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SPECTRAL TRANSMITTANCE OF ANIMAL INTRAOCULAR LENSES IN COMPARISON TO THE SPECTRAL PROPERTIES OF THEIR BIOLOGICAL LENSES

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ABSTRACT

Purpose: To determine the spectral transmittance of artificial intraocular lenses (IOLs) designed for various species (dog, cat, chinchilla, eagle, tiger) and compare them to the spectral properties of the biological lenses of these species. Methods: Twenty-seven IOLs were scanned with a spectrophotometer fitted with an integrating sphere. Results: All IOLs transmitted long wavelengths well before cutting off sharply at short wavelengths, with insignificant transmission below ca. 340nm. In comparison, the biological lenses of the cat, dog and probably the chinchilla transmitted significantly more short wavelengths. The spectral properties of the biological lenses of eagles and tigers, while uncertain, may be a closer match to the IOLs made for these species. Conclusion: It is not known if there are any visual or behavioural consequences for animals caused by a mismatch between the spectral properties of their biological lenses and IOLs. However, following IOL implantation there might be a change in the perceived hue of objects due to the removal of UV wavelengths which form a normal part of the visible spectrum for these species and/or a decrease in sensitivity.

Key words: Ultraviolet, Lens, IOL, Dog, Cat, Transmission

INTRODUCTION

When human intraocular lenses (IOLs) were first introduced in the late 1940's to correct the aphakia resulting from cataract surgery (1), although they replicated the refractive nature of the biological lenses they replaced, they did not match their spectral properties. The normal human crystalline lens absorbs ultraviolet (UV) radiation (<400nm), and in old age also absorbs increasing amounts of blue light (2). The removal of short wavelengths both protects the retina from shortwave-induced retinal phototoxicity (3) and improves image quality by reducing chromatic aberration and scatter, both of which are greatest at short wavelengths (4,5). In contrast, early human IOLs transmitted significantly more short wavelength radiation, increasing the risk of photic retinopathy following cataract surgery. For this reason, from the early 1980's, short wavelength-absorbing properties were incorporated into IOLs so that they approximated the spectral absorption of the human biological lens (6).

Veterinary ophthalmologists began implanting IOLs in patients in the late 1970s (7). As such lenses are constructed from similar materials currently used in human IOLs, they are likely to filter out UV illumination. However, for many animals the perception of UV light is important either for increasing overall sensitivity and extending the spectral range of vision or for contributing to specific visual tasks such as navigation, mate choice, foraging, predator and prey detection, or communication (5). As UV-sensitive species generally have biological lenses that allow the passage of these wavelengths to the retina (4,8), for them the insertion of UV-absorbing IOLs would not be appropriate.

The purpose of this study was to determine the spectral properties of various commercially available animal IOLs and to compare these to the spectral characteristics of the biological lenses of the animals they were designed for.

MATERIAL AND METHODS

Twenty-seven animal IOLs made for various species were provided by manufacturers (Table 1). They were fixed in front of a hole in an aluminium plate that fitted tightly within a standard quartz cuvette (Starna Scientific, 10mm pathlength) which was positioned in front of an integrating sphere within a Shimadzu 2101 UVPC spectrophotometer. As the hole within the aluminium plate was slightly smaller than the IOL, all light entering the integrating sphere will have traversed the IOL. Transmittance at 700nm was set at 100% and determined at 1nm intervals between 300-700nm. The spectral transmittance of the cat and dog biological lenses had been previously measured by a similar method (8).

RESULTS

All IOLs transmitted long wavelengths uniformly well, before cutting off sharply in the UVA and reaching negligible transmission by 340-390nm. As the scans for all lenses were similar, only data for representative lenses are shown in Fig. 1 and to separate curves horizontally they are only shown for a limited spectra range (340-440nm). Full data (300-700nm) are available for all lenses in the supplementary material. Data for three lenses over the whole spectral range are also shown in Fig. 2.

The amount of UVA transmitted by each lens is shown numerically in Table 1 by the wavelength of 50% transmission (t50: range 373-407nm) and the percent of UVA traversing the lens (%UVA: range 0.9-31.5%).

DISCUSSION

As wavelengths below ca. 300nm are absorbed by the nucleic acids and structural protein components of the ocular media, no wavelengths shorter than this will reach the retina of any animal (4). At longer wavelengths beyond ca. 500nm, transmission is uniformly high.

