Vitreous cavity replacement with SiO is indicated in complex retinal reattachment surgery in dogs by providing long-term retinal tamponade. Use of SiO in dogs is desirable because they are unable to maintain a stable head position for several hours per day and because of the extensive nature of retinal detachment in dogs. Several complications have been reported for SiO use as a permanent tamponade in humans, rabbits, nonhuman primates, and dogs. These complications include SiO emulsification, anterior chamber migration, keratopathy, glaucoma, inner retinal toxic effects, and subconjunctival migration from sclerotomy sites. Keratopathy and glaucoma are more common in aphakic and, to a lesser extent, pseudophakic eyes, potentially allowing easier access of oil to the anterior chamber than in other eyes. Keratopathy and glaucoma in dogs are more likely to develop with emulsification of the SiO in the anterior chamber. Emulsification occurs more commonly with less viscous versus more viscous SiOs and with SiOs containing higher versus lower amounts of impurities.

Removal of SiO from canine and human eyes can lead to retinal slippage or recurrence of the retinal detachment. In dogs, SiO is rarely removed, whereas in humans, removal is performed most often between 2 and 6 months after surgery to help avoid cataract formation and proliferative vitreoretinopathy and to correct anisometropia. Given that the refractive indices of SiO and vitreous humor are different (1.405 and 1.336 D, respectively), surgeons should consider the possible refractive changes induced following vitreous humor replacement, which, to the authors' knowledge, has not been determined in dogs. The purpose of the study reported here was to evaluate ocular refractive error following retinal reattachment surgery and SiO tamponade in dogs.

Materials and Methods

Animals—During a 4-year period, 47 dogs (63 eyes) referred to a board-certified veterinary ophthal-
mologist (AH or JW) for blindness secondary to retinal detachment were included in the study. All dogs underwent a fluorescein-assisted evaluation of ocular surface integrity, Schirmer tear test, and measurement of intraocular pressure by rebound tonometry. Comprehensive ophthalmic examinations were performed through slit-lamp biomicroscopy and indirect ophthalmoscopy. Refraction testing could not be performed at this point because of the height or folding of the retinal detachment or lack of clear ocular media (eg, opacified vitreous humor with traction bands, blood or pigment, or cataract formation). Indirect ophthalmoscopy could not be performed in dogs with concomitant mature cataracts.

Simultaneous phacoemulsification and retinal detachment repair were performed on 7 dogs. The remainder of the dogs had retinal detachments classified as tractional detachments following phacoemulsification (n = 19), giant dialyses (15), giant retinal tears (5), and inadvertent piercing of the retina ventromediially during previous surgical repair of a nictitating membrane gland prolapse (1). This study was performed in accordance with the guidelines set forth by the Association of Research in Vision and Ophthalmology, and informed consent was obtained from dog owners.

**Procedures**—All 63 affected eyes underwent a standard 3-port pars plana complete vitrectomy (valved or nonvalved with 20-, 23-, or 25-gauge instrumentation) with PFO and SiO® exchange. Eyes that underwent retinal reattachment surgery are referred to as treated, and eyes that did not are referred to as untreated. In brief, the surgical procedure was performed with the aid of an operating microscope,® inverter,® and noncontact viewing system® in anesthetized dogs positioned in dorsal recumbency. Five to 6.5 mm posterior to the limbus, an inferotemporal infusion port® was placed, as were 2 working port cannulae® at the 10- and 2-o’clock positions. A vitrectomy probe® and light pipe® allowed for removal of vitreous humor and traction bands. Injection of PFO liquid through a soft-tipped cannula® unfolded the retina.

The entire anterior peripheral retina (360°) was treated with diode or argon laser endophotocoagulation® to induce formation of retinal adhesions. The PFO was removed via a Charles flute cannula® and replaced simultaneously with SiO®. In all dogs, SiO (1,000 or 5,000 cSt) was injected through the automated high-viscosity infusion cannula and a complete oil fill was achieved. Working ports and the infusion port were closed with 7-0 polyglactin 910 suture. Some dogs had simultaneously performed procedures, including phacoemulsification (cataract surgery with lens implantation) or pars plana phacofragmentation (lens removal through the pars plana region), relaxing retinotomy (excision of fibrotic or contracted peripheral retina to enable attachment of the healthy retina to the underlying retinal pigment epithelium), and endocyclophotocoagulation (diode laser treatment of the ciliary body) to address preoperative ocular hypertension.

**Postoperative evaluations**—Ocular refraction testing was performed by 2 retinoscopists at each study site 1 week to 4 months after surgery (mean postoperative refraction interval, 22 days). Five dogs that lived locally underwent sequential refraction testing (at 1 week, 1 month, 6 months, and 1 year after surgery) to determine whether a change in ocular refraction developed over time. This procedure could not be performed for all dogs because many dogs lived in another state or country.

