Evaluation of 30- and 25-diopter intraocular lens implants in equine eyes after surgical extraction of the lens

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Objective—To determine appropriate intraocular lens (IOL) implant strength to approximate emmetropia in horses.

Sample Population—16 enucleated globes and 4 adult horses.

Procedures—Lens diameter of 10 enucleated globes was measured. Results were used to determine the appropriate-sized IOL implant for insertion in 6 enucleated globes and 4 eyes of adult horses. Streak retinoscopy and ocular ultrasonography were performed before and after insertion of 30-diopter (D) IOL implants (enucleated globes) and insertion of 25-D IOL implants (adult horses).

Results—In enucleated globes, mean ± SD lens diameter was 20.14 ± 0.75 mm. Preoperative and postoperative refractive state of enucleated globes with 30-D IOL implants was –0.46 ± 1.03 D and –2.47 ± 1.03 D, respectively; preoperative and postoperative difference in refraction was 2.96 ± 0.84 D. Preoperative anterior chamber (AC) depth, crystalline lens thickness (CLT), and axial globe length (AxL) were 7.12 ± 0.82 mm, 11.32 ± 0.81 mm, and 40.52 ± 1.26 mm, respectively; postoperative AC depth was 10.76 ± 1.16 mm. Mean ratio of preoperative to postoperative AC depth was 0.68. In eyes receiving 25-D IOL implants, preoperative and postoperative mean refractive error was 0.08 ± 0.68 D and –3.94 ± 1.88 D, respectively. Preoperative AC depth, CLT, and AxL were 6.36 ± 0.22 mm, 10.92 ± 1.92 mm, and 38.64 ± 2.59 mm, respectively. Postoperative AC depth was 8.99 ± 1.68 mm. Mean ratio of preoperative to postoperative AC depth was 0.73.

Conclusions and Clinical Relevance—Insertion of 30-D (enucleated globes) and 25-D IOL implants (adult horses) resulted in overcorrection of refractive error. (*Am J Vet Res* 2010;71:809–816)

Cataract extraction is routinely performed in horses. However, an appropriate IOL implant specifically designed for horses has not been developed or evaluated. Because of the current lack of a commercially available and clinically validated IOL implant, cataract removal in horses results in animals that are aphakic, which results in a marked postoperative refractive error (hyperopia).[1,2] Although most aphakic horses apparently are able to have typical behaviors and perform functions (with some even returning to their prior level of activity following surgery), compared with behavior and function of horses with intact lenses, there is a paucity of studies[1–6] that have been conducted to objectively evaluate vision postoperatively in aphakic horses.

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Abbreviations

AC	Anterior chamber
AxL	Axial globe length
CLT	Crystalline lens thickness
D	Diopter
IOL	Intraocular lens

Before the widespread use of IOL implants in dogs undergoing surgical extraction of the lens, it was thought that aphakic dogs had acceptable and functional vision and did not need to receive an IOL implant.[a] However, following development of the canine IOL implant and subsequent clinical and retinoscopic visual function studies in dogs after IOL implant insertion, it has been determined that the visual acuity of a dog can be returned to normal following lens extraction. Currently, the insertion of an IOL implant is considered the standard of care in dogs that have undergone phacoemulsification.[7,8]

Development of an IOL implant with appropriate dioptric power to approximate emmetropia after insertion in an eye requires accurate measurements of species-specific ocular dimensions, such as corneal

curvature, AC depth, CLT, AxL, and postoperative AC depth.[7–10] Although data for individual ocular dimensions are available, studies conducted to specifically evaluate the globe for the purpose of IOL implant design are limited to those in individual dogs,[9] cats,[10] and horses.[11] In addition to corneal curvature and the measurement of preoperative ocular globe dimensions (ie, AC depth, CLT, and AxL) to calculate the appropriate dioptric power for the IOL implant that is to be inserted, it is necessary to determine the position of the IOL implant relative to the cornea (ie, postoperative AC depth) after insertion.[12] In another study,[11] the AC depth plus 50% of the CLT value was selected as the postoperative AC depth when calculating the refractive power (dioptric power) necessary for the selection of an appropriate equine IOL implant. The data obtained from that study[11] were applied to 2 theoretical formulas[13,14] established for humans, which provided a power estimate of approximately 30 D as the dioptric power of the IOL implant necessary to approximate emmetropia in an adult horse. Prototype IOL implants (eg, 30- and 25-D implants) were manufactured on the basis of the curvature of the cornea and ocular dimensions.[11]

Investigators have reported[2,b] the implantation of IOLs in adult horses, but calculations of the appropriate dioptric power were not performed before their use. Results of a study[15] that was performed by use of a schematic eye,[16] the Binkhorst formula,[13] and an assumed postoperative AC depth of 13.07 mm were used to estimate that a 22.5-D IOL implant would be appropriate to approximate emmetropia in the eyes of horses. The purpose of the study reported here was to determine the appropriate equine IOL implant dimensions and dioptric power needed to approximate emmetropia in enucleated globes and eyes of adult horses after surgical extraction of the lens.

