Refractive states of eyes and associations between ametropia and age, breed, and axial globe length in domestic cats

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Objective—To determine the refractive states of eyes in domestic cats and to evaluate correlations between refractive error and age, breed, and axial globe measurements.

Animals—98 healthy ophthalmologically normal domestic cats.

Procedures—The refractive state of 196 eyes (2 eyes/cat) was determined by use of streak retinoscopy. Cats were considered ametropic when the mean refractive state was ≥ ±0.5 diopter (D). Amplitude-mode ultrasonography was used to determine axial globe length, anterior chamber length, and vitreous chamber depth.

Results—Mean ± SD refractive state of all eyes was −0.78 ± 1.37 D. Mean refractive error of cats changed significantly as a function of age. Mean refractive state of kittens (≤4 months old) was −2.45 ± 1.57 D, and mean refractive state of adult cats (>1 year old) was −0.39 ± 0.85 D. Mean axial globe length, anterior chamber length, and vitreous chamber depth were 19.75 ± 1.59 mm, 4.66 ± 0.86 mm, and 7.92 ± 0.86 mm, respectively.

Conclusions and Clinical Relevance—Correlations were detected between age and breed and between age and refractive states of feline eyes. Mean refractive error changed significantly as a function of age, and kittens had greater negative refractive error than did adult cats. Domestic shorthair cats were significantly more likely to be myopic than were domestic mediumhair or domestic longhair cats. Domestic cats should be included in the animals in which myopia can be detected at a young age, with a likelihood of progression to emmetropia as cats mature. (Am J Vet Res 2012;73:279–284)

Retinoscopy is an objective technique used to measure the refractive state of an eye. To better understand the optical factors that affect visual acuity, the refractive states of many species have been determined. The technique has been used in ophthalmically normal, pathologically affected, and surgically manipulated eyes of dogs and cats to determine species reference limits as well as factors that affect refractive error. In 1 study, investigators indicated that the mean resting refractive state of 240 dogs was within 0.25 D of emmetropia, and breeds predisposed to development of myopia were also found. A more recent study of 1,440 dogs found the mean ± SD refractive state of all eyes examined was −0.05 ± 1.36 D; breeds found to be myopic (<−0.5 D) included the Rottweiler, Collie, Miniature Schnauzer, and Toy Poodle. Furthermore, the degree of myopia increased with increasing age among all dog breeds evaluated. An increase or decrease in axial length can result in incongruity between axial and focal lengths of the refractive elements of an eye, which results in ametropia. Axial myopia, which is attributable to an increase in the vitreous chamber depth, has been identified in Labrador Retrievers. The mean ± SD refractive state of horses in a recent study was −0.06 ± 0.68 D, and vitreous body length and age were negatively correlated with refraction values. In another study in which investigators evaluated the refractive state in pseudophakic eyes of horses, the mean preoperative refractive state of enucleated eyes was between −0.46 and 0.08 D. The development of the refractive state with maturation of an animal has also been evaluated in a number of species. Eyes of ostriches are characterized by myopia at the time a chick hatches and become emmetropic as a chick ages. This is true...
of American kestrels as well, and both American kestrels and ostriches are the exception in that most of the species that have been evaluated, including nonhuman primates and humans, appear hyperopic at birth and develop emmetropia as animals mature.11,34–37 To our knowledge, the refractive states of eyes and the association between ametropia and age and breed in cats has not been reported. The purpose of the study reported here was to assess the refractive state of a mixed population of ophthalmologically normal domestic cats and to identify natural and biometric factors that affect the refractive state.

**Materials and Methods**

**Animals**—Client-owned cats (n = 13) and cats housed at a local animal shelter (85) were included in the study. The client-owned cats were patients at a veterinary ophthalmology referral center.7 Cats at the animal shelter were housed separately in cages or rooms with groups of cats of similar sex and age. This study was performed in accordance with the guidelines set forth by the Association in Vision and Ophthalmology, and informed consent was obtained from each owner.

Cats were allocated into groups on the basis of age (determined on the basis of birth history, dentition, and body size) and categorized as kittens (≤4 months old), young juveniles (6 to 9 months old), adults (>12 months old), and children. Cats were also categorized on the basis of coat as DSH, DMH, or DLH. Cats were included in the study without regard to age, sex, and breed and were excluded from the study if they were uncooperative or had preexisting ocular disease (other than feline viral rhinotracheitis or minor corneal or lens opacities that were not suspected to affect retinoscopy results).