Dogs that underwent postsurgical evaluations underwent streak retinoscopy in a standing position without pharmacologically induced mydriasis. Vertical meridians were evaluated by use of a retinoscope® in conjunction with concave and convex retinoscopy lens bars.® Purkinje images from the anterior cornea and lens surfaces were aligned, and the emerging retinal reflexes were observed. The intraobserver correlation of test results was 100%. Refraction calculations were performed to adjust for a working distance of 50 or 66 cm.

**Statistical analysis**—For their data to be included in the statistical analysis, dogs were required to have had complete oil filling of the eye and a normotensive eye throughout the study period as well as a round pupil and sight restoration. Data are reported as mean ± SD, except where otherwise indicated. The paired t test was used to compare mean refractive errors between treated (eyes that underwent surgery) and untreated eyes (no surgery was performed) of dogs that had retinal surgery on 1 eye. Subgroup comparisons were made among dogs with a phakic, pseudophakic, or aphakic lens status in both eyes. Unpaired t tests were used to compare mean refractive errors between dogs with different lens status in eyes that underwent surgery and received 1,000- or 5,000-cSt SiO®. Equality of variances was evaluated with the Levene test to select the appropriate test. A stepwise linear regression model was used to evaluate whether a linear relationship existed between refractive error values and the number of days between surgery and retinoscopy. For the statistical analyses, values of P < 0.05 were considered significant.

**Results**

**Animals**—Dogs evaluated during the study period included 27 castrated males, 2 sexually intact males, and 18 spayed females with a mean age of 5.3 years (range, 1.2 to 13.8 years). The following breeds were represented: Shih Tzu (n = 8), Miniature Poodle (7), Bichon Frise (6), Boston Terrier (5), Schnauzer (3), Chihuahua (3), Maltese (2), Cocker Spaniel (2), and Golden Retriever, Japanese Chin, German Shepherd Dog, Rat Terrier, Jack Russell Terrier, Dalmatian, Havanaese, Cavalier King Charles Spaniel, American Hairless Terrier, Lhasa Apso-Poodle cross, and Chihuahua-Poodle crosses (1 each). All dogs were normotensive during the study period, and no cataracts were detected after surgery that prevented a clear visual axis to perform retinoscopy. Fifteen eyes received 1,000-cSt SiO® and 48 eyes received 5,000-cSt SiO®.

**Refraction testing**—Mean refractive errors were summarized by ocular lens status (phakic, pseudophakic, and aphakic; Table 1). In phakic eyes that underwent retinal reattachment surgery (treated eyes), the mean refractive error indicated hyperopia, at a mean ± SD value of 2.67 ± 1.64 D. The mean refractive error of untreated phakic eyes indicated myopia at −1.11 ±
All treated pseudophakic eyes had a 41.5-D foldable acrylic IOL and a greater mean refractive error than treated phakic eyes at 3.24 ± 1.89 D (the difference was not statistically evaluated). The mean refractive error of untreated pseudophakic eyes was –1.25 ± 1.72 D.

Data sets for the refractive error were compared between the treated and untreated pseudophakic eyes (Figure 2). The mean refractive error of treated (SiO-filled) aphakic eyes was 6.50 ± 2.17 D, whereas that of untreated aphakic eyes was 12.25 ± 1.50 D. No significant linear relationship was evident between refractive error and the number of days between surgery and retinoscopy (P = 0.30). Dogs that received 5,000-cSt SiO had consistently greater positive refractive errors (mean, 3.45 ± 2.03 D), compared with dogs that received 1,000-cSt SiO (mean, 2.10 ± 1.75 D); however, the difference was not significant (P = 0.068). Refractive errors for eyes treated with 5,000- or 1,000-cSt SiO were plotted (Figure 4). For the 5 dogs that underwent sequential refraction testing (1 week, 1 month, 6 months, and 1 year after surgery), no change in results was observed.

Discussion

In the present study, the effect of intraocular administration of SiO on ocular refractive error was evaluated in client-owned dogs that underwent 3-port pars plana vitrectomy with PFO and SiO exchange. Silicone oil is a polymer of several polydimethylsiloxane chains. Its viscosity is an effect of the length of the polymer chains and thus its molecular weight.13 In the present study, 1,000- and 5,000-cSt preparations were used. Although 1,000-cSt SiO is preferred for vitrectomy when performed with small-gauge instruments, the use of 5,000-cSt SiO instead results in a better retinal tamponade. The oil has a specific gravity of 0.971 (less than

Table 1—Mean ± SD refractive error (D) in 47 dogs (63 eyes) based on lens status, following 3-port pars plana vitrectomy with PFO and SiO exchange.

