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Calculation of posterior chamber intraocular lens (IOL) size and dioptric power for use in pet rabbits undergoing phacoemulsification.

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Abstract:

Objectives: To calculate the size and dioptric power of a posterior chamber intraocular lens (IOL) to achieve emmetropia in adult rabbits, and to compare the dioptric power calculation results using a proprietary predictive formula to a retinoscopy-based method.

Animals studied: Three wild rabbit cadavers, seven pet rabbits with cataracts and ten healthy pet rabbits.

Materials and Methods: Implant size was calculated using a capsular tension ring (CTR) (Acrivet®, Berlin, Germany). Published and cadaveric biometric data were used in the predictive formula. An IOL power escalation study compared the predicted values to the refraction results of one pet rabbit (P1) fitted with a +41D canine IOL(Acrivet®, Berlin, Germany) and six pet rabbits (P2-P7) fitted with prototype IOLs (Acrivet®, Berlin, Germany). Retinoscopy of 10 healthy pet rabbits served as controls.

Results: A 13.5mm CTR fitted in all rabbits and permitted the use of a 13mm IOL. The predicted IOL power ranged between +24D and +25D. The +41D IOL resulted in a refraction error of +8D. Progressive recalculation through a calibration formula led to the insertion of three +49D IOLs in two pet rabbits and a refraction of +6D to +8D, followed by seven +58D IOLs in four pet rabbits and a refraction median of 0D (range: -1.5D to +1D).

Conclusions: A 13mm prototype IOL of +58D achieves emmetropia and is of adequate size for rabbits. The combined use of a CTR and retinoscopy is a useful method to calculate the size and refractive power of a new, species-specific, veterinary IOL.

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Introduction:

Intraocular lens implants with a fixed dioptric power are commercially available for dogs (+41D), cats (+53.5D) and horses (+14D), and the use of IOLs is considered the standard of care in dogs.[1-4] A variety of predictive formulas exist for the calculation of the dioptric power of a posterior chamber intraocular lens implant (IOL),[4-6] and retinoscopy is commonly used to prove if predicted IOL power achieves emmetropia in implanted animals.[7-9] The formulas of Binkhorst and Retzlaff have been used in the past for the IOL dioptric power calculation of dogs, cats and horses.[4-6] However, all formulas depend heavily on the accuracy of the biometric data used in the calculations. Small miscalculations in this data probably led to reported IOL power results that did not lead to emmetropia or fell within too wide a range to be useful for commercial IOL development.[9-11]

The same standard of care given to animals commonly operated for cataract removal could theoretically be extended to all veterinary species. However, this would require that some of the challenges of IOL optimization were overcome with a practical approach that facilitated the calculation of dioptric power and haptic size of new veterinary IOLs. There are no studies on the calculation of the dioptric power of a new veterinary IOL that compare the use of a predictive formula to retinoscopy-based methods in an attempt to simplify the approach to IOL power calculation. There are also no publications in the veterinary literature that describe the calculation originally used to predict the haptic diameter of commercially available veterinary IOLs for dogs, and that might serve to calculate the approximate IOL size of a new implant for a different species.

Rabbit cataracts have been described in association with Encephalitozoon cuniculi,[12-14] and at least one study indicates that age related cataracts might also develop in rabbits due to inbreeding.[15] Cataract removal via phacoemulsification has been described before in a pet rabbit.[12] However, the appropriate size and dioptric power of an IOL for use in rabbits has not been investigated and reported. The authors theorized the IOL power required to reach emmetropia in an adult rabbit would be larger than that required in adult dogs and a cats, and that the size of the implant would be smaller, given the ocular size of the rabbit is smaller than that of dogs and cats.[16,17] The aims of the current study were to describe a practical method to calculate the approximate haptic size of an adult rabbit IOL using a capsular tension ring, and to describe a practical method for IOL dioptric power calculation for an adult rabbit lens through the comparison of a proprietary predictive formula to a retinoscopy-based method that uses an IOL dioptric power escalation approach. Lastly, an additional aim of the study was to report the retinoscopy results of a small, healthy, adult rabbit population in order to serve as comparison to the retinoscopy results of adult rabbits fitted with a prototype rabbit IOL.

