Refractive states of eyes and association between ametropia and breed in dogs

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Objective—To assess the refractive state of eyes in various breeds of dogs to identify breeds susceptible to ametropias.

Animals—1,440 dogs representing 90 breeds.

 Procedures—In each dog, 1 drop of 1% cyclopentolate or 1% tropicamide was applied to each eye, and a Canine Eye Registration Foundation examination was performed. Approximately 30 minutes after drops were administered, the refractive state of each eye was assessed via streak retinoscopy. Dogs were considered ametropic (myopic or hyperopic) when the mean refractive state (the resting focus of the eye at rest relative to visual infinity) exceeded ±0.5 diopter (D). Anisometropia was diagnosed when the refractive error of each eye in a pair differed by >1 D.

Results—Mean ± SD refractive state of all eyes examined was −0.05 ± 1.36 D (emmetropia). Breeds in which the mean refractive state was myopic (≤−0.5 D) included Rottweiler, Collie, Miniature Schnauzer, and Toy Poodle. Degree of myopia increased with increasing age across all breeds. Breeds in which the mean refractive state was hyperopic (≥+0.5 D) included Australian Shepherd, Alaskan Malamute, and Bouvier des Flandres. Astigmatism was detected in 1% (14/1,440) of adult (≥1 year of age) dogs; prevalence of astigmatism among German Shepherd Dogs was 3.3% (3/90). Anisometropia was detected in 6% (67/1,440) of all dogs and in 8.9% (8/90) of German Shepherd Dogs.

Conclusions and Clinical Relevance—Refractive states of canine eyes varied widely and were influenced by breed and age. In dogs expected to have high visual function (eg, performance dogs), determination of refractive state is recommended prior to intensive training.


In an emmetropic eye, light from an object viewed at a distance (>6.1 m, in general) is focused accurately on the retina. In an ametropic eye, the image is focused in front of (myopia) or behind (hyperopia) the plane of the retina, which causes blurring at the retinal plane. Ametropias can result from inadequate or excessive refractive power of components of the optical pathway, such as the lens or cornea, or from an axial length that is too long (myopia) or too short (hyperopia), which results in incongruity between axial and focal lengths of the refractive elements of the eye. In ametropia, a blurred image is created on the retina and the degree of blurring is directly proportional to the degree of ametropia. Predictable and significant decrements in visual acuity in the canine eye associated with the induction of optical defocus (ie, myopia) have been reported. Myopia is common among humans in the United States, including young children. A population-based study of US residents (age range, 4 to 74 years) revealed a high frequency (43%) of mild myopia. The exact cause of myopia in humans is unknown, and the identification of animals with similar conditions may aid investigations into causal mechanisms and treatment protocols for myopia in humans. Myopia induced by use of visual occlusion or optical defocus techniques has been extensively investigated in chicks, tree shrews, and other animal species. The techniques induce an increase in the overall length of the eye, which is a characteristic of the most common type of myopia in humans. However, experimentally induced myopia in nonhuman animals has several limitations that preclude extrapolation of results to the understanding of juvenile myopia in humans. The magnitude of refractive errors induced in other animal species is not typical of the magnitude of refractive errors detected in humans with naturally occurring myopia. Morphologic characteristics of eyes of other animal species commonly used in experiments that involve induced myopia (ie, chicks, tree shrews, and marmosets) are fundamentally different from characteristics of human eyes. In addition, the animals used differ from

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humans with respect to the period during which eyes are sensitive to induction of myopia.\textsuperscript{15,17} Myopic defocus, or the use of a positive lens to clarify an object viewed at distance, can counteract the ability of hyperopic defocus to induce excessive axial elongation.\textsuperscript{16,17} This imbalance between the effect of myopic and hyperopic defocus on the growth of the length of the eye is evidence that the factors that contribute to myopia in humans are more likely genetic than environmental. If myopia is hereditary in humans, then identification and evaluation of another animal species that develops myopia naturally (as opposed to experimentally) may be useful for investigations of myopia in humans.

