imaging. Every ophthalmic examination was performed by one of three trained examiners (BAM, CJM, SK). The menace response was evaluated using hand motions, kept lateral to the head so as to minimize stimulation of the contralateral eye. Pupillary light reflexes (PLRs) were evaluated with a diffuse light beam from a slit lamp (Kowa SL-15, Kowa, Tokyo, Japan) set at the highest intensity setting. Slit lamp biomicroscopy and binocular indirect ophthalmoscopy (Keeler All Pupil II LED Vantage Plus Wireless Headset, Keeler Instruments Inc, Broomall, PA, USA, and 90 D handheld lens, Volk Optical Inc, Mentor, OH, USA) were performed in both eyes of all birds in dim lighting without pharmacologic pupil dilation. Intraocular pressure (IOP) was estimated via rebound tonometry (Tonolab, Icare Finland Oy, Vantaa, Finland). Horizontal palpebral fissure length from medial to lateral canthus across the shortest route was measured using calipers accurate to 0.1 mm (Dial Calipers, Mitutoyo Corp., Japan). Streak retinoscopy was performed using a streak retinoscope and retinoscopy bars (Welch-Allyn, Skaneateles Falls, New York).

Ophthalmic imaging without pharmacologic pupil dilation was performed on five conscious adult Anna's Hummingbirds as follows. Fundus photographs (Micron III, Phoenix Research Laboratories, Candler, NC, USA) and digital slit lamp images (Haag-Streit BQ900, Switzerland) were obtained. The cornea, anterior chamber, iris, and anterior lens were imaged with Fourier-domain optical coherence tomography (FD-OCT, RTVue[®] 100, software version 6.1; Optovue Inc., Fremont, CA, USA; 26000 A scan/sec, 5 μ m axial resolution, 840 nm superluminescent diode). Measurements of central corneal thickness, peripheral corneal thickness, corneal diameter, pupil diameter, and maximum anterior chamber depth were obtained manually using the OCT software caliper function. Retinal OCT was performed on a single Anna's hummingbird using a Bioptogen (Leica Microsystems Inc., Buffalo Grove, IL, USA). Thickness of the total retina, nerve fiber layer, retinal ganglion cell layer, inner plexiform layer, combined inner nuclear, outer plexiform, and outer nuclear layers, inner segments, outer segments, and retinal pigmented epithelium, as well as maximum foveal width, and maximum foveal depth were manually measured using the OCT software caliper function.

The results are expressed as mean values $\pm$ standard deviation (SD). Statistical analysis for comparing mean between species was performed using a paired Student's *t*-test and were expressed as estimated mean and 95% confidence intervals where $P < .05$ was considered significant.

3 | RESULTS

3.1 | Normative findings

In total, 263 hummingbirds (526 eyes) were examined (116 females and 147 males). Results are summarized in Table 1. A greater number of Anna's Hummingbirds were examined (186) than Black-chinned Hummingbirds (77). A menace response was not elicited in any bird tested. Direct PLRs were brisk and complete, with a rapid partial return to resting pupil diameter following initial constriction. An apparent consensual PLR was only observed when a focal light source was directed through the pupil toward the medial plane. The globes were laterally placed with at least one eye visible across the majority of their visual field and both eyes visible when viewed from above the head and below the bill (Figure 1). Binocularity was not measured but was subjectively small ($<20^\circ$ maximum) based on observations of eye position. The typically small globe movements expected of hummingbirds were observed in every bird throughout the examination.

The normal appearance of the eyes and adnexa of Anna's and Black-chinned Hummingbirds is illustrated in Figure 2. Darkly pigmented, featherless eyelid margins were surrounded by small distinct rimal feathers. The superior and inferior eyelids conformed tightly to the corneal surface. Movement of the upper and lower eyelids was not observed in any of the birds under restraint. Movement of the nictitating membrane was observed infrequently in many birds, only when it was swept laterally across the globe. The nictitating membrane was translucent except at the leading edge which was pigmented. It contained a fine vascular network. The sclera, limbus, and conjunctiva were