<table>
<thead>
<tr>
<th>Lens status</th>
<th>Treated</th>
<th>Untreated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phakic</td>
<td>2.67 ± 1.64</td>
<td>–1.11 ± 1.13</td>
</tr>
<tr>
<td>Pseudophakic</td>
<td>3.24 ± 1.89</td>
<td>–1.25 ± 1.72</td>
</tr>
<tr>
<td>Aphakic</td>
<td>6.50 ± 2.17</td>
<td>12.25 ± 1.50</td>
</tr>
</tbody>
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Pseudophakic eyes were more hyperopic than phakic eyes when filled with SiO. Aphakic eyes underwent a myopic shift when filled with SiO.
that of water) and forms a buoyant sphere within the ocular vitreous cavity, exerting a tamponade effect. These properties result in an SiO bubble that floats toward the superior vitreous cavity. Failure to fill the vitreous cavity completely prevents proper tamponade of the inferior retinal surface. Therefore, an incomplete SiO fill limits accurate refraction test results and may also lead to retinal slippage. For this reason, study dogs were excluded when the SiO fill was incomplete (n = 2).

In a refraction study of 240 phakic dogs of various breeds, streak retinoscopy revealed a mean refractive error of –0.27 ± 1.41 D. These results were not significantly different from those of the present study, in which untreated phakic eyes had a mean refractive error of –1.11 ± 1.13 D. Dogs that were phakic with SiO tamponade had a mean refractive state of 2.67 ± 1.64 D. Hyperopia was observed in all treated phakic eyes. As a result, anisometropia was observed for all dogs that had unilateral surgery in that the treated eye was hyperopic and the untreated eye was myopic.

The treated pseudophakic dogs of the present study had a greater mean refractive error than did treated phakic dogs (3.24 vs 2.67 D, respectively). The mean refractive error for untreated pseudophakic eyes was –1.25 ± 1.72 D. In a study of 23 human eyes, the mean refractive error was 3.57 D for SiO-filled pseudophakic eyes. The refracting surface of the SiO and subsequent refracting power are determined by the posterior shape of the IOL and the extent of oil fill. Human plano-convex IOLs that have less posterior convex curvature induce less refractive change than do nonplane-convex IOLs and are used in conjunction with SiO-filled eyes to optimize vision. Development of a plano-convex-type IOL for dogs may improve the refractive outcome for those that undergo combined phacoemulsification, IOL placement, and SiO tamponade.

All treated eyes in the aphakic dogs of the present study had hyperopia with a mean refractive error of 6.50 ± 2.17 D. In another study, the mean refractive state for aphakic eyes (without SiO) was 14.4 ± 2.10 D. The preoperative refractive state was unknown for treated eyes in the study dogs; however, the mean refractive error for untreated aphakic eyes was 12.25 ± 1.50 D, which is similar to the range in the other study. By comparison, treated eyes were far less hyperopic than the untreated eyes in the other study or had a myopic shift in part because of the higher SiO viscosity, compared with native canine vitreous humor. Therefore, the SiO appears to behave as a lens and converges light rays to improve vision in aphakic patients.

In aphakic humans with SiO tamponade, hyperopia is observed and the SiO causes a shift in vision toward myopia. A 10.50-D myopic shift was identified in aphakic humans that negated the need for 10.00-D contact lenses. Another study of aphakic humans with SiO oil tamponade showed hyperopia in all patients and a reduction in hyperopia (mean myopic shift, –6.70 D) from preoperative to postoperative refraction testing. Vision was improved with the instillation of SiO in those patients. The investigators concluded that the refractive error was dependent on the anterior refracting surface of the SiO.
Experimental SiO studies typically involve use of the Gullstrand standard eye model. This model accounts for a change in the curvature of the SiO surface to anticipate refractive changes in humans. Silicone oil has a higher refractive index than does the vitreous body (1.405 vs 1.336). In aphakic eyes, SiO forms a convex anterior surface, whereas in phakic eyes, SiO forms a concave surface behind the lens. The concave surface works as an intraocular minus lens, which re-forms a concave surface behind the lens. The concave curvature (flattening) of the anterior surface of the SiO facedown position because of the decrease in the curvature.

Hyperopic. The degree of hyperopia decreased in the pronation altered refraction results, but all dogs were hyperopic because of a considerable difference in sound velocity between the vitreous humor and SiO. Sound attenuation in the SiO reduces the size of the retinal instillation. Calculations on the basis of Gullstrand results in development of a hyperopic shift following SiO surface works as an intraocular minus lens, which re-forms a concave surface behind the lens. The concave surface works as a minus lens because previous studies have shown that results can vary in humans with SiO tamponade when the head position is changed. Head position was evaluated in aphakic and phakic humans with SiO-filled eyes. In both groups, supination, sitting, and pronation altered refraction results, but all dogs were hyperopic. The degree of hyperopia decreased in the facedown position because of the decrease in the curvature (flattening) of the anterior surface of the SiO. Use of a standing head position not only standardized the refraction technique, but also allowed for alignment of Purkinje images and minimized spherical aberration.