In other studies,\textsuperscript{16,17} investigators from our laboratories determined that the refractive state of canine eyes is affected by breed and age. Those studies involved statistical analysis of data reported for 240 dogs as well as calculation of the mean refractive state of the eyes of 771 dogs. The purpose of the study reported here was to assess the refractive state of eyes of a greater number of dogs and breeds than was evaluated previously to identify breeds susceptible to ametropia.

**Materials and Methods**

**Animals**—Data regarding 1,440 privately owned dogs were collected during routine CERF examinations conducted at the School of Veterinary Medicine of the University of Wisconsin and CERF clinics set up throughout the Midwestern United States from 1991 through 2006. Because refractive values were obtained via a noninvasive procedure as a component of routine CERF examinations, owner consent was not required. The study protocol was approved by the Institutional Animal Care and Use Committee of the University of Wisconsin. Data that were collected in other studies\textsuperscript{9,13,16} from 1984 through 1991 were included in the study reported here to provide a database of sufficient size to evaluate breed differences in refractive states of canine eyes.

**Determination of refractive state of canine eyes**—Refractive state of canine eyes was determined by use of streak retinoscopy. Prior to retinoscopic examination, dogs received 1 drop of 1% cyclopentolate\textsuperscript{c} or 1% tropicamide\textsuperscript{c} in each eye. Although cyclopentolate is a more effective cycloplegic, values for refractive errors in human eyes do not appear to be significantly affected by choice of cycloplegic.\textsuperscript{18} In addition, values for refractive errors in canine eyes do not change significantly after induction of cycloplegia.\textsuperscript{18} A streak retinoscope\textsuperscript{c} was used to examine both eyes approximately 30 minutes after administration of cycloplegic. All examinations were performed by board-certified veterinary ophthalmologists or optometrists, all of whom were experienced and competent in performing retinoscopic examination of canine eyes.

To determine refractive state, trial lenses held in a lens bar that contained a series of negative (concave) and positive (convex) spherical lenses of various powers were used at a working distance of approximately 67 cm from an eye. Eyes were considered emmetropic when refractive errors measured between –0.5 and +0.5 D. Astigmatism was defined as ≥ 0.5 D difference between refractive errors for the vertical and horizontal planes within 1 eye. When astigmatism was detected, the diagnosis was recorded and values for the 2 eyes were averaged to provide the spherical equivalent refraction value used in additional analyses. Intra-individual and interindividual variation in retinoscopic evaluation of eyes was not formally evaluated; however, all who performed the retinoscopic evaluations verified their ability to obtain approximately equivalent values during clinical evaluations of dogs or experimental studies over many years. Eyes were considered myopic when the refractive error was ≥ –0.5 D (ie, the degree of myopia equalled or exceeded –0.5 D); they were considered hyperopic when the refractive error was ≥ +0.5 D. When a difference of ≥ 1.0 D was detected between 2 eyes in the same dog, anisometropia was diagnosed.

**Statistical analysis**—Results are reported as mean ± SD. Mean refractive states were calculated for each breed represented by ≥ 20 dogs. Assumptions for performing various statistical tests (eg, normal distribution of data) were confirmed by graphic analysis. Variables examined for associations with refractive states of eyes and their corresponding refractive errors (D) included age (years), sex, and breed. Univariate ANOVA was used to evaluate differences in mean refractive errors; breed was treated as a between-subject factor, and eye was treated as a repeated factor. A Bonferroni correction for multiple comparisons was used to reduce the risk of Type I errors. Least squares regression was used to evaluate associations between refractive error and age by breed. A 1-sample t test was used to identify breeds with mean refractive errors that were significantly different from emmetropia. Differences in proportions of dogs with various degrees of anisometropia were analyzed by use of a χ\textsuperscript{2} test. Statistical analyses were performed by use of statistical software.\textsuperscript{1} A value of P < 0.05 was considered significant for all analyses.