TABLE 1 Mean $\pm$ SD intraocular pressure, horizontal palpebral fissure length, and refractive error in free-living Anna's (*Calypte anna*; ANHU) or Black-chinned (*Archilochus alexandri*; BCHU) Hummingbirds captured (and subsequently released) in coastal and inland central California

	Measured values			
	Total Birds/Eyes	ANHU Birds/Eyes	BCHU Birds/Eyes	P-value
Intraocular pressure (mm Hg)	11.12 $\pm$ 2.20 183/362	11.55 $\pm$ 2.41 140/274	10.19 $\pm$ 0.91 43/85	<.01
Palpebral fissure length (mm)	2.59 $\pm$ 0.19 54/108	2.71 $\pm$ 0.17 26/52	2.49 $\pm$ 0.14 28/56	<.01
Refractive error (D)	+0.32 $\pm$ 0.33 19/38	26/51 19/38	- -	-

FIGURE 1 Frontal (A,B) and dorsal (C,D) views of the head of an after-hatch-year male Anna's Hummingbird (A,C,D) and an after-hatch-year male Black-chinned Hummingbird (B)

FIGURE 2 External photographs of normal right (A) and left (B) eyes and ocular adnexa of an after-hatch-year female Anna's Hummingbird. Note the small rimal feather units surrounding the featherless eyelid margins; the dark brown iris; and central circular pupil

completely covered by the eyelids, and not observed. The cornea was optically clear. The iris was dark brown and formed a circular, centrally placed pupil. The lens was optically clear with a large axial length. The equatorial region of the lens could not be observed when examined through the nondilated pupil. The vitreous was optically clear. Observation from a distance using the binocular indirect

ophthalmoscope revealed a pale gray fundic reflex filling the pupillary aperture. An excellent view of the fundus was obtained using indirect ophthalmoscopy. The fundus was a homogenous gray (Figure 3). The retina was anangiotic; however, choroidal blood vessels were frequently observed in regions possessing less pigment (Figure 3). A single fovea was clearly observed in every bird examined as a

FIGURE 3 Fundus photography. A, An after-hatch-year female Anna's Hummingbird positioned for funduscopic imaging OD using a Micron III (Phoenix Research Laboratories, Candler, NC, USA). B, Fundus photograph of the same bird, note the pecten (asterisk) and choroidal vasculature (arrowheads). This fundus was considered normal

dark pinpoint depression approximately one-half pecten length medial and slightly dorsal to the superior margin of the pecten. It was not possible to photograph the fovea due to head movements of unsedated birds and because the pupils were not pharmacologically dilated. A second temporal fovea was not ophthalmoscopically evident in any bird. The pecten was of the pleated variety, darkly pigmented, and located in the ventral fundus. It was oriented in a dorsotemporal direction with a slight concavity on its temporal side. The optic nerve head was obscured by the pecten except at its periphery where it was visible as a distinct, flat, thin white structure extending outward from the base of the pecten (see Figure 3).

Intraocular pressure was measured in 362 eyes (183 birds; 140 Anna's and 43 Black-chinned Hummingbirds; Table 1). Mean $\pm$ SD (range) IOP for all birds was 11.12 ± 2.20 (7-21) mm Hg. A significant difference between the intraocular pressure of Anna's Hummingbirds (11.55 ± 2.41 mm) and Black-chinned Hummingbirds (10.19 ± 0.91 mm) was detected ($P < .01$). Mean $\pm$ SD horizontal palpebral fissure length in 108 eyes (54 birds; 26 Anna's and 28 Black-chinned Hummingbirds) was 2.59 ± 0.19 mm (2.21-3.02 mm) (Table 1). A significant difference between the horizontal palpebral fissure length of Anna's Hummingbirds (2.71 ± 0.17 mm) and Black-chinned Hummingbirds (2.49 ± 0.14 mm) was detected ($P < .01$). Refractive error was measured in 38 eyes (19 Anna's Hummingbirds; see Table 1). Mean $\pm$ SD (range) refractive error was $+0.32 \pm 0.33$ (−0.25 to +1) D, with 82% of eyes being emmetropic (i.e. a refractive error of −0.5- to +0.5 D). Digital slit lamp photographs documented a thin cornea, shallow anterior chamber, and large axial lens length (Figure 5). These findings were confirmed using FD-OCT with axial corneal thickness being 59 μ m, peripheral corneal thickness being 48 μ m, and anterior