**Determination of refractive state of feline eyes**—Ocular examination with a slit-lamp biomicroscope and indirect ophthalmoscope was performed on the eyes of all cats to rule out ocular disease. The refractive state of the cats’ eyes then was determined via streak retinoscopy by use of a streak retinoscope, and intraocular pressure was measured by use of a rebound tonometer.7 Refractive state of the eyes of 4 cats was determined immediately before and 45 minutes after administration of 1 drop of cyclopentolate HCl in each eye to induce mydriasis and cycloplegia. The other cats in the study did not receive a mydriatic or cycloplegic agent.

Streak retinoscopy was performed with each cat in a sitting or sternal position. An assistant helped with the procedure. Refractive state of each eye of a cat was determined separately at a working distance of 50 cm (2.0 D). Horizontal meridians were evaluated with a streak retinoscope in conjunction with concave and convex retinoscopy lens racks.5 The Purkinje images from the anterior cornea and lens surfaces were aligned, and the emerging retinal reflexes were observed. Two investigators (KAK and ARH) performed all retinoscopic evaluations. Both investigators were in agreement for all refractive values. Eyes were considered emmetropic when refractive errors were between −0.5 and +0.5 D. Eyes were considered myopic when the refractive error (degree of myopia) was ≥−0.5 D, and eyes were considered hyperopic when the refractive error was ≥+0.5 D. Eyes were considered anisometropic when the refractive error for each pair of eyes differed by ≥1 D.

**Determination of axial globe dimensions**—After retinoscopy was completed, 0.5% proparacaine was administered topically to each eye. Amplitude-mode ultrasonographic biometry and brightness-mode ultrasonography were performed simultaneously to determine axial globe length, anterior chamber length, and vitreous chamber depth, as described elsewhere.33 Briefly, coupling gel was applied to the tip of a 12.5-MHz ultrasound probe; the probe was then placed perpendicular on the corneal surface in a longitudinal position (sagittal plane). Accurate positioning was evident when the wall of the posterior globe was visible and echoic images of the cornea, anterior and posterior lens surfaces, and retina were visible and perpendicular. Measurements were made from the distances of the echoic images that corresponded to the midcornea and retina (axial globe length), midcornea and anterior lens capsule (anterior chamber length), and posterior lens capsule and retina (vitreous chamber depth), as described elsewhere.44 A single investigator (KAK) performed all amplitude-mode biometry measurements.

**Statistical analysis**—Descriptive statistics, including mean, SD, and frequency distribution, were calculated, when appropriate, for refractive measurements, signalment data, and other associated eye measurements. Bi-variate Pearson correlation coefficients were calculated to evaluate the degree of linear association between refractive values and other variables in the data set. Linear regression was used to estimate the values of variables that best fit linear equations that explained functions of 1 or more independent variables related to the refractive measurement that served as the outcome or dependent variable. A forward, stepwise variable procedure was used to select independent variables for the final regression model, with a value of P < 0.05 needed to enter a variable and a value of P > 0.15 needed to remove a variable. A commercial software package was used for statistical calculations, and values of P < 0.05 were considered significant.

**Results**

The study population consisted of 98 cats (31 [52.0%] females and 47 [48.0%] males). There were 57 (58.2%) adults, 22 (22.4%) juveniles, 7 (7.1%) young juveniles, and 12 (12.2%) kittens. On the basis of coat length, there were 17 DLH cats (14 adults, 2 juveniles, and 1 kitten), 10 DMH cats (5 adults, 2 juveniles, and 3 kittens), and 71 DSH cats (38 adults, 18 juveniles, 7 young juveniles, and 8 kittens). Of the 98 cats, 22 (22.4%) were sexually intact and 66 (67.3%) were neutered; the status of 10 (10.2%) cats was unknown. Mean ± SD intraocular pressure for the right and left eye was 18.9 ± 5.87 mm Hg and 19.51 ± 6.03 mm Hg, respectively. Mean refractive error for both eyes was myopic (−0.78 ± 1.37 D; range, −5.75 to +1.50 D; Figure 1). Mean refractive error was myopic for the right (−0.77 ± 1.418 D; range, −6 to +1.0 D) and left (−0.78 ± 1.397 D; range, −5.5 to +1.5 D) eyes. Refractive values did not change significantly across age groups.
not differ significantly between the right and left eyes or between eyes of males and females. Of 98 cats, 53 (54.1%) were myopic and 16 (16.3%) were hyperopic; 29 (29.6%) cats were emmetropic. Two (2.0%) cats had anisometropia (refractive error for a pair of eyes that differed by > 1 D); 58 (59.2%) had refractive error for a pair of eyes that differed by > 0.5 D but < 1.0 D.