Materials and Methods

Sample population—Sixteen enucleated globes were obtained from 16 horses. Ten eyes were obtained from horses following slaughter and used during phase 1. The remaining 6 enucleated globes were obtained from horses owned by North Carolina State University, which were euthanized for reasons unrelated to this study, and used during phase 2. Insertion of an IOL implant was performed in 4 adult horses during phase 3. Written consent was obtained from each owner for use of client-owned horses. The North Carolina State University Institutional Animal Care and Use Committee approved all protocols and procedures used during the study. The North Carolina State University Veterinary Teaching Hospital Board approved the study protocol for client-owned horses.

Procedures—The study comprised 3 phases. During phase 1, the shape and diameter of the lens were determined in 10 enucleated globes collected from the cadavers of 10 adult horses; these results were used to select the appropriate size of an IOL implant[c] for insertion in 6 enucleated globes obtained from the eyes of equine cadavers and 4 adult horses during phases 2 and 3, respectively.

Phase 1: measurement of the diameter of the equine lens

Six globes were enucleated from 10 adult horses of unknown age, breed, or sex immediately after death at a slaughterhouse and provided to our laboratory within 24 hours after slaughter. After removal of the posterior segment and exposure of the posterior surface of the lens, lenses were evaluated in situ as described elsewhere.[17] Briefly, an equatorial incision was made with a No. 15 scalpel blade, and the incision was continued circumferentially by use of scissors until the posterior hemisphere of the globe was completely separated from the anterior hemisphere. The remaining vitreous body was separated from the posterior lens capsule, and the anterior hemisphere was positioned to expose the posterior lens capsule (**Figure 1**). Axial, anterior-posterior CLT was evaluated in all 10 globes via B-mode ocular ultrasonography[d] with a 20-MHz transducer (effective frequency, 12.5 MHz). The lens shape was determined via visual inspection of the posterior surface of the lens. After the posterior hemisphere of the globe was removed, the lens diameter was measured by use of digital calipers[e] in the horizontal, vertical, 45° oblique, and 135° oblique planes. Diameter measurements were repeated 5 times in each of the 4 planes, and the mean of these measurements was calculated. Mean values from each plane were then combined to obtain a mean lens diameter. After removal of the lens from the globe, CLT was measured by use of digital calipers in the vertical and horizontal planes. The CLT results from each plane were used to calculate a mean CLT value. On the basis of predictive power calculations reported elsewhere,[11] measurement results obtained by use of the calipers[e] and ultrasonography unit[d] were used to develop a prototype 30-D IOL implant for horses.

Phase 2: in vitro evaluation of a 30-D IOL implant

Globes were enucleated from 6 horses of various ages and breeds that were euthanized for reasons unrelated to this study. Each eye was examined for ocular disease by use of slit-lamp biomicroscopy and direct ophthalmoscopy, indirect ophthalmoscopy, or both. Even when both eyes were available, only 1 eye from each horse was used for the study.

After each lens was surgically extracted, but before retinoscopic examination, intraocular pressure was evaluated by use of an applanation tonometer.[f] Intraocular pressure was maintained between 22 and 25 mm Hg by infusion of saline (0.9% NaCl) solution into the vitreous body via the site of insertion of the optic nerve.

Refractive error of each globe was evaluated by use of streak retinoscopy before and after IOL implant insertion. Streak retinoscopy was performed by use of a streak retinoscope[g] and a skiascopy rack[h] equipped with 16-mm lenses (range, –0.5 to +15 D; working distance, 67 cm).[7,18] For each eye, retinoscopy was repeated 3 times in both the horizontal and vertical meridians. Results obtained were combined and a mean value calculated for provision of the net refractive error of each eye. Additionally, preoperative and postoperative mean refractive error values were compared.

Both A- and B-mode ocular ultrasonography were used to examine each globe before lens extraction and after insertion of the 30-D IOL implant. Ultrasonography was performed with each globe positioned on a moistened paper towel within a small plastic container to ensure that the corneal surface was located near the opening of the container. Coupling gel[i] was applied to the corneal surface of each globe, and globes were stored in a refrigerator until examination. The AC depth, CLT, and AxL values were measured prior to lens extraction, and postoperative AC depth was determined immediately following insertion of the 30-D IOL implant.

Extracapsular lens extraction was performed by use of a controlled curvilinear capsulorrhexis technique across approximately 80% of the surface of the anterior lens capsule and removal of the lens nucleus and cortex by expression.[19] Methylcellulose gel[j] was infused into the AC and lens capsule before and after placement of a 30-D hydrophilic acrylate IOL implant (total diameter, 24 mm; optic diameter, 13 mm). The corneal incision was closed by use of 8-0 polyglactin.[k]

Phase 3: in vivo evaluation of a 25-D IOL implant

Four adult horses were included in this phase of the study. One horse (a 22-year-old Thoroughbred gelding) was owned by North Carolina State University, and 3 horses (an 11-year-old Quarter Horse gelding, a 7-year-old Rocky Mountain mare, and an 8-year-old Thoroughbred gelding) were owned by clients of the North Carolina State University College of Veterinary Medicine. Physical examinations (which included evaluation of results of a CBC and serum biochemical analysis) and ophthalmologic examinations (which included slit-lamp biomicroscopy,[l] indirect ophthalmoscopy,[g] and applanation tonometry[f]) were completed prior to surgery in each horse.

