Association of height, body weight, age, and corneal diameter with calculated intraocular lens strength of adult horses

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Objective—To determine whether differences exist in the calculated intraocular lens (IOL) strengths of a population of adult horses and to assess the association between calculated IOL strength and horse height, body weight, and age, and between calculated IOL strength and corneal diameter.

Animals—28 clinically normal adult horses (56 eyes).

Procedures—Axial globe lengths and anterior chamber depths were measured ultrasonographically. Corneal curvatures were determined with a modified photokeratometer and brightness-mode ultrasonographic images. Data were used in the Binkhorst equation to calculate the predicted IOL strength for each eye. The calculated IOL strengths were compared with a repeated-measures ANOVA. Corneal curvature values (photokeratometer vs brightness-mode ultrasonographic images) were compared with a paired t test. Coefficients of determination were used to measure associations.

Results—Calculated IOL strengths (range, 15.4 to 30.1 diopters) differed significantly among horses. There was a significant difference in the corneal curvatures as determined via the 2 methods. Weak associations were found between calculated IOL strength and horse height and between calculated IOL strength and vertical corneal diameter.

Conclusions and Clinical Relevance—Calculated IOL strength differed significantly among horses. Because only weak associations were detected between calculated IOL strength and horse height and vertical corneal diameter, these factors would not serve as reliable indicators for selection of the IOL strength for a specific horse. (*Am J Vet Res* 2012;73:1977–1982)

Phacoemulsification is the treatment of choice for vision-impairing cataracts. After lens removal in dogs, cats, and humans, an IOL is routinely implanted to correct hyperopia (farsightedness).[1] The IOL minimizes postoperative refractive error, thereby improving the quality of postoperative vision.[2]

Phacoemulsification is increasingly being used to treat horses with vision-impairing cataracts.[3] However, IOLs are not routinely implanted in horses after lens removal.[3] Although vision is improved, horses are markedly hyperopic after surgery.[4,5,a] Difficulties with contrast and vision at night have also been reported.[4,6,7] To improve postoperative visual acuity, equine-specific IOLs have been developed. In 1 study,[8] implantation of a +18 D IOL was recommended to restore emmetropia. In another study,[9] results close to emmetropia were detected after implantation of +14 D IOLs.[9]

ABBREVIATIONS

ACD	Anterior chamber depth
AGL	Axial globe length
B-mode	Brightness mode
CLT	Crystalline lens thickness
D	Diopter
IOL	Intraocular lens
LED	Light-emitting diode
VBL	Vitreous body length

When a human patient undergoes cataract surgery, IOLs with a wide variety of strengths are available. The AGL, corneal curvature, and estimated postoperative ACD are used to calculate an ideal dioptric strength for each individual.[10,11] This individualized approach is required because of the wide variation in globe size and preoperative refractive error. In contrast, when canine and feline patients undergo cataract surgery, an IOL with a standardized strength is used for each species.[12] This approach is possible because most of the animals are emmetropic prior to surgery and globe sizes are extremely similar.[1]

Most horses are emmetropic[5,a]; however, horses of various breeds, heights, body types, and ages can have globe lengths that differ by $\geq$ 10 mm.[3,7,8,13–17] Variations

in corneal curvature also exist, and breed, body weight, height, age, and AGL all significantly influence the degree of corneal curvature.[13] However, to the authors' knowledge, the impact of variation in AGL and corneal curvature on appropriate selection of an equine IOL has not been reported. Both factors contribute to the dioptric strength of the IOL required to restore emmetropia after cataract surgery. The variation among equine eyes may require a more individualized approach to selection of an IOL with the appropriate strength.

The purposes of the study reported here were to determine whether there was a significant difference in the calculated IOL strength among horses; to assess correlations between the calculated IOL strength and height, body weight, age, and corneal diameter of horses; and to determine whether there was a significant difference in corneal curvature measured with B-mode ultrasonography and a modified photokeratometer. The hypotheses of the study were that a significant difference would exist in the calculated IOL strengths among a population of adult horses; a correlation would exist between the calculated IOL strength and height, weight, age, and corneal diameter for a population of adult horses; and a significant difference would exist in corneal curvature when measured with B-mode ultrasonography and a modified photokeratometer.