Materials and Methods:

The study included seven pet-rabbit patients (P1-P7) with naturally occurring cataracts (Table 1) and that were seen over a period of 14 months (2014-2015), three wild, adult, rabbit cadavers without cataracts, ten pet rabbits without cataracts. The study consisted of three parts. The first part (Part I) dealt with cadaveric eyes used for the acquisition of biometric data and for sham-phacoemulsification in one of the eyes. The latter was used to test the introduction of preselected sizes of a CTR (Acrivet®, Berlin, Germany) and a 60V canine IOL model (Acrivet®, Berlin, Germany). A proprietary formula was also used in this part of the study for the calculation of the theoretical IOL dioptric power needed to reach emmetropia in an adult rabbit. The formula used the biometric data collected as well as previously published biometric data. The second part of the investigation (Part II) focused on an IOL diopter power-escalation study in pet rabbits with naturally occurring cataracts that underwent phacoemulsification with CTR and IOL implantation, followed by retinoscopy. The third part of the investigation (Part III) focused on performing retinoscopy of 10 adult, healthy rabbits without cataracts.

Part I – Calculation of CTR and IOL size and predictive IOL dioptric power. Three adult, fresh, wild rabbits cadavers were obtained from a near-by farm, and had been sacrificed at the farm for reasons other than the study. The lenses of two cadavers were dissected from each eye and their anterior-posterior axi and their equatorial diameter were measured. One eye of the third rabbit underwent sham phacoemulsification with a Signature phacoemulsification machine (AMO Whitestar Signature®, Abbot Laboratories, Illinois, USA). The goals of the surgery were to assess the fit of a capsular tension ring (CTR) and an IOL, and to measure the IOL position within the eye using B-mode ultrasonography. A 14.5mm, a 13.5 mm and a 12.5mm CTR, as well as a 14mm, a 13mm and a 12mm, 41D, 60V IOL models (Acrivet, Berlin, Germany) were available. The CTR size was calculated by introducing the CTR, from largest to smallest, into the capsular bag of the cadaveric eye after phacoemulsification. The CTR introducer was not disengaged from the CTR if all of the CTR's eyelets, or more, overlapped. In such a case a smaller CTR was trialed for sized until a CTR size showed its eyelets had a small amount of overlap or touched. An IOL with a diameter 0.5mm smaller than the CTR was considered a match for the CTR.

Intraocular lens power calculations were made using a proprietary algorithm that uses a series of formulas and was primarily developed for human IOL power calculation

(Table 2), as well as measurements from a variety of sources. These included a radius of corneal curvature (aka corneal radius) of R=7.848mm, which was obtained through an equation that converts the dioptric power of corneal curvature into radius of corneal curvature (Table 3). This equation was originally described in a classic text from 1909. [18] The formula utilized a corneal power value of K=+43D, which is available in the veterinary literature. [19] The corneal power value of K=+73.67D was also used and this was recalculated with the same equation using data obtained from the radius of corneal curvature of a wild cadaver rabbit eye that did not undergo sham phacoemulsification and measured R=4.5813 with B-mode ultrasonography. The n_C in the formula is usually the refractive index of the cornea or the refractive index of a keratometer. The latter was used, which is conventionally n = 1,3375. [20] In the same formula, n_{air} is the refractive index of air, which is 1.0 (Table 3). The anterior posterior axis of the rabbit lens used in the proprietary formula was obtained through the direct measurement with B-mode ultrasound of the eyes of the two wild rabbit cadavers that did not undergo sham phacoemulsification. The actual position of the IOL was also calculated with B-mode ultrasonography from the cadaveric wild rabbit eye that underwent sham phacoemulsification.

Part II - IOL diopter power-escalation study in pet rabbits with naturally occurring cataracts.