Streak retinoscopy was used to determine the preoperative refractive error of each eye. Both A- and B-mode ocular ultrasonography were used to determine preoperative AC depth, CLT, and AxL values. Beginning 2 hours before the induction of anesthesia and continuing for a 48-hour period, penicillin G procaine[m] (22,000 U/kg, IV, q 6 h), gentamicin sulfate[n] (6.6 mg/kg, IV, q 24 h), flunixin meglumine[o] (1.1 mg/kg, IV, q 12 h), and ranitidine[p] (7 mg/kg, PO, q 8 h) or omeprazole[q] (2 mg/kg, PO, q 24 h) were administered. A previously inserted subpalpebral lavage catheter[r] was used for the administration of a 1% solution of atropine sulfate[s] (0.2 mL, q 12 h), neopolydex[t] (0.2 mL, q 6 h), and a 0.05% solution of moxifloxacin[u] (0.1 mL, q 2 h) onto the surface of the eye beginning 24 hours before the start of surgery. Beginning 2 hours before the start of surgery, neopolydex (0.2 mL), flurbiprofen[v] (0.2 mL), atropine (0.2 mL), and moxifloxacin (0.1 mL) were administered via the subpalpebral lavage catheter every 30 minutes. Neopolydex (0.2 mL, q 6 h) and moxifloxacin (0.1 mL, q 4 h for 24 hours, then reduced to 0.1 mL, q 6 h for 72 hours [or until no more drug remained in the initial bottle]) were administered via the subpalpebral lavage catheter during the postoperative period.

Each of the 4 horses was premedicated via IV administration of xylazine hydrochloride (1.1 mg/kg) and butorphanol tartrate (0.02 mg/kg). Anesthesia was induced by IV administration of diazepam (0.1 mg/kg) and ketamine hydrochloride (2.2 mg/kg). Following orotracheal intubation, each horse was positioned in lateral recumbency and maintained at a surgical plane of anesthesia by administration of isoflurane vaporized in oxygen. Butorphanol tartrate (0.02 to 0.05 mg/kg) was administered IV to any horses that required additional analgesia.

Hair surrounding the supraorbital fossa was shaved, and the region was aseptically prepared. A retrobulbar block was performed to provide local anesthesia.[20] The eye was then aseptically prepared and surgically draped in preparation for intraocular surgery. A 4-mm groove was incised approximately 1 mm from the limbus at the 10-o'clock position by use of a No. 64 microsurgical blade.[w] The AC was entered with a 2.8-mm beveled microsurgical blade.[x] Epinephrine hydrochloride[y] (0.2 to 0.3 mL) was infused into the AC to facilitate dilation of the pupil and to control intraocular hemorrhage. The AC was subsequently filled with a viscoelastic material.[z] High-frequency diathermy[aa] was used to perform anterior capsulotomy (diameter, 11 to 12 mm).[21] Cataracts were removed by use of a 1-handed technique[2] and a 45° 4-cm equine-specific phacoemulsification system.[2,3,5,6,aa] The area was irrigated, and residual cortical lens material was aspirated. The lens capsule and AC were reinflated with the viscoelastic material. Then, a 25-D hydrophilic acrylate IOL implant (total diameter, 24 mm; optic diameter, 13 mm) was inserted into the lens capsule. The AC was reinflated with viscoelastic material, and the corneal incision was closed by use of 8-0 polyglactin.

After completion of the 48-hour course of antimicrobials administered IV, each horse was treated with sulfamethoxazole-trimethoprim[bb] (20 mg/kg, PO, q 12 h for 7 to 10 days), flunixin meglumine (1.0 mg/kg, PO, q 12 h on days 1 through 5, then 0.5 mg/kg, PO, q 12 h on days 6 through 10), and ranitidine (7 mg/kg, PO, q 8 h for 14 days) or omeprazole (2 mg/kg, PO, q 24 h for 14 days). After the initial volume of moxifloxacin was administered, each horse received only neopolydex (0.2 mL, q 6 h) and a 1% solution of atropine sulfate (0.2 mL/subpalpebral lavage system, q 12 h [frequency decreased to q 24 h for 30 days after complete mydriasis was achieved]).

Refractive error of each globe was evaluated before lens extraction and after IOL implant insertion. Additionally, retinoscopy was performed as described. Retinoscopy was performed on the university-owned horse within 24 hours before the start of surgery and at 2, 24, and 72 hours and 7, 14, 21, and 28 days after surgery. In the client-owned horses, retinoscopy was performed within 24 hours before the start of surgery and at 2 time points (ie, 7 and 28 days) within a 30-day period after surgery. Preoperative and postoperative refractive error values were compared.