Materials and Methods

Animals—Twenty-eight horses, both client-owned horses and horses that were part of Purdue University veterinary teaching and research herds, were used in the study. All horses underwent a complete ophthalmic examination, which included applanation tonometry, slit-lamp biomicroscopy, and bilateral indirect ophthalmoscopy. Horses with ocular abnormalities were excluded from the study. Owner consent was provided for use of those horses in the study. The protocol was approved by the Purdue University Animal Care and Use Committee and conformed to the Association for Research in Vision and Ophthalmology Statement for the Use of Animals in Ophthalmic and Vision Research.

Procedures—Horses were placed in stocks and sedated with xylazine hydrochloride (0.22 to 1.00 mg/kg, IV) and butorphanol tartrate (0.01 to 0.02 mg/kg, IV) prior to examination. An auriculopalpebral nerve block was performed with 1.5 mL of 1% lidocaine solution. Sedative administration was repeated as necessary to complete the examination. Breed and age of each horse were recorded. Height was measured with a measuring stick from the ground to the most dorsal aspect of the shoulders (ie, withers), and body weight was measured by use of a weight tape.

Refractive error—Mydriasis was achieved by topical ocular application of 1% tropicamide solution. Streak retinoscopy then was performed by a single investigator (WMT). Streak retinoscopy was repeated 3 times for each eye in both the horizontal and vertical meridians.[18] Results were used to calculate a mean refractive error for each eye in each meridian.

Ocular measurements—An aliquot (0.2 mL) of 1% proparacaine ophthalmic solution was topically ap-

plied to the corneal surface of each eye. Horizontal and vertical corneal diameters then were measured with a Jameson caliper. A 12-MHz B-mode ultrasonographic probe[b] was used to obtain images. Ultrasonography was performed in accordance with the manufacturer's instructions with the following settings: gain, 53 dB; velocity, 1,532 m/s; probe frequency, 12 MHz; and depth, 60 mm. A transcorneal approach was used. An examination glove filled with distilled water was used as a standoff device to minimize accidental compression of the globe.[3]

The internal calipers of the ultrasonographic unit were used to obtain measurements of ACD, CLT, VBL, and AGL; all measurements were obtained in triplicate by 1 investigator (MCM). The ACD was the distance from the central anterior corneal vertex to the anterior lens capsule. The CLT was the distance from the anterior lens capsule to the posterior lens capsule. The VBL was the distance from the posterior lens capsule to the retina. The AGL was the sum of the ACD, CLT, and VBL.

Keratometry—The corneal curvature was calculated via 2 methods. First, a modified photokeratometer[19,c] that projected a mire ring was used to determine the horizontal and vertical corneal curvatures in accordance with a technique described elsewhere.[19] The modified photokeratometer was constructed[d] from aluminum rods shaped into 2 concentric rings. The outer ring was 215 mm in diameter, and the inner ring was 175 mm in diameter. Multicolored LED bulbs were placed in cylindrical aluminum cups spaced equidistantly and welded to the inner and outer rings. Twenty LED bulbs were placed on each ring. The rings were attached to a video camera via the tripod mounting screw at the base of the video camera. This attachment positioned the lens of the video camera in the center of the rings. The corneal reflection from the lights of the inner ring was used to measure the corneal curvatures of the horses. The 175-mm ring of LED bulbs mounted to the video camera was held 133 mm from the corneal surface (**Figure 1**).

Images were obtained in triplicate of the reflected lights on the corneal surface (Figure 1). The diameter of the reflected lights of the rings was measured in triplicate via computer software[e] at a standard magnification. The diameter of the reflected image, the actual diameter of the light ring, and the distance from the cornea were used to calculate the corneal radius of curvature by use of the mirror-image principle[19] via the following equation:

$$r = 2uI/O$$

where r is the corneal radius of curvature, u is the distance from the inner ring to the cornea (ie, 133 mm), I is the diameter of the reflected inner ring measured in the recorded images, and O is the actual size of the inner ring (ie, 175 mm). The photokeratometer was calibrated by measuring the radius of curvature of steel balls of known diameters.