Affected rabbit patients underwent ocular b-mode ultrasonographic examination pre-operatively, conscious and non-sedated for general ocular health and lens assessment. A topical anesthetic (proxymetacaine hydrochloride 0.5% w/v, Bausch + Lomb, Surrey, UK) was applied prior to corneal application of sterile lubricant gel (Sutherland Health Ltd, Berkshire, UK), which was used as an ultrasound-coupling medium in all eyes. Dorsal and sagittal plane images were acquired. All of the rabbit patients underwent phacoemulsification with the same machine used in the sham phacoemulsification of the cadaveric wild rabbit eye. The CTR size was chosen based on the results of the first part of the investigation (Part I), and its fitting potential was calculated in each rabbit patient following the same criteria used in the sham phacoemulsification eye. The escalation study initially included one rabbit (Patient 1, P1) that was scheduled to undergo bilateral cataract surgery before the new prototype IOL dioptric power calculation had been planned. As agreed with the owner, the left eye (OS) would have a CTR (AcrivetR®, Berlin, Germany) but it would be left aphakic and, if surgery in that eye was successful, the right eye (OD) would have a CTR and a 41D, 60V, foldable, acrylic, canine IOL implant (Acrivet®, Berlin, Germany). The results of retinoscopy of the pseudophakic eye of P1 (OD) would be later used in a simple calibration formula (Δ IOL = 2 x Refractive Error) to calculate the IOL power needed to reach emmetropia. The results of the calibration would then be compared to the results of Part I of the study. The authors planned to use the calibrated IOL power in the next IOLs to be implanted. All the rabbits would undergo retinoscopy postoperatively and the calibration formula would be used again if further calibration were deemed to be necessary. Retinoscopy (Elite Streak Retinoscope Gold, Welch Allyn, Buckinghamshire, UK) of the vertical axis was planned at approximately two and eight weeks postoperatively in all operated rabbit patients with natural dilation in a room with a low level of light and was performed by the same experienced ophthalmologist. Only animals would undergo retinoscopy if they free of problems that could have interfered with the test.

Part III - Retinoscopy of adult, healthy rabbits.

Retinoscopy (Elite Streak Retinoscope Gold, Welch Allyn, Buckinghamshire, UK) of the vertical axis was performed in 10 control rabbits by the same experienced ophthalmologist. The results were used for comparison to the results of the operated rabbit patients.

Results:

Part I – Calculation of CTR and IOL size and predictive IOL dioptric power.

The size of the lenses of the two cadaveric wild rabbits that did not undergo sham-phacoemulsification measured approximately between 10mm and 12mm (Figure 1). The CTR could be introduced and extracted with ease post nuclear and cortical extraction so long as the hook of the CTR introducer was not disengaged from the CTR introducer. If the CTR was disengaged, it could still be retrieved from the capsule, although intraocular engagement of the introducer with one of the loops of the CTR could be challenging. The 14.5mm CTR was trialed first and it showed there was overlap of the entire eyelet sections of the ring. The 13.5mm CTR had only a small amount of overlap. The eyelets of the 12.5mm CTR did not touch. The 13.5mm CTR was fitted followed by the fitting of an IOL with a13mm in diameter haptic. The proprietary predictive formula results ranged between +29D and +33D, as seen in Table 4.

Part II - IOL diopter power-escalation study in pet rabbits with naturally occurring cataracts.

There were a total of 7 pet rabbits included in this study (Table 1). Several breeds were represented with the Dwarf-lop (a.k.a. Mini-lop) being the commonest. One wild pet rabbit was also included. The B-mode ultrasonography measurements of the pet rabbit eyes are shown in Table 5.

Patient-1 (P1) underwent bilateral phacoemulsification as planned, and before the results of the proprietary formula were known. The patient underwent bilateral implantation of a 13.5mm CTR, which demonstrated to be a good fit in each eye, followed by unilateral implantation of a 13mm, canine IOL in the eye operated second (OD), which also demonstrated to be a good fit.

A total of twelve 13.5mm CTRs were implanted and all implants showed a good fit following the criteria used in this study. All the eyes with a CTR also had a 13mm IOL with the exception of one eye (OS, P1) that did not have an IOL, as agreed with the owner pre-operatively. Therefore, a total of eleven, 13mm IOLs were implanted, including one +41D, 60V, canine IOL model, three +49D, 20S, rabbit prototype IOL models, and seven +58D, 20S rabbit prototype IOL models. Like the +41D, 60V, canine IOL model used, all of the rabbit IOL models used in this study were also foldable and acrylic.