chamber depth being 527 μ m (Figure 6). Lens thickness could not be assessed with FD-OCT. Pupil diameter was 216 μ m. Retinal OCT permitted measurement of the thickness of retinal layers in the nasal peripheral retina, as well as regions immediately nasal to and temporal to the fovea (Table 2). The nerve fiber layer was notably thicker temporal to the fovea than it was in the nasal perifoveal region. A deep, convexiculate central fovea was documented (see Figure 7). The maximum foveal width and depth was 647

TABLE 2 Retinal thickness of the nerve fiber layer (NFL), retinal ganglion cell layer (RGC), inner plexiform layer (IPL), combined inner nuclear layer (INL), outer plexiform layer (OPL), and outer nuclear layer (ONL), photoreceptor inner segment layer (PRIS), photoreceptor outer segment layer (PROS), and retinal pigmented epithelium layer (RPE) of an after-hatch-year free-living Anna's Hummingbird

Retinal thickness (μ m)			
Retinal layer	Nasal peripheral retina	Nasal perifoveal retina	Temporal perifoveal retina
Total retina	241	237	242
NFL	14	22	47
RGC	9	11	9
IPL	63	65	57
INL, OPL, ONL	100	111	100
PRIS	17	17	20
PROS	7	6	5
RPE	4	5	4

All measurements were determined using inbuilt calipers of a Fourier-domain optical coherence tomography unit.

and 133 μm , respectively. A second fovea was not evident in any eye imaged.

3.2 | Adnexal and ocular lesions

Adnexal or ocular lesions were identified in 6/263 (2.28%) birds (7/526 eyes) examined (Table 1). Of these, three birds had adnexal lesions only, and three had only ocular lesions. In one after-hatch-year female Anna's Hummingbird, nodular, scaly changes of the surface of all four eyelids with cicatrization and loss of normal periocular pigmentation were noted (Figure 4A). No ocular changes were noted in this bird. A similar but less severe lesion was found involving the eyelids of the right eye (OD) only of one after-hatch-year male Anna's Hummingbird. A 0.5-mm notch defect in the central inferior eyelid margin along with minor hemorrhage in the tear film was noted OD in one after-hatch-year female Anna's Hummingbird. Two birds had corneal opacities. In one after-hatch-year female Anna's Hummingbird, these were multifocal punctate to

coalescing superficial stromal to subepithelial crystalline deposits extending from the temporal region of the limbus to almost the axial region of the cornea OD (Figure 4B). A mid-to-deep stromal opacity interpreted as fibrosis was noted in the cornea OD of an after-hatch-year female Black-chinned Hummingbird (Figure 4C). The only intraocular abnormality detected was a narrow ventronasal posterior synechia to the axial lens with associated mild anterior subcapsular cataract OS in an after-hatch-year female Anna's Hummingbird (Figure 4D).

4 | DISCUSSION

This work describes for the first time normative values and findings that will serve as a reference for clinical evaluation, advanced imaging, and interpretation of diagnostic test values of 2 species of free-living hummingbirds. Additionally, the frequency and distribution of ocular lesions in this population are reported. Gross inspection of the eyes of

FIGURE 4 Ophthalmic lesions observed in a survey of free-living Anna's ($n = 186$) and Black-chinned ($n = 77$) Hummingbirds. A, Right eye of an after-hatch-year male Anna's Hummingbird with marked chronic blepharitis. Note the nodular and scaly changes of the surface of the eyelid with cicatrization and loss of normal periocular pigmentation. These changes were bilateral. B, Right eye of an after-hatch-year male Anna's Hummingbird with multifocal punctate to coalescing superficial stromal to subepithelial crystalline deposits from the temporal region of the limbus to almost the axial corneal. C, Right eye of an after-hatch-year female Black-chinned Hummingbird with a mid-to-deep corneal stromal opacity interpreted as fibrosis (D) Left eye of an after-hatch-year male Anna's Hummingbird with a narrow ventronasal posterior synechia to the axial lens with associated mild anterior subcapsular cataract. No other ocular abnormalities were found, and no evidence of trauma or previous globe penetration was detected