Second, the horizontal and vertical corneal curvatures were manually calculated from B-mode ultrasonographic images, as described elsewhere.[3] Ultrasonographic images were obtained in triplicate, and
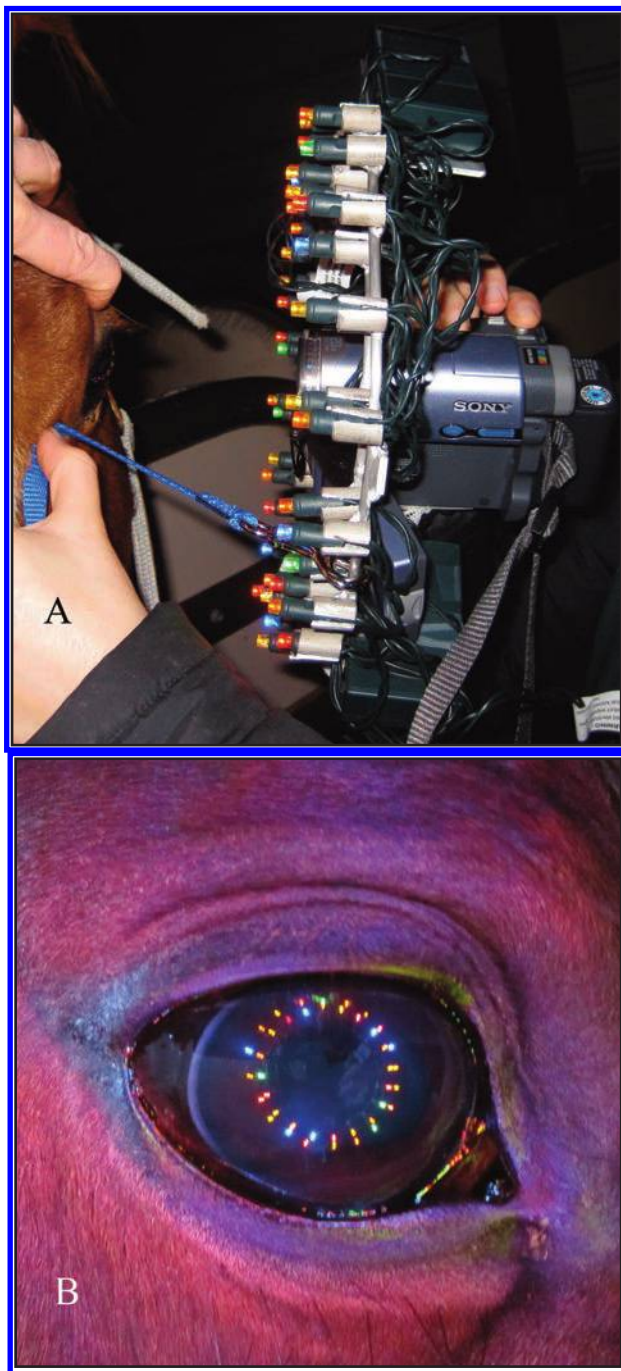
Figure 1—Modified photokeratometer constructed with a 175-mm ring of LED bulbs mounted to a video camera and held 133 mm from the corneal surface of a horse (A) and the reflected image of the lights on the equine corneal surface (called mire rings [B]) that were used to determine the horizontal and vertical corneal curvatures.

measurements were performed in triplicate. A mean value was calculated for the horizontal and vertical corneal curvatures for each eye.

IOL calculation—Collected data were used to calculate the predicted IOL strength for each eye by use of the Binkhorst equation as follows:

$$Pe = (1,366 \bullet [4r - L])/([L - C] \bullet [4r - C])$$

where Pe is the predicted IOL strength, 1,366 is the refractive index of aqueous and vitreous humors, r is the corneal radius, L is the AGL, and C is the postoperative ACD. The measured ACD was used as the predicted postoperative ACD on the basis of data obtained in a previous study.[9] In that study,[9] the postoperative ACD ranged from 5.73 to 9.70 mm, which were values similar to the preoperative ACD of those horses.

Statistical analysis—Data distribution was tested for normality via the Shapiro-Wilk test. A repeated-measures ANOVA was used to compare group means for the calculation of IOL strength. Comparisons of measurements from the same eye or from the same horse were evaluated via a paired t test. Associations between continuous variables, including IOL strength and age, height, weight, and corneal diameter, were assessed via linear regression. Coefficients of determination were used to measure associations. Summary statistics were reported as mean ± SD. Values of $P < 0.05$ were considered significant.