A total of 12 eyes were used for postoperative retinoscopy with P1-P3 undergoing retinoscopy at 2 and 8 weeks and with the other operated rabbits (P4-P9) undergoing retinoscopy only at 8 weeks postoperatively. Retinoscopy in P1 at 2 weeks revealed values of +4D OD and >+14D OS. It was clear the use of a +41D IOL led to a much lower refraction error than the formula predicted, had an IOL power of +25D to +33D been used. The IOL power required to reach emmetropia was recalculated using the data from the first retinoscopy and the calibration formula (Δ IOL = 2 x Refractive Error). This demonstrated that using a relationship of 1:2, if a +41D IOL was used and this resulted in an error of +4D, the IOL strength required to reach emmetropia would be approximately +49D. This, in turn, led to the development and insertion of a preliminary model of rabbit IOL of +49D IOLs in three eyes of two dwarf-lop rabbits (P2 and P3), which resulted in mean refractive errors of +6D, +7.5 and +8D at two weeks postoperatively. By then, repeat retinoscopy of P1 eight weeks postoperatively, revealed a refraction error of +8D. Repeat retinoscopy at eight weeks postoperatively in P2 and P3 revealed no further changes.

The calibration formula indicated that a refraction error of +8D obtained when using a +41D IOL meant the eye required a +57D IOL. The calibration formula also indicated that a refraction error between +6D and +8D when using a +49D IOL required a +61D to +65D IOL. The IOL power chosen for the cases that followed was +58D, as this was between +57D (e.g. the power obtained through the calibration formula) and +59D (e.g. the average between a +49D IOL and a +65D IOL). This led to the development of a second rabbit IOL model (e.g. of +58D) and the insertion of seven of these IOLs in four rabbits. All of these eyes were available 8 weeks after the surgery for retinoscopy, which resulted in a median refraction of 0D (range: -1.5D to +1D), as seen in Table 1.

Part III - Retinoscopy of adult, healthy rabbits.

The majority of the control rabbits were within 0.5D of emmetropia (median: +0.125D with a range of +1D to -2.5D) (Table 6).

Discussion:

This is the first study to detail the dioptric power calculation of a rabbit IOL for use in clinical practice, and to demonstrate via retinoscopy that the use of a 13mm in diameter, +58D IOL resulted in emmetropia with a maximal median refraction of 0D (range: -1.5D to +1D) in the implanted rabbits, which compared favorably to the control population. This is also the first study to demonstrate the difference between the predicted IOL dioptric power calculated through a predictive formula, and the actual IOL power calculated through retinoscopy and a calibration formula. Lastly, the study also describes for the first time the use of a capsular tension ring as a method to measure the approximate IOL haptic size required.

Cataract removal without implantation of an IOL leads to hyperopia. This is estimated to be roughly +10D in humans (Wolfe 1942), +14D in dogs,[1,2,21] and +10D in horses.[22,23] Like-wise, removal of a cataract without IOL implantation in one eye of one rabbit (P1) in this study led to hyperopia of >14D.

A variety of formulas exist for IOL power calculation. The use of the theoretical formulas of Binkhorst and Retzlaff to calculate the intraocular lens power of an IOL for equines predicted that an IOL of +14.2 to +18.7D was required to reach emmetropia.[11] Later, other authors demonstrated the use of the same formulas resulted in a diopter power of approximately +30D.[4] However, it was later shown through retinoscopy that the use of a +14D IOL achieved near emmetropia in 5 out of 6 operated equine eyes with naturally occurring cataracts.[7] Therefore, when first calculating the power of a new IOL for veterinary use, it seems reasonable to employ methodology that relies both on the use of biometric data as well as clinical trials that include retinoscopy.

The calculation of the power of the rabbit intraocular lens (IOL) in the present study was carried out with the support of an optometrist. The results obtained through the formula were very different to those made using retinoscopy. The use of refraction data from the first patient (P1) resulted in an IOL power calculation of +49D. The use of a +49D IOL led to hyperopia in three eyes of two rabbits. Further recalculation of the dioptric power resulted in a power of +58D, which resulted in emmetropia in the majority of the implanted rabbit eyes. In contrast, the use of the proprietary formula resulted in a recommendation to fit rabbit eyes with IOLs of a much lower dioptric power than +58D. This highlights the importance of using highly accurate biometric data in formulas that calculate IOL power.