FIGURE 5 Digital slit lamp photographs of an after-hatch-year female Anna's Hummingbird. A, Slit beam focused on the cornea. Note the shallow anterior chamber bounded by a thin cornea (yellow arrow) and the anterior lens capsule (white arrow). B, Slit beam focused on the lens. Note the thick lens bounded by the anterior (white arrow) and posterior (blue arrow) lens capsule. The cornea (yellow arrow) is not in focus in this image

hummingbirds revealed lateral globe placement (see Figure 1), where at least one eye was visible across the majority of their celestial hemisphere, corroborating findings on the visual fields of hummingbirds (LP Tyrrell, personal communication). Binocularity was suggested based on globe position in most of the frontal visual field, but was subjectively smaller ($<20^\circ$ maximum) than that reported for many other visually guided foragers (ie, over 40° in some sparrows, over 50° in chickadees and titmice, and over 60° in crows).³²⁻³⁴ However, increased bill length in visually guided foragers is often related to narrower binocular fields because the tip of a longer bill is more easily encompassed by a smaller binocular field.³⁵⁻³⁸ Overall, the position of the eyes of the hummingbirds may have exemplified a compromise between use of binocularity for foraging and wide visual coverage for detection of predators.

Data presented here suggest an ocular disease prevalence in free-living hummingbirds of only 2.28%. This is similar to another survey of 1510 long-eared owls (*Asio otus*) in which 2.5% had ocular lesions,²³ but greater than that reported for two species of wild-caught vultures (*Aegypius monachus* and *Gyps fulvus*; $n = 62$ in none had observed ocular lesions).²² Meanwhile, up to 15% of ill or injured raptors presented to rehabilitation centers have ocular lesions.³⁹ Others have estimated ocular morbidity can be seen in 30%-50% of wild raptors.^{23,25,26,40,41} However, hummingbirds are rarely presented to rehabilitation centers and veterinary clinics, possibly due to their small size and infrequency of being found ill or injured, or maybe because ocular lesions severely impact survival in wild hummingbirds due to their dependence on high quality vision.

Two ocular abnormalities identified in this study were likely the result of trauma: an eyelid margin notch defect with recent hemorrhage and a posterior synechia with associated cataract (see Figure 4). Given the acute appearance

of the hemorrhage and eyelid notch defect, it is possible that the injury took place during capture, although other recent injury cannot be ruled out. No evidence as to cause of the posterior synechia was found. Specifically, there was no evidence of ocular penetration, glaucoma, or other signs

FIGURE 6 Fourier-domain optical coherence tomography (FD-OCT). A, An after-hatch-year female Anna's Hummingbird is positioned next to the short-axis FD-OCT lens. B, Cross-sectional FD-OCT image of the hummingbird's anterior segment with measurements using the software caliper function: axial corneal thickness = 59 μm , peripheral corneal thickness = 48 μm , anterior chamber depth = 527 μm , and pupil diameter = 216 μm

of uveitis. Although a developmental abnormality was considered, the involvement of the pupillary margin rather than the collarette made this a less likely consideration. Traumatic ocular pathology is most commonly reported in raptors, comprising up to 90% of ocular lesions seen in wild raptors.^{25-27,39} Reports of ocular trauma have also included waterfowl, parrots, songbirds, chickens, hornbills, bustards, herons, roadrunners, and penguins.²⁷ The large size of the avian eye relative to body mass and size of the head with much of its outline lying outside the bony orbit likely predisposes it to involvement during many incidents of head trauma.