Results

Horses—Twenty-eight adult horses (11 mares and 17 geldings; 56 clinically normal eyes) were included in the study. Breeds of horses represented included 8 (28.6%) Quarter horses, 7 (25.0%) Thoroughbreds, 4 (14.3%) Standardbreds, and 1 (3.6%) each of Appaloosa, Arabian, Haflinger, Morgan–Quarter Horse crossbred, Oldenburg, Paint, Saddlebred, Tennessee Walking Horse, and Trakhener crossbred. Mean ± SD age was 14.9 ± 6.2 years. Mean body weight was 493 ± 52 kg, and mean height was 159.3 ± 7.6 cm.

Refractive error—Mean ± SD horizontal refractive error was +0.32 ± 0.58 D. Mean vertical refractive error was +0.33 ± 0.58 D. Emmetropia (refractive error between –0.5 D and +0.5 D) was detected in 6 (21.4%) horses, hyperopia was detected in 16 (57.1%) horses, and myopia was detected in 2 (7.1%) horses. Anisometropia (unequal refractive errors between the 2 eyes) was evident as emmetropia in one eye and hyperopia in the other eye in 4 (14.3%) horses.

Ocular measurements—Mean ± SD AGL was 40.4 ± 1.8 mm. Mean ACD was 6.8 ± 0.5 mm. Mean CLT was 11.7 ± 0.6 mm, and mean VBL was 21.8 ± 1.3 mm. Mean horizontal corneal diameter was 32.2 ± 1.2 mm, and mean vertical corneal diameter was 24.9 ± 1.4 mm.

Keratometry—Mean ± SD corneal curvature as determined with the modified photokeratometer was 16.5 ± 1.6 D. Mean corneal curvature as determined via B-mode ultrasonographic images was 15.3 ± 2.3 D. There was a significant ($P = 0.004$; paired t test) difference between the corneal curvature values determined with the modified photokeratometer and B-mode ultrasonographic images.

IOL strength—Mean ± SD IOL strength calculated with the corneal curvature data obtained with the modified photokeratometer was 21.9 ± 2.1 D (range, 15.4 to 26.2 D). Mean IOL strength calculated with the corneal curvature data obtained with B-mode ultra-

sonography was 23.2 ± 3.4 D (range, 17.1 to 30.1 D). There was a significant (P = 0.011) difference between calculated IOL strength for left and right eyes. There also was a significant (P < 0.001) difference in calculated IOL strength among horses. Age and body weight were not significantly (P = 0.164 and P = 0.161, respectively) associated with IOL strength. There was a significant (P = 0.002) association between height and calculated IOL strength; however, the association was weak (R^2 = 0.165). There also was a significant (P = 0.013) association between vertical corneal diameter and calculated IOL strength; however, the association was weak (R^2 = 0.109). There was not a significant (P = 0.119) association between horizontal corneal diameter and calculated IOL strength.

Discussion

In the study reported here, calculated IOL strength differed significantly among horses via corneal curvature data for both the modified photokeratometer and B-mode ultrasonography. Age, body weight, height, vertical corneal diameter, and horizontal corneal diameter did not have a strong association with IOL strength. Therefore, none of these factors could be used to predict the required IOL strength for a horse. Instead, it would be necessary to use the corneal curvature and globe dimensions of each horse in a theoretical equation, such as the Binkhorst equation, to determine the appropriate IOL strength.

The Binkhorst equation has been adapted from human medicine. The equation has been used for initial predictions of IOL strength in cats and dogs.[1,12,20] However, the Binkhorst equation initially overestimated the IOL strength for the eyes of cats by approximately 20 D.[1] Unfortunately the Binkhorst equation also appears to consistently overestimate the IOL strength required to restore emmetropia to the eyes of horses.[3] In that study,[3] the predicted equine IOL strength determined by use of the Binkhorst equation was 29.10 D. In the present study, the calculated IOL strength was 22 to 23 D, depending on the method used to determine the corneal curvature. However, on the basis of data from in vivo studies, an IOL strength within the range of 14 to 18 D appears most appropriate for equine eyes.