Mean refractive error of cats changed significantly (P < 0.001) as a function of age. Kittens or young juveniles were more likely to have negative refractive errors. Mean ± SD refractive error was –2.45 ± 1.57 D (range, –5.75 to −0.50 D) for kittens (Figure 2), –2.11 ± 2.19 D (range, –5.50 to +1.00 D) for young juveniles, –0.43 ± 1.20 D (range, –3.25 to +1.50 D) for juveniles, and –0.39 ± 0.85 D (range, –4.25 to +1.25 D) for adults. Compared with other breeds, DLH cats were more likely to be emmetropic. Mean ± SD refractive error was –0.13 ± 0.79 D for DLH cats, –0.58 ± 0.33 D for DMH cats, and –1.02 ± 1.48 D for DSH cats. Axial measurements of the right and left eye of the cats did not differ significantly, and values were similar to those in other reports. For the right eye, mean ± SD axial globe length, anterior chamber length, and vitreous chamber depth were 19.8 ± 1.62 mm, 4.76 ± 0.86 mm, and 7.89 ± 0.89 mm, respectively. For the left eye, mean ± SD axial globe length, anterior chamber length, and vitreous chamber depth were 19.7 ± 1.53 mm, 4.55 ± 0.86 mm, and 7.94 ± 0.83 mm, respectively. Axial globe length changed significantly (P < 0.001) as a function of age. Mean ± SD axial globe length was 16.08 ± 0.97 mm for kittens, 19.21 ± 0.86 mm for young juveniles, 19.91 ± 1.33 mm for juveniles, and 20.43 ± 1.06 mm for adults. When data for all 98 cats were analyzed, there was a significant positive correlation (r = 0.493; P < 0.001) between axial globe length and refractive error. When only the data for the kittens were analyzed, there was a nonsignificant negative correlation (r = –0.53; P = 0.076) between axial globe length and refractive error. No significant correlations were detected between anterior chamber length and vitreous chamber depth or between anterior chamber length and refractive error.

### Discussion

Few studies have been conducted to examine the refractive states of ophthalmologically normal feline eyes, with mean refractive error in cats ranging from –0.81 to +1.4 D. Many studies have been performed in cats to develop useful methods for evaluating and understanding the development of myopia in humans. Variables among studies include methods used to determine refractive error, methods used to alter refractive error, sample size, and age of cats, which make it difficult to accurately compare results. To the authors’ knowledge, the study reported here is the first in which the refractive state of a large, mixed population of ophthalmologically normal domestic cats was evaluated and natural factors that affect refractive state among groups of cats were identified.

In the present study, mean ± SD refractive state among ophthalmologically normal domestic cats was myopic (–0.78 ± 1.37 D). Studies in domestic dogs and horses determined that the mean refractive state of each species is emmetropic, with mean ± SD refractive errors of –0.05 ± 1.36 D and +0.06 ± 0.68 D, respectively, although breeds of dogs predisposed to develop myopia and hyperopia were indicated. It is known that interspecies and intraspecies differences exist in the natural refractive state.

Various factors contribute to the refractive state of the globe, including refractive indices of the refractive elements of the globe (cornea, aqueous humor, lens, and vitreous humor); distances between the cornea, anterior lens, posterior lens, and retina; and radii of curvature and dioptric power of the anterior and posterior cornea and lens. The refractive state can also be temporarily or permanently modified by adaptations to the globe or changes to the environment. In the present study, many cats were housed in an animal shelter in cages or allowed to roam freely in large rooms or were indoor or indoor-and-outdoor client-owned cats. In another study on the effect of visual environment on refractive error in cats, 18 cats were raised in cages or small rooms under conditions of near vision and 11 cats were street cats. Refraction of the caged cats revealed that 17 of 22 of eyes were myopic (mean refractive error, –0.8 D) and 29 of 33 eyes of the street cats were hyper-
opic (mean refractive error, 1.4 D); the anterior-posterior diameter, as measured via amplitude-mode ultrasonography, was almost equal in both groups.46 This led the authors of that study to speculate that myopia in the caged cats was not attributable to axial globe measurements, but rather to permanent refractive changes in the lens. It is unknown how many cats in the present study resided in animal shelters or homes or were free roaming for most of their lives, so it is possible that differences in environment affected the overall mean refractive error.