**Results**

Mean age of all 1,440 dogs was 2.4 years (range, 0.1 to 15 years). Mean refractive state was emmetropic (mean ± SD refractive error, –0.05 ± 1.36 D; range, –6.00 to +6.00 D), and individual values for refractive errors were normally distributed (Figure 1). Sixteen breeds were represented by ≥ 20 dogs. Of those breeds, a mean emmetropic refractive state was identified in 9 breeds, including English Springer Spaniel (mean, +0.09 ± 1.10 D; range, –4.50 to +3.75 D), German Shepherd Dog (mean, –0.15 ± 1.06 D; range, –3.50 to +1.50 D), Golden Retriever (mean, +0.15 ± 0.76 D; range, –3.13 to +1.75 D), Siberian Husky (mean, +0.22 ± 0.80 D; range, –1.00 to +1.13 D), Shetland Sheepdog (mean, +0.22 ± 0.80 D; range, –2.75 to +1.50 D), other Terrier (Fox, Scottish, Belgian, Boston, Border, Bull, Belgian, and Parson Russell; mean, +0.01 ± 1.18 D; range, –2.90 to +3.75 D), Labrador Retriever (mean, –0.12 ± 1.19 D; range, –3.00 to +3.50 D), Border Collie (mean, +0.02 ± 0.89 D; range, –1.50 to +1.25 D), and Samoyed (mean, –0.22 ± 0.80 D; range, –3.00 to +1.50 D; Figure 2). Although the mean refractive state was emmetropic for the aforementioned breeds, discrete subpopulations of myopic dogs were detected within certain breeds.
the mean refractive error for German Shepherd Dogs that were myopic was $-1.60 \pm 0.88$ D (range, $-0.50$ to $-2.75$ D). The mean refractive error for Rottweilers was $-0.90 \pm 1.88$ D (range, $-5.00$ to $+1.75$ D), and the mean refractive error for Rottweilers that were myopic was $-2.70 \pm 1.33$ D (range, $-0.75$ to $-5.00$ D). The mean refractive error for Collies was $-0.80 \pm 2.32$ D (range, $-5.00$ to $+5.00$ D), and the mean refractive error for Collies that were myopic was $-2.34 \pm 1.30$ D (range, $-0.50$ to $-5.00$ D). The mean refractive error for Miniature Schnauzers was $-0.63 \pm 0.79$ D (range, $-2.50$ to $+0.25$ D), and the mean refractive error for Miniature Schnauzers that were myopic was $-1.41 \pm 0.64$ D (range, $-0.50$ to $-2.50$ D). The mean refractive error for Toy Poodles was $-1.87 \pm 1.70$ D (range, $-6.25$ to $+1.50$ D), and the mean refractive error for Toy Poodles that were myopic was $-2.62 \pm 1.19$ D (range, $-0.50$ to $-6.25$ D).

A myopic refractive state was identified in 3 breeds, including Australian Shepherd, Bouviers des Flandres, and Alaskan Malamute. Twenty-six of 41 (63.4%) Australian Shepherds, 42 of 71 (59.2%) Bouviers des Flandres, and 14 of 23 (60.7%) Alaskan Malamutes were hyperopic. Of all hyperopic dogs, the mean refractive error was $+1.48 \pm 0.82$ D (range, $+0.50$ to $+3.25$ D). Mean refractive error among all Australian Shepherds was $+1.28 \pm 1.93$ D (range, $-1.63$ to $+6.00$ D), and the mean refractive error for hyperopes within the breed was $+2.24 \pm 1.65$ D (range, $+0.50$ to $+6.00$ D). Mean refractive error among all Bouviers des Flandres was $+0.62 \pm 0.92$ D (range, $-2.75$ to $+2.88$ D), and the mean refractive error for hyperopes within the breed was $+1.19 \pm 0.58$ D (range, $+0.50$ to $+2.88$ D). Mean refractive error among all Alaskan Malamutes was $+0.98 \pm 0.98$ D (range, $-0.73$ to $+3.25$ D), and the mean refractive error for hyperopes within the breed was $+1.48 \pm 0.82$ D (range, $+0.50$ to $+3.25$ D).