A primary reason theoretical equations may lack accuracy is the difficulty in predicting the postoperative ACD. A key factor in regard to the amount of dioptric power required for an IOL is the closeness of the IOL to the retina. The closer the IOL is to the retina, the higher the IOL strength required to focus images. The main reason for the differences in IOL strength calculated in the present study and a previous study[3] is the difference in the predicted postoperative ACD. In that other study,[3] the predicted postoperative ACD was arbitrarily selected as the distance from the cornea to the midpoint of the lens. In the present study, the ACD measurement obtained for each horse was used in the Binkhorst formula as the predicted postoperative ACD. The decision to use this measurement was made on the basis of similarities between postoperative ACDs to measured preoperative ACDs in another study.[9]

In addition, a preoperative-to-postoperative ACD ratio of 0.73 was reported in 1 study.[8] In the present study,

use of 0.73 for the ratio would have resulted in a mean ± SD predicted postoperative ACD of 9.25 ± 0.67 mm. Substitution of these predicted postoperative ACD values in the Binkhorst equation would have resulted in a mean predicted IOL strength of 24.5 ± 2.4 D for corneal curvature data obtained with the modified photokeratometer and 26.0 ± 3.6 D for corneal curvature data obtained with B-mode ultrasonography. Use of the mean postoperative ACD of 7.9 mm from another study[9] in the Binkhorst equation would have resulted in a mean ± SD predicted IOL strength of 23 ± 2.3 D for corneal curvature data obtained with the modified photokeratometer and 24.5 ± 3.8 D for corneal curvature data obtained with B-mode ultrasonography. These values are still greater than the range of 14 to 18 D that reportedly can restore emmetropia in vivo.

Final assessment for the accuracy of the Binkhorst equation in predicting the required IOL strength for horses will require the use of postoperative data. After phacoemulsification and placement of an IOL, the corneal curvature, AGL, and postoperative ACD (actual position of the IOL) will have to be measured, and those values then will be used in the Binkhorst equation. The predicted IOL strength could then be compared with the strength of the IOL implanted and the refraction status achieved. However, when such an approach was used in another study,[8] the Binkhorst equation continued to overpredict the required IOL strength. It is likely that further refinement of the Binkhorst equation will be required.

Refraction data should be obtained after surgery for all horses that undergo phacoemulsification and IOL implantation. The refraction data will allow further refinement in selection of an IOL with the appropriate strength. The dioptric power of an IOL implant can be divided by the effective refractive power to determine an implant-to–corrective power ratio.[8] This ratio can then be used to determine the adjustment in IOL strength that would be required to achieve emmetropia. Investigators of 1 study[8] found an implant-to–corrective power ratio of 1.8:1, which indicated a reduction of IOL power by 7.14 D would have resulted in emmetropia. If the 7 D correction factor had been applied to the calculated IOL strength in the present study, the mean predicted IOL strength would have been 15 to 16 D, which is within the currently recommended range of 14 to 18 D.[8,9]

In the study reported here, there was a significant difference in calculated IOL strength among horses, with an observed range of 15.4 to 30.1 D. However, investigators of another study[3] found a difference of only 2 to 4 D in calculated IOL strength among diverse horses (a miniature horse and a draft horse). This may have been attributable to the fact that only a weak association was detected between height and IOL strength in the present study. Other factors such as age, body weight, and corneal diameter were also poorly correlated with IOL strength. Therefore, it appeared that variation in corneal curvature and globe size among horses, as opposed to associations with external characteristics, determined the required IOL strength.

Intraocular distances (including CLT and AGL) measured with B-mode ultrasonography in the present

study corresponded with mean ± SD values reported in another study[3] (11.75 ± 0.80 mm and 39.23 ± 1.26 mm, respectively). Other investigators[13] used B-mode ultrasonography in 90 horses to determine mean values for AGL (41.04 ± 2.67 mm), ACD (6.19 ± 0.75 mm), CLT (11.74 ± 0.71 mm), and VBL (22.98 ± 1.86 mm), which were similar to measurements obtained for the present study. Investigators in that study[13] found that the shortest intraocular distances were found in the smallest horses, and the longest distances were found in the largest horses. However, this differed from the data for the present study because the longest AGL (44.2 mm) was not from the tallest horse and the shortest AGL (36.2 mm) was not from the smallest horse in our study population. Interestingly, the shortest AGL (36.2 mm) was found in the youngest horse of our population, and the second-longest AGL (44.0 mm) was found in the oldest horse of our population. Analysis of these data may suggest that AGL is related more to age than to height, as has been reported by other investigators[14] who found positive correlations between ACD, CLT, VBL, and AGL and increasing age.