The reasons for the introduction of errors into predictive formulas are varied. The rabbit IOL calculations made through the use of the proprietary formula were based on an algorithm primarily developed for IOL power calculation of human eyes.[24] The algorithm takes the user through a step by step calculation of the required lens power for a schematic model eye using real measured parameters of a patient's eye, assumed parameters from the literature and equations from the field of simplified geometric optics (Gaussian optics). The curvature of the anterior corneal surface and the thickness of the central cornea were taken from pre-existing, peer-reviewed literature.[19] The refractive index of all the optical media and the ratio of anterior to posterior corneal curvature were based on *Gullstrand's* relaxed 'exact' schematic eye published in 1909. [18] It is possible that published calculations might contain errors. Moreover, the calculation itself is divided into three parts including the prediction of the postoperative estimated lens position (ELP), the calculation of the lens power to achieve a residual refractive error (e.g. emmetropia or ametropia) and the calculation of the residual refractive error for an implanted lens power.[24] However, as a rabbit IOL was not commercially available the last calculation could not be made. In addition, the prediction of the postoperative estimated lens position (ELP) is a considerable challenge.[24] In humans, this is calculated through a prediction algorithm that describes the postoperative ELP as a function of the preoperative measured distances of axial length (*AXL*) and anterior chamber depth (*ACD*), and the prediction of the ELP for human eyes has been previously published and patented.[24] However, in the case of the rabbit, the ELP had to be calculated through an equation (e3, Table 1), which assumed the IOL would sit at the central point of the anterior-posterior axis of the natural lens (e.g. predicted position). In this study, this was predicted to be the equator of the crystalline lens and was measured through B-mode ultrasonography in a rabbit cadaver eye. To the authors' knowledge, there are no studies on the inter and intra-user reproducibility of B-mode ultrasound measurements of the anterior-posterior and the equatorial axi of naturally occurring cataractous lenses in animals, and it is possible the use of B-mode ultrasound might have introduced another source of error into the calculation. A-mode ultrasonography was not available, though the authors acknowledge it might have been more accurate. However, the effect of assuming the position of the IOL would have remained unchanged. The calculation also used the measured position of the IOL. However, IOLs can move in the capsular bag leading to a change in refraction over time until the IOL settles.[25,26] It is very possible that the change in refraction result in P1 over an eight-week period was due to settling of the IOL. Central corneal thickness (cth_c) was another value required in the calculation of predicted IOL power, and there are several cth_c values published in the literature. A study reported a mean corneal thickness in rabbits of 0.507mm,[27] and another study reported it to be 0.388 ± 0.039 mm.[28] The current study used a mean value of 0.35mm (0.30mm - 0.40mm) for cth_c, and this might have added another source of error in the calculation. The present study demonstrates that given the varied nature of sources of error for the calculation of the dioptric power of an IOL, the use of a retinoscopy-based method that employs an IOL dioptric power escalation approach, is successful, flexible and relatively rapid in finding the power of a new veterinary IOL that leads to emmetropia. This is an approach that could bring the use of IOLs, as a standard of care, to a wide variety of veterinary species because it requires a relatively small amount of simple data compared to the large amount of complex data required by a predictive formula.

The average size of patient rabbit eyes is in agreement with what has been previously reported.[17] As average size of the eye of a rabbit is smaller than the reported average size of a dog and cat,[16] it was not surprising to find the IOL power required to reach emmetropia was larger than that of dogs and cats.

IOL size is typically referred to by its haptic diameter. To the authors' knowledge, there are no publications in the veterinary literature that describe the calculation originally used to predict the haptic diameter of the veterinary IOLs that are currently commercially available or that study the reliability of imaging methods for this purpose. One review article suggests that the haptic diameter chosen depends on surgeon's preference, the size of the patient's eye and the memory of the haptic.[29] Commercially available IOL implant diameters commonly used in adult dogs and cats come in 12mm, 13mm and 14mm sizes. The use of capsular bag biometry using a CTR to measure the circumference of a capsular bag in vivo has been described in humans.[30] The findings of the present study revealed that CTRs may be used to measure the approximate diameter of a CTR and IOL needed in a particular rabbit patient in vivo.