Both A- and B-mode ocular ultrasonography were performed on each eye before and after lens extraction and IOL implant insertion. To facilitate the ocular ultrasonographic examination, each horse was restrained by a handler and sedated by IV administration of detomidine[cc] (0.01 mg/kg), and palpebral and frontal nerve blocks then were performed by use of SC administra-

tion of lidocaine hycrochloride.[20,dd] Proparacaine hydrochloride[ee] (0.2 mL) was instilled onto the surface of the cornea, and ultrasound coupling gel was applied to both the cornea and ultrasound probe. A custom-made standoff was used to ensure accurate examination of the surface of the cornea.[11] A 20-MHz (effective frequency, 12.5 MHz) probe was used to obtain AC depth, CLT, and AxL values preoperatively and AC depth after surgery.

Statistical analysis—Data were entered into a software package[ff] for subsequent calculations and manipulation. Sample size prevented an extensive statistical comparison of results. However, descriptive statistics were calculated and reported as the mean ± SD.

Results

Equine lens diameter—Abnormal findings were not detected during ophthalmologic examination of the enucleated eyes. Mean ± SD diameter of the circular lens (n = 6 lenses) measured by use of digital calipers in the horizontal, vertical, 45° oblique, and 135° oblique planes was 20.54 ± 0.89 mm, 20.18 ± 0.82 mm, 20.18 ± 0.92 mm, and 20.13 ± 0.88 mm, respectively. Mean ± SD cumulative lens diameter (n = 10) was 20.14 ± 0.75 mm. Mean ± SD CLT (n = 10 lenses) measured by use of ocular ultrasonography was 11.21 ± 0.38 mm. The CLT measured by use of digital calipers was only possible for 5 of 10 lenses because the lens was damaged during removal from 5 of the globes; mean ± SD CLT for the 5 lenses was 12.53 ± 0.37 mm. An IOL implant with a total diameter of 24 mm was determined to be an appropriate size implant for insertion during phases 2 and 3.

In vitro evaluation of the 30-D IOL implant—Mean ± SD preoperative refractive error measured by use of streak retinoscopy (n = 6 lenses) was –0.46 ± 1.03 D. Mean ± SD refractive error after insertion of a 30-D IOL implant was –2.47 ± 1.03 D. Mean ± SD difference for refractive error between preoperative and postoperative values after insertion of the 30-D IOL implant was 2.96 ± 0.84 D.

Mean ± SD preoperative AC depth, CLT, and AxL values measured by use of ocular ultrasonography in eyes were 7.12 ± 0.82 mm, 11.32 ± 0.81 mm, and 40.52 ± 1.26 mm, respectively (**Figure 2**). The mean ± SD postoperative AC depth measured after insertion of a 30-D IOL implant was 10.76 ± 1.16 mm. The mean preoperative-to-postoperative AC depth ratio was 0.68.

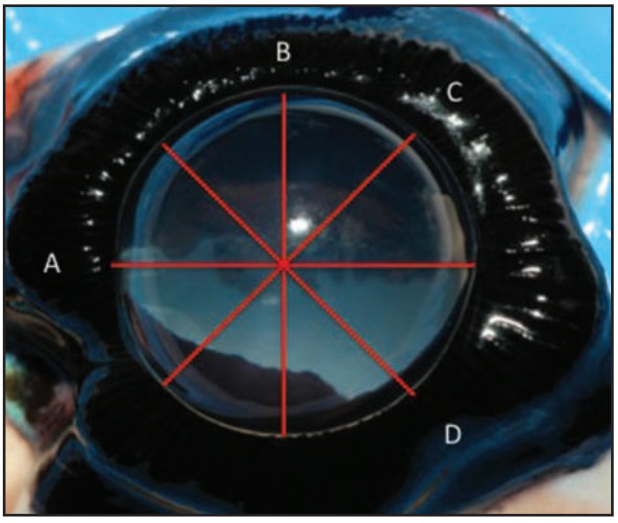

Figure 1—Photograph of the posterior view of an equine lens following removal of the posterior segment. Four planes of manual measurements were obtained by use of digital calipers: A, horizontal; B, vertical; C, 45° oblique; and D, 135° oblique.