Between ca. 300-450nm, however, ocular media transmission varies depending on the species. Although the corneas of some fish contain short wavelength absorbing pigments, the lens is the structure determining the amount of UV incident on the retina of all other vertebrates (4). In many animals, the lens is as transparent as biologically possible and transmits short wavelengths well. Such species are often nocturnal and benefit from increased absolute sensitivity and potential UV-sensitivity. In other species, however, the lens contains shortwave-absorbing pigments preventing such wavelengths reaching the retina (4). These animals are often diurnal and the retina will both be protected from the most damaging wavelengths and spatial acuity will be improved by removing that part of the spectrum most prone to chromatic aberration and Rayleigh scatter (8).

Ideally, any IOL implanted into an animal should replicate the spectral properties of that species' biological lens. If an IOL removes less shortwave radiation than the biological lens there is a possible danger that retinal damage may occur. Removing more or less short wavelengths may affect colour perception. For example, humans that receive an IOL implant that transmits more blue light than their aged biological lens, may experience vision with a blue tint (cyanopsia) (6). Conversely, if the IOL filters out more blue light than the biological lens, the image may appear more yellow. Currently available animal IOLs seem to remove significantly more UV-radiation than the respective biological lenses of some species.

For example, the single cat IOL scanned here (t50-382nm, %UVA-20.0%) removed significantly more short wavelength radiation than the biological lens of this species (t50-345nm, %UVA-58.9%; Fig. 2a). Similarly, the t50 of the 23 canine IOLs scanned ranged from 373-395nm transmitting 8.4-31.5% of the UVA (Table 1), while the biological lens of the dog was much more transparent to short wavelengths (t50 335nm, %UVA transmission 61.3%; Fig. 2b). While there is a clear mismatch between the spectral transmission of dog and cat IOLs and the biological lenses of these animals, it is unclear whether this represents a

significant problem. Unfortunately, there are no behavioural studies of vision in dogs and cats after cataract surgery, which could demonstrate possible visual deficits due to the longer wavelength cut off resulting from IOL implantation.

Single IOLs designed for chinchillas, eagles and tigers were also scanned (Fig. 1, Table 1). Although no data for the biological lenses of these species are available, it is often possible to make a reasonable estimate of the transmission of the lens of an animal, using its lifestyle and the lenses of related species as a guide.

Chinchillas are nocturnal in the wild, mostly eat vegetation and live in burrows or rock crevices. Thus, like most other nocturnal rodents (8), their lens probably transmit large amounts of UVA. The single IOL destined for a chinchilla scanned here, in contrast, removed most of the short wavelengths (Table 1, Fig. 1).

The most UV-absorbing IOL scanned (Fig. 1), with a t50 of 407nm and transmitting only 0.9% of the UVA, was designed for an unknown species of eagle. Although the spectral transmission of eagle biological lenses have not been determined, the lenses of diurnal raptors, including other Accipitriformes (the order that includes all eagles) contain UV-absorbing pigments (9). Thus, the eagle IOL is probably a closer match to the spectral transmission of its biological lenses than for the other species examined.

The single tiger IOL scanned in this study, like all other IOLs studied, removed most of the UVA (Table 1, Fig. 1). Unfortunately, it is not possible to predict with any degree of certainty the spectral characteristics of the tiger's biological lens. The only member of the family Felidae whose lenses have been evaluated were those of the domestic cat reported in this study. However, while tigers are largely diurnal, domestic cats, although active at both day and night, are primarily nocturnal. Thus, the biological lenses of tigers may have significantly different UV light absorbing properties compared to domestic cats, so the straight comparison may not be useful.

Sensitivity to UV is widespread among both vertebrates and invertebrates (5). Many species have visual pigments with a wavelength of maximum sensitivity (λ_{max}) in the UV. However, this is not a prerequisite for UV sensitivity as the wavelength range absorbed by visual pigments is broad and all pigments have a secondary absorption maximum in the UV (the cis-peak or β-band) (Figs. 2a&b). As long as a species has ocular media that are transparent to short wavelengths, it is likely that it will be sensitive to light in this part of the spectrum even in the absence of a visual pigment with λ_{max} in the UV range (8).

Although physiological, behavioural, morphological and molecular techniques suggest neither the cat (Fig. 2a) nor the dog (Fig. 2b) contain a visual pigment with λ_{max} in the UV, the fact that both species have UV-transmissive lenses suggests these wavelengths are part of their normal perceptual repertoire. As feline and canine IOLs remove most of the UV-radiation it seems possible that the visual experience of these animals after lens removal surgery and IOL implantation may in some way be altered. For example, objects such as food may no longer appear their normal hue and sensitivity may be decreased as less photons are incident on the retina. However, whether such theoretical, potentially deleterious, consequences of a mismatch between the spectral properties of IOLs and biological lenses have any actual consequences for an animal's visually-driven behaviour or physiology remains to be verified experimentally.