When the frequency of various magnitudes of refractive error was compared for all 1,440 dogs of all 90 breeds, the proportion of dogs with low values ($-0.5$ to $-4.0$ D) of myopic refractive error (23.9%) was significantly ($P < 0.001$) higher than the proportion with high values of refractive errors ($+4.00$ to $+6.00$ D or $-4.00$ to $-6.00$ D; 1.5%). The proportion of all dogs with a refractive error of $-0.50$ D was 8%; only 0.07% of dogs had a refractive error of $-6.00$ D.

Mean refractive error of dogs varied significantly ($P < 0.001$) as a function of breed. Of the numerous possible pairwise combinations that involved the 16 breeds represented by $\geq 20$ dogs, several comparisons were informative after results were adjusted by use of a Bonferroni correction factor. Terriers (Fox, Scottish, Belgian, Boston, Border, Bull, Tibetan, and Parson Russell) were the closest to an emmetropic state. Australian Shepherds and Alaskan Malamutes were significantly ($P < 0.005$) more hyperopic than Terriers; Collies, Rottweilers, and Toy Poodles were significantly ($P < 0.01$) more myopic than Terriers. The mean hyperopic refractive error of Alaskan Malamutes was not significantly different from mean values for Australian Shepherds, Bouviers des Flandres, and Siberian Huskies. The mean myopic refractive error of Rottweilers (a breed with a moderate mean myopic refractive error) was not significantly different from mean values for Shetland Sheep-
dogs, Samoyeds, Miniature Schnauzers, or Collies. The breed with the highest mean myopic refractive error, Toy Poodle, was significantly more myopic than all other breeds (P < 0.001). The breed with the highest mean hyperopic refractive error, Australian Shepherd, was significantly (P = 0.023) more hyperopic than all breeds except Alaskan Malamute. Prevalence of myopia among all 1,440 dogs of all 90 breeds increased for both sexes with increased age of dog (Figure 3). The association between age and an increasingly more myopic refractive error was significant for both sexes (P < 0.001), but was significantly greater in females (ie, the interaction between age and sex was significant [P = 0.033]). Breeds identified as becoming significantly (P < 0.001) more myopic with age (ie, the slope of the association identified by least squares regression was negative) included English Springer Spaniel (slope, –0.13), Australian Shepherd (slope, –0.39), Bouvier des Flandres (slope, –0.12), Collie (slope, –0.21), German Shepherd Dog (slope, –0.13), and Alaskan Malamute (slope, –0.24). However, substantial variability existed within these relationships because refractive errors for some breeds were associated with age more strongly than refractive errors for other breeds.

Longitudinal data were available for 4 English Springer Spaniels that had been evaluated retinoscopically several times over many years (mean time span over which multiple evaluations were performed was 4 years). The data on the 4 dogs were consistent with data for all 4 English Springer Spaniels used in the study reported here. All 4 dogs became more myopic with time. Although the dogs were not evaluated at regular intervals, analysis of the data revealed that 3 of the 4 dogs became more myopic at a rate of approximately −0.1 D/y. Over 6 years, 1 dog became more myopic at a rate of approximately −0.5 D/y.

Six percent of all 1,440 dogs of all 90 breeds were anisometropic (Table 1). Prevalence of anisometropia among breeds ranged from 2.4% in Miniature Schnauzers to 8.9% in German Shepherd Dogs. Normally, the retinoscopic reflex has sharp borders to the edge of the moving streak and direction of movement in the pupil is clearly evident. However, 3.0% of dogs had poor optical quality to the retinoscopic reflex as indicated by an ambiguity to the borders and direction of the reflex. Astigmatism was detected in only 1.0% of all dogs. German Shepherd Dogs had the highest prevalence of astigmatism (3.3%). Of all dogs with astigmatism, the mean value for astigmatism was 1.12 ± 0.50 D (range, 0.50 to 2.50 D).