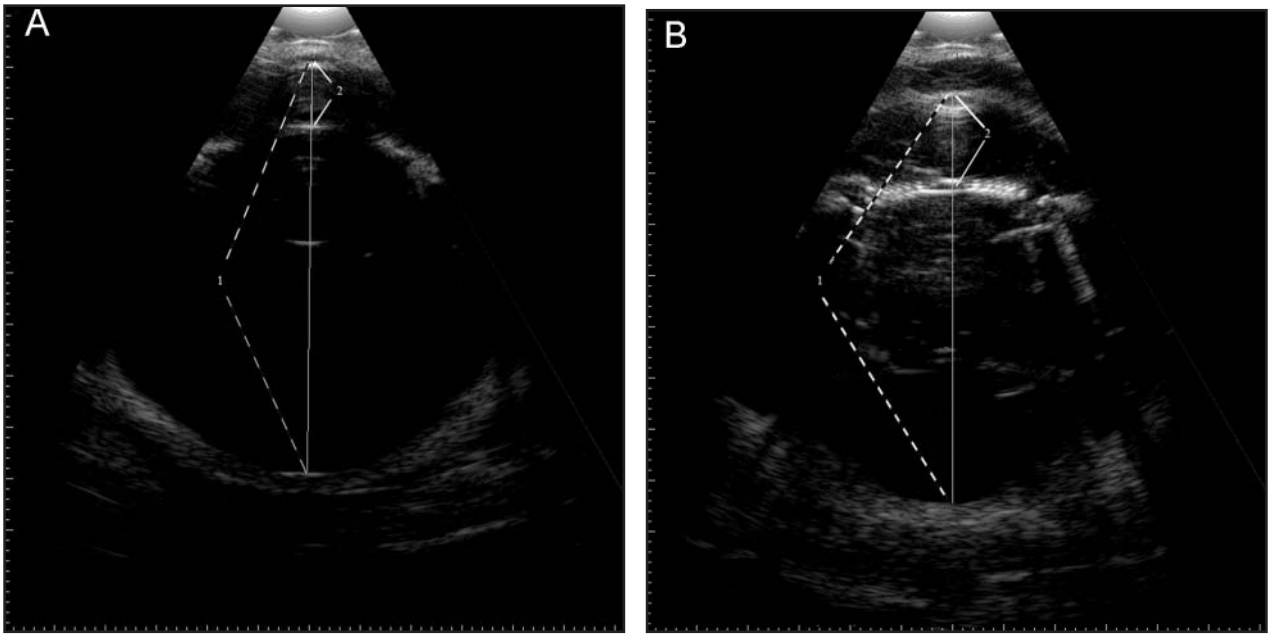

Figure 2—Images obtained by use of B-mode ocular ultrasonography of a representative enucleated globe before (A) and after (B) insertion of a 30-D IOL implant during phase 2. Notice that AxL (1) and AC depth (2) are provided. Marks on the left and bottom of the figure are at intervals of 1 mm. Sweep angle = 60°. Sound velocity = 1.5 mm/s.

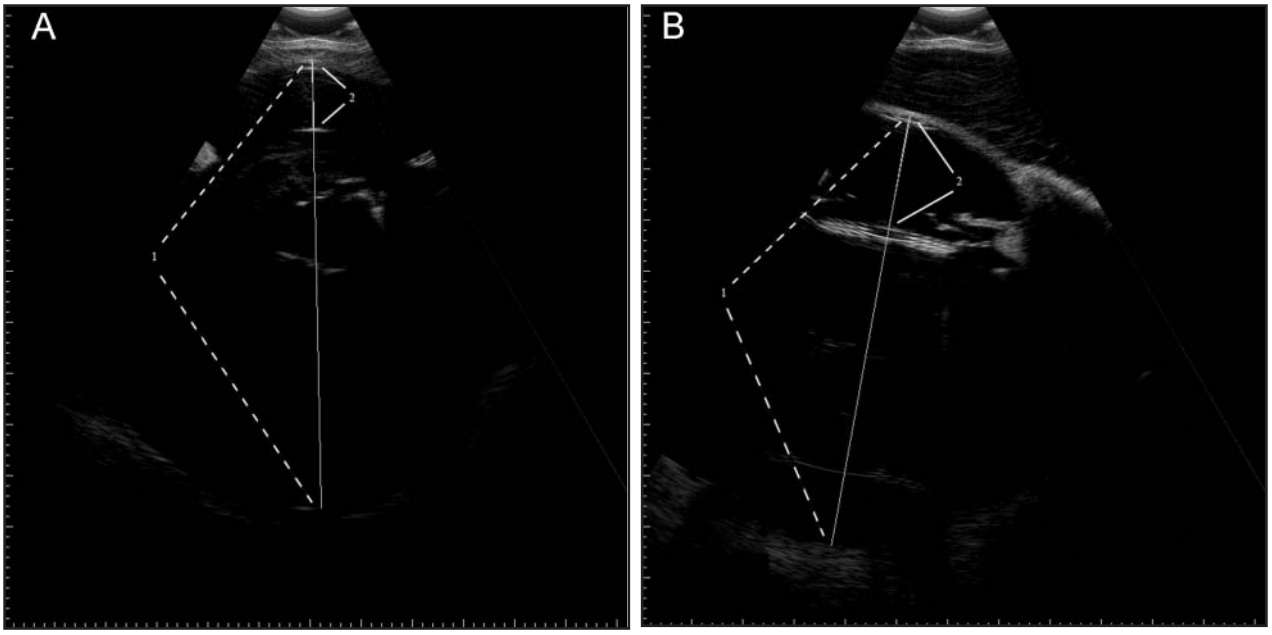

Figure 3—Images obtained by use of B-mode ocular ultrasonography of a representative eye of an adult horse before (A) and after (B) insertion of a 25-D IOL implant during phase 3. *See* Figure 2 for remainder of key.