Although axial globe length, vitreous chamber depth, and age are factors that increase the prevalence of myopia in various species,46,47 including humans,48 dogs,1,32 and horses,30 other optical factors likely lead to the predominance of myopia in the cats of the present study. In other studies in which investigators measured axial globe length and myopic refractive error in kittens20,21,44 and dogs,22 factors such as a change in corneal curvature or lenticular changes were considered the main factors that affected myopia. Kittens in the present study were considerably more myopic than were the adult cats. When data for all 98 cats were analyzed, there was a significant positive correlation (r = 0.493; P < 0.001) between axial globe length and refractive error; however, when only the data for the kittens were analyzed, there was a nonsignificant negative correlation (r = –0.53; P = 0.076). When the group was expanded to include kittens and young juveniles (n = 19 animals), there was a slightly positive but nonsignificant correlation (r = 0.08; P = 0.740). Perhaps a better understanding of the relationship between age, axial length, and myopic refractive error could have been determined if the sample size was larger. Axial globe length or the ratio of anterior chamber depth and vitreous chamber depth to axial globe length were also not important for describing myopic refractive error.

Mean refractive error changed significantly (P < 0.001) as a function of age in the cats of the present study. Interestingly, the degree of myopia decreased with increasing age. Although most species, including guinea pigs,37 Thomson gazelles,38 tree shrews,39 maroons and other nonhuman primates,40 chickens,40 and humans,50 have a decrease in hyperopia from birth to maturity, the opposite is true of only a few species. Conversely, we detected myopia in young cats, which is similar to results of only a few other species that have been evaluated at a young age; these species include ostriches,11 American kestrels,34 and wild type C57BL/6 mice.36 To our knowledge, these are the only species in which myopia has been detected at the time of hatching or birth. A study45 conducted to examine postnatal development of corneal curvature in cats revealed an increase in central corneal curvature during the first 12 to 15 months after birth, with a corneal curvature of 54.5 D in 9-week-old kittens and 39 D in adult cats. The most dramatic change in the optical surface of the cornea was during the first 9 months after birth, with a decrease in corneal strength of 12 to 15 D.51 It is likely that a decrease in mean corneal curvature (corneal power) with increasing age in the cats of the present study contributed to a decrease in myopic refractive error with maturity. Additionally, we monitored 2 indoor kittens from 4 weeks to 6 months of age (data not shown); both of these kittens had an extreme myopic refractive error at 4 weeks that decreased with age (from –7.0 to –1.0 D). Given that kittens are altricial mammals and rely on nursing for nutrition and growth during the first months after birth, it is possible that the myopic state of kittens serves some functional value in feeding and maturation. Emmetropization develops as they mature, and they eventually acquire clear and functional vision that aids in their survival. Future studies conducted to determine the development of refractive states in cats should include a group of kittens that is monitored from birth to maturity. Also, keratometry may be performed to determine the manner by which the cornea influences the net refractive state in growing cats.

Coat length was correlated with refractive error; DSH cats were significantly (P = 0.01) more likely to be myopic. In addition, DLH cats were more likely to be emmetropic; although this association was not significant. There were more adult cats in the DLH group, compared with the number of adult cats in the DSH group, which could have accounted for the differences in refractive error, although the distribution of kittens and young juveniles in the DSH and DMH groups were similar, with DMH cats having no correlation with refractive error. A true breed disposition for development of myopia may exist among DSH cats, but future studies with a greater number of cats are warranted.

Potential limitations of the study reported here include refraction measurements performed in only 1 meridian and without pharmacological mydriasis and cycloplegia. Astigmatism in dogs was defined in 1 study1 as a difference of ≥ ± 0.5 D between refractive errors for the vertical and horizontal meridians within 1 eye, and refractive state is calculated as a mean spherical refraction of the net results of the 2 meridians.51 It is possible that refraction performed in 2 meridians would have uncovered astigmatism and changed the overall spherical refractive error, although in 1 refraction study32 in horses, refraction was performed for only 1 meridian, and results were consistent with those of other studies. Furthermore, all cats were evaluated by use of slit-lamp biomicroscopy and assessed as free of corneal disease prior to evaluation of the refractive state, which should mean the likelihood of astigmatism was low. The refractive state was determined in 4 kittens (4 weeks old) before and after they received 1 drop of cyclopentolate hydrochloride in each eye, and cycloplegia did not change the measurement of the refractive state in these 4 kittens. Other studies1,11,14 in animals have not detected an effect of the lack of cycloplegia on the refractive state, even in animals (eg, Asian elephants) that have an accommodative range of approximately 3 D.3 Therefore, it is unlikely that the use of a cycloplegic agent would have substantially changed the refraction results in the present study.

Mean refractive state among the 98 ophthalmologically normal domestic cats of the present study was myopic (mean ± SD, –0.78 ± 1.37 D). Mean refractive error changed significantly as a function of age, and kittens had greater negative refractive error than did adult cats. Although axial globe length changed as a function of age, the main optical factors that affected refractive error among age groups were likely changes in corneal curvature or the lens.
References