The mean timing of refraction testing after surgery did not appear to have any effect on the refraction value (P > 0.10). This was important to evaluate because the interval between surgery and refraction testing varied (1 week to 4 months). It was not possible to have all dogs undergo refraction testing at the same time after surgery nor serially over time because of the great distances dog owners would need to travel to visit the ophthalmology practice. Five dogs that lived locally had no significant change in refractive error was identified.

Retinoscopic evaluations involving preoperative and postoperative ultrasonic biometry allow for interpretation of refraction test results. Ultrasonography was not performed in the present study because A-scan axial globe measurements are inaccurate in SiO-filled eyes. Silicone oil in the vitreous cavity leads to a false increase in the axial length measured by ultrasonography because of a considerable difference in sound velocity between the vitreous humor and SiO. Sound attenuation in the SiO reduces the size of the retinal echospike, making it more difficult to detect. Low-viscosity (1,000-cSt) SiO slows sound waves to approximately 1,040 m/s. Typically, when ultrasonographic measurements are obtained through SiO, large erroneous axial lengths (eg, 35 mm) are displayed. The common acoustic disturbance caused by SiO-filled eyes is referred to as the lighthouse effect, reflecting the similarity in appearance to a slightly divergent cone of light emitted in darkness from a lighthouse.

Recently, partial coherence interferometry, MRI, and x-ray CT have been used to overcome the problems encountered with ultrasonic biometry in SiO-filled eyes. These diagnostic modalities have reliably determined the axial globe measurements in humans with SiO tamponade. These techniques would also be reliable in dogs but were not used in the present study given the lack of availability of interferometry and the impracticality of performing MRI or CT before and after surgery.

In the present study, dogs that received 5,000-cSt SiO had consistently greater positive refractive errors (mean, 3.45 D), compared with dogs that received 1,000-cSt SiO (mean, 2.10 D), and the difference approached but did not attain significance (P = 0.068). Aphakic dogs that receive 5,000-cSt SiO may better approach emmetropia because the SiO behaves similarly to a lens. A change in refraction dependent on the viscosity of intraocular SiO was evaluated in 25 phakic humans. Refraction test findings varied with SiO viscosity, in which the use of 1,000- and 5,000-cSt SiO resulted in refractive errors of 5.84 and 6.86 D, respectively. Hyperopia was evident in all phakic humans, with a consistently greater refractive error for those who received the higher-viscosity versus lower-viscosity SiO. These findings mirror the results of the present study for 5,000-cSt versus 1,000-cSt SiO.

Hyperopia was detected in phakic, pseudophakic, and aphakic dogs that underwent SiO tamponade in the present study. Aphakic eyes undergo a noticeable myopic shift when filled with SiO. Pseudophakic eyes are more hyperopic than phakic eyes when filled with SiO. On the basis of refraction test findings in our study, dogs with aphakia would be closer to emmetropia following instillation of 5,000-cSt SiO. On the other hand, phakic and pseudophakic dogs would be closer to emmetropia following instillation of 1,000-cSt SiO.

Other considerations influence vitreoretinal surgeons when determining SiO viscosity selection for canine patients. Surgery involving smaller-gauge instrumentation requires lower-viscosity SiO because 5,000-cSt oil will not pass rapidly through the 23- and 25-gauge infusion cannulae. The patient’s temperament should also be taken into account. Lower-viscosity SiO is more likely to emulsify, leading to keratopathy or glaucoma, and should not be used in extremely active dogs. Intraoperative meniscal followability (the ability to discern a visible difference between optically clear substances) during direct PFO-SiO exchange may be more challenging with 1,000-cSt SiO. Surgeons should consider using 5,000-cSt SiO when visibility is suboptimal. High-viscosity (5,000-cSt) SiO will also provide better tamponade for more chronic detachments. High-viscosity SiO may provide a more reliable tamponade
for dogs with less ocular pigment when a diminished effect of diode endolaser choriretinal adhesions is anticipated and when an argon laser is unavailable.

Retinal reattachment surgery in dogs has become a refined and successful procedure. Newer equipment and intervention by use of smaller-gauge instrumentation have allowed for surgical treatment involving ocular trauma, endophthalmitis, and diagnostic vitrectomy in dogs. With these advancements, it is important to provide the best possible understanding and explanation of postoperative vision to clients. As shown in the present study, emmetropia is unlikely given the presence of SiO in the eye. Despite the degrees of ocular refractive error, dogs had a clinically important improvement in their quality of life and ability to return to usual activity following retinal reattachment.

References

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