In vivo evaluation of the 25-D IOL implant—A cataract was identified in the left eye of all client-owned horses and the right eye of the university-owned horse. Because of the extent of opacification caused by the cataracts, streak retinoscopy was not performed preoperatively on the eyes undergoing surgery in all client-owned horses. Because of bilateral cataracts in 1 client-owned horse (Thoroughbred gelding), preoperative evaluation by use of streak retinoscopy was not possible. For the eyes in which preoperative streak retinoscopy was possible (n = 3), mean ± SD preoperative refractive error was +0.08 ± 0.68 D. Mean ± SD refractive error in the client-owned horses during the initial (7 days after surgery) and follow-up (28 days after surgery) postoperative retinoscopic examinations was –3.48 ± 1.62 D and –3.94 ± 1.88 D, respectively. The mean ± SD difference in refractive error between preoperative and postoperative values after insertion of the 25-D IOL implant was 4.02 ± 2.24 D.

Mean ± SD preoperative AC depth, CLT, and AxL values measured by use of ocular ultrasonography were 6.36 ± 0.22 mm, 10.92 ± 1.92 mm, and 38.64 ± 2.59 mm, respectively (**Figure 3**). Mean ± SD postoperative AC depth and AxL evaluated 7 days after surgery were 9.01 ± 1.70 mm and 39.48 ± 2.78 mm, respectively. At 28 days after surgery, mean ± SD postoperative AC depth and AxL measurements were 8.99 ± 1.68 mm and 39.93 ± 3.07 mm, respectively. The mean preoperative-to-postoperative AC depth ratio was 0.73.

Discussion

Phase 1 was used to determine that the lens in adult horses is circular when viewed from the posterior surface[17] and has a mean diameter of 20.14 mm and that a 24-mm IOL implant was an appropriate size for the treatment of hyperopia in aphakic horses to approximate emmetropia. Although the equine lens is approximately 20 mm in diameter, the mean CLT value (12.53 mm) resulted in the insertion of an IOL implant that was of a larger diameter to ensure optimal centering of the optic portion of the IOL implant as well as to ensure that stable placement within the lens capsule and contact of the implant between the posterior surface of the IOL implant with the anterior surface of the posterior lens capsule were accomplished. Mean ± SD postoperative AC depth of 30-D IOL implants inserted into enucleated globes of adult horses was 10.76 ± 1.16 mm and, on the basis of streak retinoscopy results, led to a mean ± SD overcorrection of refractive error of 2.96 ± 0.84 D. Mean ± SD postoperative AC depth for 25-D IOL implants was 8.99 ± 1.68 mm, and mean ± SD overcorrection of refractive error was 4.02 ± 2.24 D.

The dioptric strength of IOL implants in humans and several other animal species has been estimated by use of theoretical formulas.[9–11,22] Factors essential for these calculations include the curvature of the cornea, AxL, and postoperative AC depth (relative to the cornea and the retina).[22] Despite the fact that aphakic refractive error has a narrow range (8 to 15 D) among various species,[2,4,7,8,23] variability among these 3 anatomic criteria results in dramatically different strengths of the IOL implant inserted.

The use of IOL implants and the determination of the appropriate dioptric strength of an IOL implant in dogs were initially determined by a trial-and-error approach because of misconceptions surrounding the relationship between postoperative refractive error and the necessary dioptric strength of the IOL implant inserted.[gg] It was assumed that the relationship between refractive error and dioptric strength was approximately 1:1. Attempts[24,25] to correct aphakic hyperopia in dogs were made by the insertion of 25- to 30-D IOL implants following manual extracapsular extraction or endocap-

sular phacoemulsification of cataracts. The resulting postoperative hyperopia indicated that a more powerful lens would be necessary to approximate emmetropia in dogs.[24,25] Theoretical calculations[9,26] suggested that an IOL implant of approximately 40 D would be needed for dogs. This was determined on the basis of a flatter cornea, shorter AxL, and deeper postoperative AC depth in dogs, compared with these criteria in humans, which require an IOL implant of approximately 18 to 21 D.[9,26] A subsequent study[7] conducted to evaluate the postoperative refractive error in pseudophakic eyes of dogs revealed that IOL implants ranging in refractive power from 14 to 38 D consistently caused some degree of hyperopia. Linear regression analysis from compiled data revealed that an IOL implant with a refractive power of 41.53 D would be necessary to approximate emmetropia in dogs.[7] Subsequently, the 40 D IOL implant became the modal IOL implant, and analysis of results of additional studies[27] of postoperative refractive power have confirmed that most dogs were corrected to within ± 1 D by use of a 40-D IOL implant.