**Discussion**

A wide range of values have been reported for the resting refractive state of canine eyes. The mean resting refractive state is predominantly myopic; however hyperopia has been reported to predominate in some breeds such as Greyhound. In a commonly referenced schematic diagram of the canine eye, the refractive error of a typical eye was assumed to be +0.6 D. In the study reported here, the mean refractive state for all dogs was emmetropic and mean refractive errors varied with age, breed, and line within a breed. Degree of myopia increased with increasing age in both sexes of dogs. The same association between myopia and age was detected in 4 English Springer Spaniels examined multiple times over several years. Studies of humans have also revealed an increase in degree of myopia with advanced age, presumably attributable to age-related changes in lenses of eyes.

Defocus (natural or experimentally induced) of the retinal image will decrease visual acuity in humans and dogs. Of interest, results of the present study indicated that breeds often used in activities where high visual functioning is required (eg, Labrador Retriever, English Springer Spaniel, or German Shepherd Dog) had a mean emmetropic refractive state. Guide dogs, working dogs, and performance dogs are typically bred through rigor.

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**Table 1**—Frequency of astigmatism (≥0.5 D difference between refractive errors for the vertical and horizontal planes within 1 eye) and anisometropia (≥1.0 D difference between 2 eyes in the same dog) in selected breeds of dogs evaluated by use of streak retinoscopy from 1984 through 2006.

<table>
<thead>
<tr>
<th>Breed</th>
<th>No. of dogs evaluated</th>
<th>No. of dogs with astigmatism (%)</th>
<th>No. of dogs with anisometropia (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All breeds</td>
<td>1,440</td>
<td>14 (1.0)</td>
<td>87 (6.0)</td>
</tr>
<tr>
<td>English Springer Spaniel</td>
<td>337</td>
<td>2 (0.6)</td>
<td>11 (3.3)</td>
</tr>
<tr>
<td>Labrador Retriever</td>
<td>208</td>
<td>0 (0.0)</td>
<td>11 (5.3)</td>
</tr>
<tr>
<td>German Shepherd Dog*</td>
<td>90</td>
<td>3 (3.3)</td>
<td>8 (8.9)</td>
</tr>
<tr>
<td>Miniature Schnauzer</td>
<td>42</td>
<td>0 (0.0)</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Collie</td>
<td>50</td>
<td>0 (0.0)</td>
<td>3 (6.0)</td>
</tr>
<tr>
<td>Toy Poodle</td>
<td>48</td>
<td>0 (0.0)</td>
<td>3 (6.3)</td>
</tr>
<tr>
<td>Rottweiler</td>
<td>23</td>
<td>Six percent</td>
<td>1 (4.3)</td>
</tr>
</tbody>
</table>

*Data for German Shepherd Dogs include 12 guide dogs (a population that typically has low prevalence of myopia).
ous selection processes that select against poor visual acuity. Because optical defocus will negatively affect visual acuity, this breeding process also selects against ametropias. For example, German Shepherd Dogs used as guide dogs have a lower frequency of myopia than German Shepherd Dogs in the general population.

Optical defocus causes a predictable decrement in visual performance. For each 2.0 D of defocus (myopic or hyperopic), a reduction in grating acuity of approximately 1 octave (eg, reduction of visual acuity from 20/20 to 20/100) results.² The impact of optical defocus on the performance of a dog can vary with expectations of the owner. For typical pet dogs, a refractive error of −1.0 D is unlikely to be detected by owners because a high degree of visual acuity is not required for routine activities (eg, finding the door, the couch, and the food bowl). For performance dogs, such as those that compete in field trials, various activities may require various degrees of visual acuity. For example, English Springer Spaniels involved in field trials are typically expected to visually mark a large target (eg, pheasant) within 27 to 46 m from the dog. In our study, 2 English Springer Spaniels with a national or national amateur field trial champion title were identified as having low myopia (−1.00 D and −0.75 D, respectively, in both eyes).