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Table 1 Specifications of the 27 IOLs scanned in this study as well as two measures of their transmissivity to UV radiation. Details of how t50 and the %UVA are calculated is given in reference (8).

ID	Name	Manufacturer	Species	t50	%UVA
1	LENTE CANINA TXY651125	AJL Ophthalmic	Canine	376	28.8
2	OOV00607 TXY651325,	AJL Ophthalmic	Canine	380	23.9
3	OOV00607 TXY651325	AJL Ophthalmic	Canine	381	21.5
4	MD4-13	an-vision	Canine	373	31.5
5	MD8-12	an-vision	Canine	377	26.3
6	MD2-15	an-vision	Canine	382	20.0
7	MD8-13	an-vision	Canine	379	23.6
8	MD6-13	an-vision	Canine	378	26.0
9	MC1-14	an-vision	feline	382	20.0
10	MD4-14	an-vision	canine	382	21.1
11	MD8-14	an-vision	canine	386	16.3
12	Loki -PL	Cristalens	Canine	379	23.8
13	lx-xvet sn: cv176aa13	Medicontur	Canine	382	21.2
14	lx-svet sn: cw306aa10	Medicontur	Canine	382	20.5
15	K-9114AR	Ocularvision, Inc.	Canine	378	25.3
16	K-9311A	Ocularvision, Inc.	Canine	380	22.3
17	K-9112AR	Ocularvision, Inc.	Canine	379	23.9
18	K-9313A	Ocularvision, Inc.	Canine	379	24.5
19	K-9113AR	Ocularvision, Inc.	Canine	380	23.6
20	K-9312AR	Ocularvision, Inc.	Canine	379	24.4
21	K-9314A	Ocularvision, Inc.	Canine	380	23.8
22	K-9111A	Ocularvision, Inc.	Canine	379	24.2
23	C-144 Ser: 6070	Ocularvision, Inc.	Tiger	405	1.6
24	K-9110 Ser: 6259	Ocularvision, Inc.	Canine	395	8.4
25	CH5511 Ser: 6073	Ocularvision, Inc.	Chinchilla	384	19.3
26	K-9000 Ser: 6310	Ocularvision, Inc.	Canine	394	8.9
27	Eagle Ser: 6071	Ocularvision, Inc.	Eagle	407	0.9