Results of 2 studies[10,12] established the importance of postoperative AC depth in cats. Keratometry, biometry, and retinoscopy were performed to obtain the necessary data to calculate (by use of theoretical calculations) the appropriate dioptric power of an IOL implant for cats. Initial calculations predicted the dioptric power of an IOL implant was between 73 and 76 D.[10] Analysis after insertion of canine IOL implants into globes of feline cadavers revealed that the calculated strength of the IOL implant, which is based on a shallower postoperative AC depth, was between 53 and 55 D.[12] The insertion of 3 IOL implants of various strengths (ie, 48, 51, and 60 D) was evaluated postoperatively by use of streak retinoscopy, which led to the prediction that a 52.8-D IOL implant is required to approximate emmetropia in cats.[12] Thus, although being similar in overall size to the canine globe, the feline globe requires an IOL implant with a much higher dioptric strength (ie, 50 D) to approximate emmetropia, compared with a dioptric strength of 40 D in dogs.[12] The required higher dioptric strength of the IOL implant inserted in cats is attributable to the closer proximity of the IOL implant to the retina following insertion, compared with the proximity of an IOL implant to the retina in dogs.[12]

A relationship exists between dioptric strength of the IOL implant and the effective power of the IOL implant in an eye. Because of differences in AxL, curvature of the cornea, and postoperative AC depth (especially), the preoperative-to-postoperative AC depth ratio is approximately 1:1 in humans, 3:1 in dogs, and 4:1 in cats. Thus, the farther from the cornea an IOL implant is positioned, the closer the implant is to the retina. Because an IOL implant is thin and its refractive power fixed, any changes in the position of the implant within an eye has a dramatic effect on the overall refractive state of the eye following implantation. Therefore, the required dioptric strength of an IOL implant that is necessary to focus light onto the retina will increase as the postoperative AC depth increases.

The mean postoperative AC depth measured during phases 2 and 3 (4 weeks after insertion for phase 3) was 10.67 and 8.99 mm, respectively. This difference in postoperative AC depth between these phases may have resulted from the IOL implant being forced caudally within the AC of the globe by residual viscoelastic substance in the immediate postoperative period. Alternatively, the difference in postoperative AC depth between these phases may have resulted from differences between the enucleated globes and eyes of adult horses for the volume of the vitreous body shifting in the relative position of the anterior surface of the vitreal body. Thus, small differences in postoperative AC depth can have a great impact on the relative refractive power of the IOL implant in an eye and postoperative refraction measurements. This is illustrated by the postoperative refraction results and degree of overcorrection (myopia), which were greater during phase 3 when a 25-D IOL implant was inserted, compared with those during phase 2 when a 30-D IOL implant was inserted. Because postoperative AC depth and refraction results during phase 2 were used to establish the dioptric power of the 25-D IOL implant used during phase 3, the necessary dioptric power was overestimated and therefore overcorrected the refractive state of the eye.

Theoretical calculations,[11,15] which used the Binkhorst formula and were made on the basis of postoperative AC depths of 13.07 and 11.75 mm, that predicted dioptric strengths of 22.5 and 30 D, respectively, for the inserted IOL implants. Investigators in another study[15] used previously reported[16] globe measurements and the radius of the curvature of the cornea (17.2 mm) to predict a postoperative AC depth of 13.07 mm. Other investigators[11] calculated the radius of the curvature of the cornea (20.66 mm) by use of B-mode ocular ultrasonography. Insertion of the 30-D IOL implants selected for use during phase 2 caused substantial overcorrection of mean refractive error. However, the postoperative AC depth in the enucleated globes of the 10 equine cadavers of this study was more shallow than that predicted in previous studies.[11,15] A reduction in dioptric strength was necessary to ensure that incoming light was refracted onto the retina from the IOL implant. A 25-D IOL implant was selected for use during phase 3 to compensate for the more shallow postoperative AC depth detected during phase 2. Postoperative AC depth was shallower in the eyes of live adult horses than in the enucleated globes. The mean overcorrection of the refractive state of the eyes of adult horses after insertion of a 25-D IOL implant led to the calculation of a further reduction in dioptric strength of 7.14 D on the basis of an IOL implant-to-corrective power ratio of approximately 1.8:1.

Analysis of data recorded during phase 3 revealed an overcorrection of the refractive state of eyes of adult horses by approximately 4 D after insertion of the 25-D IOL implant. Assuming that the refractive state of the aphakic globe of horses is approximately hyperopic by 10 D, the 25-D IOL implants had an effective refractive power of approximately 14 D after insertion. The 25-D IOL implant corrected the aphakic hyperopia, and this implant also overcorrected the refractive state of the eyes by an additional 4 D. By dividing the dioptric power of the 25-D IOL implant by the effective refractive power (14 D), an IOL implant-to-corrective power ratio of approximately 1.8:1 was revealed. By multiplying the

amount of overcorrection (ie, in D as determined by use of streak retinoscopy) by 1.8 (ie, each 1 D of overcorrection required an IOL implant adjustment of 1.8 D), we determined that a reduction of approximately 7.14 D in the dioptric power of the 25-D IOL implant would be necessary to approximate emmetropia in the horses evaluated in the study reported here. Thus, subtracting 7.0 D from 25.0 D results in an 18.0-D IOL implant; an IOL implant of this strength may be of appropriate power to approximate emmetropia in adult horses. However, further studies are required to determine whether an 18-D IOL implant will approximate emmetropia in adult horses.