In contrast, Labrador Retrievers involved in field trials are often expected to visually mark objects hundreds of meters away. The image of a duck at 274 m on the canine retina approximates the resolution limits of the canine visual system. In our experience, Labrador Retrievers involved in field trials are evaluated more frequently for vision problems, compared with frequency of evaluation in other breeds. The high frequency of evaluation is likely attributable to the high demands for visual acuity placed upon the dogs by their handlers. Labrador Retrievers with eyes that have mild to moderate refractive errors (generally ≤ 2.5 D) will mark well over distances of 183 to 229 m, and beyond that, they will begin to perform poorly in field trials. We have detected noticeable improvements in performance of myopic field dogs after fitting the dogs with corrective contact lenses, and it is our clinical experience that refractive errors of ≥ 1.5 D are most often associated with impaired performance in high performance dogs, regardless of breed. In addition, young performance dogs with refractive errors with refractive errors (generally more myopic than −1.5 D) require a longer training period than emmetropic dogs. The overall performance of a dog in rigorous conditions of testing, training, and performance depends on many factors, including motivation of the dog, quality of training, quality of interaction with the trainer, and visual acuity of the dog. An exceptional performance dog will develop strategies to optimize its performance and, in some situations, will compensate for minor refractive errors. However, all things equal, an emmetropic dog will visually perform better than a myopic dog.

Results of the present study support the findings of our other reports of myopia (mean refraction > −0.50 D) in certain breeds of dog such as Rottweiler, Collie, and Toy Poodle. For Toy Poodles, selective breeding is used to obtain desired physical attributes, but selective pressure is not typically toward dogs with high visual acuity, which may explain a high prevalence of myopia in the breed. In the present study, analysis of results from a limited sample of Toy Poodles suggested that myopia is inherited in that breed. Entire families were affected (data not shown); however, specific genes associated with myopia in any breed of dog have not yet been identified. Within the group of Toy Poodles used in this study, at least 1 parent (usually the dam) was myopic. Data regarding the genealogy of dogs of other breeds, such as Labrador Retrievers and English Springer Spaniels, were insufficient to conclude whether myopia may be heritable in those breeds. The identification of breeds with naturally occurring myopia and hyperopia and the publication of data regarding the canine genome provide an opportunity for a detailed investigation into the contribution of genetics to the development of refractive error.

Data on myopia in dogs may also be useful for understanding the development of myopia in humans. Dogs have large eyes that approximate the dimensions of human eyes. In humans, the onset of juvenile myopia begins in early childhood and continues into the teenage years.²⁹ Myopia in humans is typically caused by elongation of axial length of eyes relative to the anterior refracting elements.²⁸ Elongation of the vitreous chamber is also a factor.²⁹-³² Interference with equatorial growth in human eyes may interfere with compensatory changes in lens power and may amplify axial elongation, thereby causing myopia. Results of studies of human siblings indicate that genetic elements play a role in the development of myopia. In Labrador Retrievers, a detailed optical component analysis that included corneal curvature, lens curvature, and axial length of emmetropic and myopic eyes revealed that myopia in that breed is associated with lengthening of the vitreous chamber and not an increase in the overall axial length of the globe.³¹ Results of a less detailed analysis of myopia in German Shepherd Dogs also indicated that myopia was not associated with a change in overall axial length of the globe.³² Chemical compounds administered systemically can induce a myopic shift in the refractive state of canine eyes. Dimethyl sulfoxide reportedly alters the refractive index of the nuclear portion of the crystalline lens, which causes myopia.³³,³⁴ Organic phosphorous pesticides (ethylthiometon) also induce myopia, mainly through elongation of the optic axis in conjunction with reduced concentrations of acetycholinesterase in the bloodstream.³³,³⁴ In these respects, studies in dogs may be useful for investigation of therapeutic modulation of human emmetropization.

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