Additional measurements obtained from the horses of the present study were the corneal curvatures determined with both B-mode ultrasonography and a modified photokeratometer. Comparison of values obtained with the 2 methods revealed that there was a significant (P = 0.004) difference, which suggested that the corneal curvature determined via these 2 methods cannot be used interchangeably in the theoretical equations for predicting the IOL strength. Therefore, if a theoretical equation becomes the standard for predicting IOL strength in horses in the future, the method used to calculate corneal curvature would need to be specified.

Corneal curvature in horse eyes has been measured with B-mode ultrasonography[3] and a keratograph.[13] The mean ± SD horizontal and vertical corneal curvature in the present study, as determined with B-mode ultrasonographic images (15.3 ± 2.3 D) and via the modified photokeratometer (16.5 ± 1.6 D), differed by approximately only 1 D from results reported in another study[3] (16.49 ± 1.50 D). However, results for the present study differed by approximately 5 to 6 D from the horizontal corneal curvature (21.56 ± 1.68 D) and vertical corneal curvature (22.89 ± 1.65 D) values determined by other investigators.[13] The variation in measurements of equine corneal curvature among studies may be attributable to differences in the working distances as well as differences in the region of the cornea in which the corneal curvature was measured. The working distance for the present study was set at 133 mm from the cornea, whereas the keratograph used in another study[13] was positioned approximately 40 mm from the eye. In the present study, corneal curvature measurements were obtained from sedated, standing horses whose heads were positioned at the level of the heart. The corneal curvature measurements in that other study[13] were obtained from anesthetized horses that were positioned in lateral recumbency. The effect of globe position and general anesthesia on the measurement of corneal curvature in horse eyes is not known.

The keratograph used by other investigators[13] to measure corneal curvature has a measurement zone of 10 mm, compared with 13 mm of the corneal surface for the photokeratometer used in the present study. The keratograph used in that other study[13] was designed to measure the round cornea of humans and not the oval cornea of horses. Therefore, that other device was able to measure only the central and paracentral regions of the equine cornea. When comparing the corneal curvature data for the present study with the data from that other study,[13] there is a difference of 5 to 6 D. This greater variation in corneal curvature may have been attributable to the area of the cornea measured because our device had a larger measurement zone.

The mean ± SD refractive error of horses in the present study for both the horizontal and vertical meridians was +0.3 ± 0.6 D, which is within 0.5 D of the mean refractive state (+0.25 D) of horses reported in other studies.[5,a] Refraction data in 2 other studies[13,b] revealed that most of the horses were myopic (–0.37 ± 0.67 D and –0.06 ± 0.68 D, respectively). In the present study, hyperopia was detected in 16 (57.1%) horses, emmetropia was detected in 6 (21.4%) horses, myopia was detected in 2 (7.1%) horses, and anisometropia was detected in 4 (14.3%) horses. In another study,[13] in which refraction was only determined in the horizontal plane, emmetropia was detected in 77 of 158 (48.7%) horses, myopia was detected in 40 (25.3%) horses, and hyperopia was detected in 38 (24.1%) horses. In that study,[13] more of the horses were myopic by 7.5 years of age. The same association between myopia and age has been reported in dogs and humans.[21–24] This trend was not evident in the present study, despite the fact that most of the horses in our study population were > 7.5 years old and mean ± SD age was 14.9 ± 6.2 years. In the study reported here, most horses were within 0.5 D of emmetropia and were not myopic. The oldest horse in our study population was 26 years old; however, it was one of 2 myopic horses (the other myopic horse was 18 years old).

In the study reported here, a wide range of predicted IOL strengths was calculated for the 28 horses in our study population. Analysis of the results indicated that factors such as height, body weight, age, and corneal diameter were not useful for predicting appropriate IOL strength. Therefore, it will be crucial that future equine cataract surgery patients undergo biometric screening and retinoscopy. Ultimately, postoperative data will allow clinicians and researchers to determine whether equine cataract patients will be corrected to an emmetropic state with a standard IOL with a strength between 14 and 18 D or whether they will need a customized implant selected from an inventory of implants of various dioptric strengths. The refraction data may also allow further refinement for selection of an IOL with the appropriate strength via the corrective power ratio.[3,8,25]

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