Two birds in the present study had eyelid abnormalities consistent with chronic poxvirus infection; one bird was affected bilaterally (see Figure 4). Poxviral ocular disease is the most common ocular manifestation of viral disease in birds^{42,43} and has been described in over 230 species of birds including hummingbirds.^{20,44-49} In most avian species, disease arising from poxvirus infection is typically mild and rarely causes mortality.^{20,50} However, poxvirus

lesions can be severe and affect the wings, beak, feet, or legs and lead to increased risk of predation, secondary infections, changes in behavior, and reduced reproductive success.^{20,50-54} Although poxvirus infection does not always result in ocular lesions, and infrequently results in intraocular disease, devastating residual ocular disease including corneal disease, uveitis, cataract, and phthisis bulbi can occur and lead to blindness.^{55,56} In hummingbirds, wart-like eyelid lesions have been ascribed to poxvirus infections and have become severe enough that the palpebral fissure can be completely occluded.²⁰ Although no evidence of lesions consistent with poxvirus in Black-chinned Hummingbirds were found, there are anecdotal reports of such lesions occurring in this species.²⁰ Given their sympatric relationship with Anna's Hummingbirds, it is possible that cross-species poxvirus transmission is occurring among hummingbirds (as has been documented in other groups of avian species). However, whether or not a particular hummingbird species is serving as a primary host for poxvirus remains to be determined.^{20,57,58}

FIGURE 7 Retinal optical coherence tomography (OCT). A, An after-hatch-year female Anna's Hummingbird is positioned for OCT assessment of the left eye. B, Image of the central foveal and perifoveal retina. Total retinal thickness of the retina immediately nasal and temporal to the fovea are provided, as well as maximum foveal width and depth. C, OCT image of the nasal peripheral retina. D-F, Segmentation of the peripheral nasal (D), immediately nasal perifoveal (E), and immediately temporal perifoveal (F) retinal regions, with nerve fiber layer (NFL), retinal ganglion cell layer (RGC), inner plexiform layer (IPL), combined inner nuclear, outer plexiform, and outer nuclear layers (INL, OPL, ONL), photoreceptor inner segments (PRIS), photoreceptor outer segments (PROS), and retinal pigmented epithelium (RPE) outlined. The external limiting membrane is indicated with a white arrow in D, E, and F

Ocular examinations and imaging of all hummingbirds revealed a very thin cornea, a shallow anterior chamber, and large axial lens length (see Figures 5 and 6). The corneal thickness is the thinnest avian cornea reported to date and thinner than similarly sized mammals (approximately 2/3 that of the common laboratory mouse).⁵⁹ Like the hummingbirds reported here, other small-eyed terrestrial vertebrates have large lenses that occupy, in some cases, up to 75% of the intraocular space (eg, mice).⁵⁹ This is a requirement to achieve the refractive power necessary to focus light across a short axial globe length. Additionally, a significant difference in the intraocular pressures between species was noted; however, the difference observed is likely of little clinical significance.

Optical coherence tomography has been successfully used in birds for morphologic studies and as a diagnostic tool for retinal disease and proved particularly useful in the present study to permit better characterization of the hummingbird fovea.⁶⁰⁻⁶² Using ophthalmoscopy and OCT, a single, deep, convexiculate fovea was visualized (see Figure 7). This is in contrast to an initial report that described the hummingbird retina as bifoveate with one central and one temporal fovea.¹² More recently, a single, central fovea, and a temporal area centralis have been described (LP Tyrrell, personal communication).⁴ Although visualization of the temporal area centralis using OCT was not possible in the present study, a marked thickening of the nerve fiber layer temporal to the central fovea was evident, consistent with a temporal retinal center of acute vision (Figure 7). Further OCT and/or histologic studies of the temporal retina of hummingbirds are warranted to corroborate these findings.

Overall, these findings support conclusions from previous reports suggesting that hummingbirds have visual characteristics typical of species that exhibit predatory (eg, two distinct retinal regions specialized for increased visual resolution) and prey behavior (eg, large visual field and low visual acuity). Presumably this combination enables them to capture insects and dock and feed at flowers, while simultaneously avoiding predation (LP Tyrrell, personal communication).⁸ The low incidence and relatively benign nature of ocular lesions identified in this study suggest that hummingbird anatomy and likely behavior render them relatively resistant to major ocular lesions or that animals acquiring such lesions do not survive or get caught in the traps used in this study. The results reported provide a resource for clinicians and researchers working with hummingbirds.

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