Recalculation of the predicted dioptric strengths of the IOL implants by use of the Binkhorst formula[13] and data collected during ocular ultrasonography in phases 2 and 3 continued to result in an overprediction of the refractive power of the IOL implant necessary to approximate emmetropia, compared with refractive data in enucleated and adult horse eyes. Although the calculated postoperative AC depth was much greater in the study reported here, it is noteworthy that other investigators[15] also overestimated the dioptric strength of the IOL implant. Different values for the curvature of the cornea, postoperative AC depth, and AxL were used to calculate the predicted dioptric strength of the IOL implant in both reported[11,15] attempts and to calculate the appropriate power of an IOL implant for use in horses. On the basis of recalculation of the dioptric strength of the IOL implant by use of the data collected in the study reported here, it was determined that measurements of the curvature of the cornea continued to overestimate the dioptric strength of the IOL implant (data not shown). Another reported value[16] 19.62 D for the curvature of the cornea was more closely able to predict the actual dioptric strength of the IOL implant necessary to approximate emmetropia than the value 20.66 D reported in another study[11] conducted by our laboratory group. However, the mean ± SD curvature of the equine cornea is likely even smaller than 16.46 ± 1.50 D.[11] By use of the Binkhorst theoretical formula[13] and data collected by use of ocular ultrasonography during phase 3, radius of the curvature of the cornea, which was 14.0 and 15.0 mm, respectively, for the Binkhorst formula and phase 3 ultrasonography, was used to predict the dioptric strength of IOL implants of 17.80 and 18.87 D, respectively.

On the basis of results and recalculation of the dioptric power of the IOL implant by use of the Binkhorst formula[13] and application of the IOL implant-to-corrective power ratio of 1.8:1, we suggest that an IOL implant of approximately 18 D would be appropriate to correct an aphakic refractive error in horses. This recommended strength of an IOL implant is less powerful than for an IOL generally inserted in cats (53 D),[12] dogs (41 D),[7] or humans (22.62 D).[26] Investigators reported[b] mean refractive error results close to emmetropia in 4 horses that received 14-D IOL implants after phacoemulsification. Complete ultrasonography data were not available for that study, but analysis of those results also suggest that the selection of IOL implants with a dioptric power between 16 and 18 D is appropriate. Further refractive and ultrasonographic studies in horses after insertion of an 18-D IOL implant are necessary to confirm and refine the suggested dioptric power of IOL implants in horses.

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e. Electronic digital calipers, Fowler & NSK, Tokyo, Japan.
f. Tono-Pen Vet, Reichert, Depew, NY.
g. Heine Optotechnik, Herrsching, Germany.
h. Luneau SAS, Prunay-Le-Gillon, France.
i. Aplicare Inc, Meriden, Conn.
j. First Priority Inc, Elgin, Ill.
k. Polyglactin 910, Ethicon Inc, Somerville, NJ.
l. Kowa SL-14, Kowa Ltd, Tokyo, Japan.
m. Pfizerpen, Roerig, Division of Pfizer Inc, New York, NY.
n. GentaMax 100, Phoenix Pharmaceutical Inc, St Joseph, Mo.
o. Banamine, Schering-Plough Animal Health Corp, Union, NJ.
p. Ranitidine tablets (300 mg), Wockhardt USA Inc, Bedminster, NJ.
q. GastroGard, Merial Ltd, Duluth, Ga.
r. Mila International Inc, Erlanger, Ky.
s. Atropine sulfate ophthalmic solution 1%, E. Fougera & Co, Melville, NY.
t. Neomycin and polymyxin B Sulfates and dexamethasone ophthalmic suspension, Bausch & Lomb Inc, Tampa, Fla.
u. Vigamox, Alcon Laboratories Inc, Fort Worth, Tex.
v. Flurbiprofen sodium ophthalmic solution 0.03%, Pacific Pharma, Irvine, Calif.
w. Millenium Surgical Corp, Narberth, Pa.
x. Unique Technologies Inc, Mohnton, Pa.
y. Epinephrine injection (1:1,000), IMS Ltd, South El Monte, Calif.
z. Acrivet Biovisc 1.2% hyaluronic acid, Acrivet, Hennigsdorf, Germany.
aa. Alexos, Oertli Instrumente AG, Berneck, Switzerland.
bb. Amneal Pharmaceuticals of NY, Hauppage, NY.
cc. Dormosedan (10 mg/mL), Orion Corp, Espoo, Finland.
dd. Lidocaine hydrochloride 2%, Sparhawk Laboratories Inc, Lenexa, Kan.
ee. Proparacaine hydrochloride ophthalmic solution, 0.5%, Akorn Inc, Buffalo Grove, Ill.
ff. JMP, version 8.0, SAS Institute Inc, Cary, NC.
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