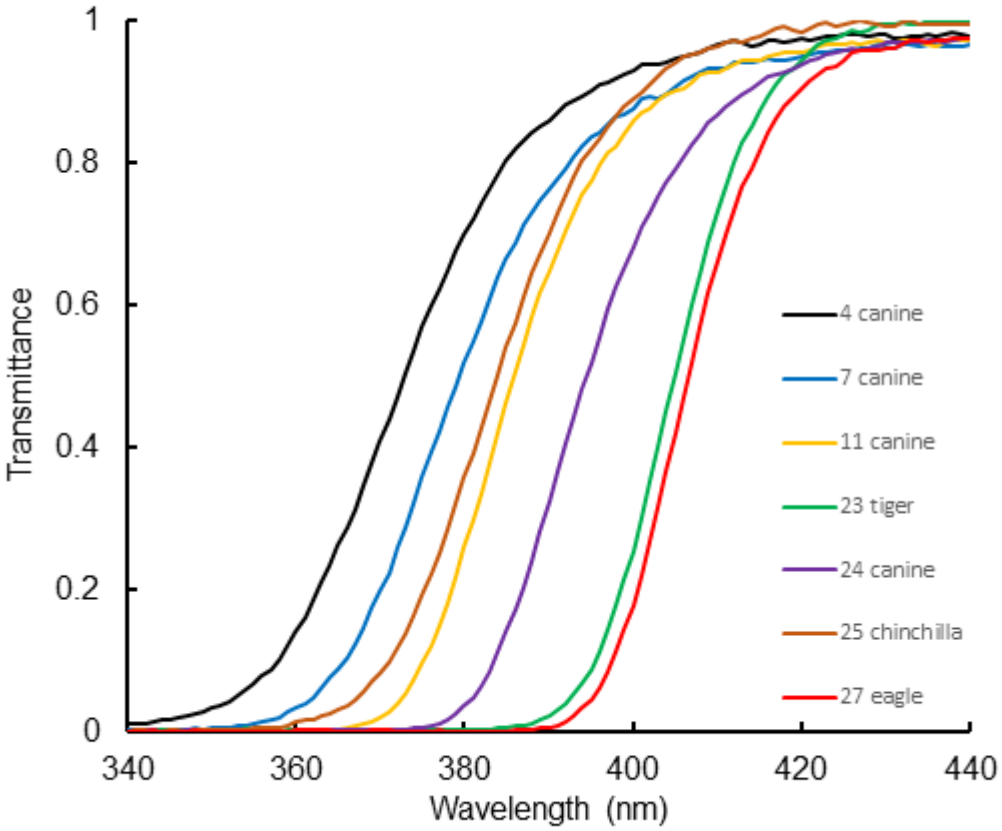

Figure 1 **Spectral transmittance of representative animal IOLs**. Source data and curves for all lenses scanned are available in the supplementary material. The labels of the curves represent the lenses detailed in table 1.

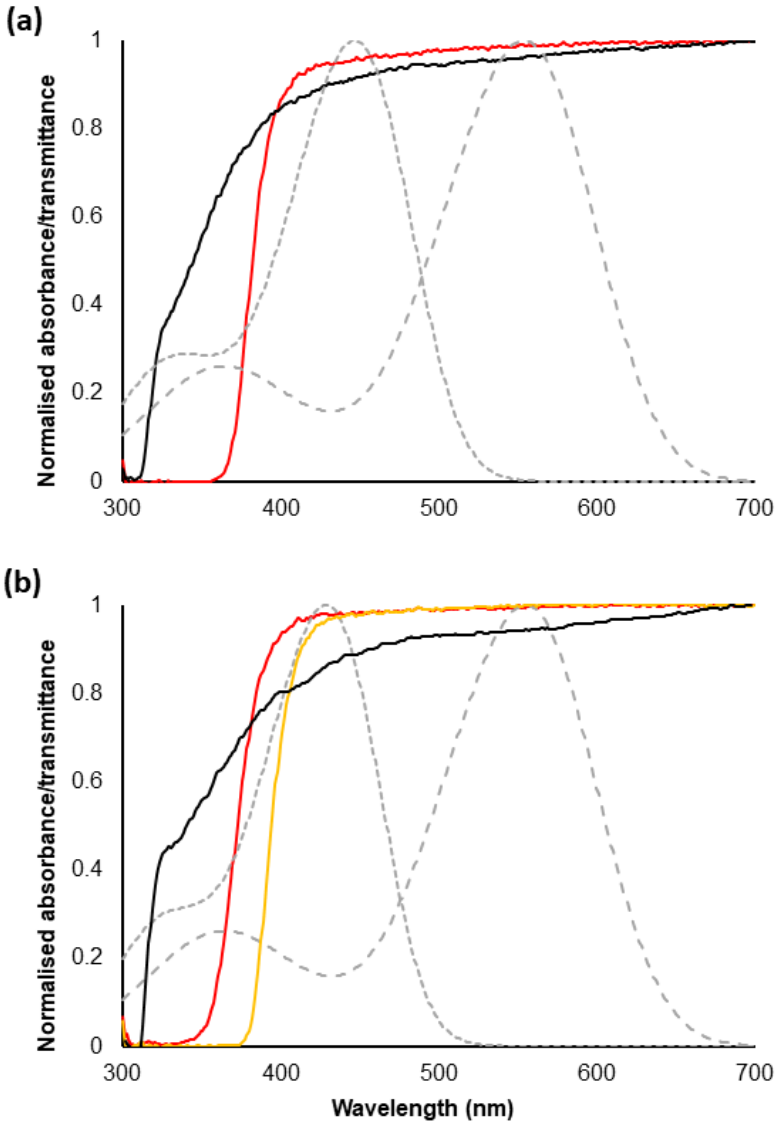

Figure 2 Spectral transmittance of (a) a single feline and (b) two canine IOLs in comparison to the transmission of their biological lenses. The spectral transmission of the feline IOL (red) is based on a single lens, while the spectrum of the biological lens (black) represents the average of 6 lenses (8). The two canine IOL spectra shown represent the most UV-transparent (red) and UV-opaque (orange) examples of the 23 canine IOLs scanned, while the spectrum of the biological lens is the average of the two lenses from a single Labrador (8). Also shown (grey) are the feline and canine cone visual pigments represented by visual pigment templates (10) using the wavelength of maximal absorbance determined by psychophysical measurements (11, 12).