The average lens diameter size measured through B-mode ultrasonography in this study were similar to the lens diameters of the eyes of two adult, wild-rabbit cadavers that were measured directly after lens dissection, and both were smaller than the CTR and IOL diameters implanted in rabbit patients. One of the aims of CTR use is to make contact with 360-degrees of the capsular equator to reduce lens epithelial cell centripetal proliferation and migration by physically blocking the cells.[30,31] Therefore, the ideal CTR is as large or slightly larger than the equatorial diameter of the natural lens prior to phacoemulsification. Clinically, a 13.5mm CTR and a 13mm IOL fitted all the implanted eyes without obvious problems, suggesting a 13.5mm CTR and a 13mm IOL may be used in pet rabbits of a similar size to the rabbit patients included in this study. It is interesting to note that the lenses in the adult wild rabbits included in this study were different in size, which the authors theorized simply reflected natural variation, and this was not mirrored in the pet rabbit population included. It was also interesting to note that the pet rabbit patient with the smallest body weight (P5) did not have smaller lens diameter or a smaller anterior-posterior ocular axis than the rest of the pet rabbit patient. It remains to be seen if a range of CTRs and rabbit IOL haptic sizes would be useful in clinical practice.

At the time of the surgery there were no reports in the veterinary literature of CTR or IOL fitting in pet rabbits with naturally occurring cataracts. However, there were many reports that described the use of sham phacoemulsification in laboratory rabbits for the study of IOL implants manufactured for use in humans.[19,32-37] Some of these studies concluded IOLs may reduce the amount of posterior capsular opacification (PCO).[34,35] The use of CTRs has also been associated with a reduction of PCO in humans[31,38] and in dogs.[39] Moreover, rabbits have been described to produce large amounts of PCO through lens epithelial cell regrowth.[40-42] Therefore, the use of a CTR and IOL was generally recommended to help reduce the potential for regrowth and PCO development postoperatively. The IOL size for adult rabbits is described for the first time in this study, and it is up to the surgeon to decide if they want to use a CTR to measure the size of the capsular bag and/or to help reduce potential PCO.

Ametropia is reported to occur naturally in dogs, cats and horses and to vary with breed and age.[43-45] Some dog breeds have been shown to have myopia, which increases with age in both sexes.[43] The insertion of a +58D IOL in adult pet rabbits in this study resulted in a refraction error that compared favorably to the 10 adult pet rabbits used as retinoscopy controls. However, the control population used was not large and included a variety of ages. The effect of breed and age on the refractive results of rabbits remains unknown and further studies that investigate this are warranted.

Conclusions:

A retinoscopy-based method that uses an IOL dioptric power escalation approach can be used to calculate the power of a new veterinary IOL that leads to emmetropia. The use of a +58D IOL resulted emmetropia in the implanted rabbits in this study. A CTR may be used to calculate the approximate IOL size required in vivo. A CTR of 13.5mm in diameter with an IOL haptic size of 13mm is adequate for rabbits of a similar size to the rabbits included in this study.

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Tables 1-6

Patient	Signalment	13.5mm CTR	13mm IOL power	Retinoscopy OS
P1	Dwarf-lop, 4 year 3 month old, F/N	OU	OS: left aphakic OD: +41D	OS: > +14D OD: +8D
P2	Dwarf lop, 7 year 6 month old, F/N	OU	OU: +49D	OS: +8D OD: +6D
P3	Dwarf lop, 3 year 7 month old, F/N	OS only	OS: +49D	OS: +7.5D
P4	Dwarf lop, 3 year old, M/N	OU	OU: +58D	OS: +0.5D OD: 0D
P5	Mixed breed, 8 year 5mo old, M/N	OU	OU: +58D	OS: 0D OD: 0D
P6	French Lop-Mix, 5 year 2 month old, M/N	OD only	OD: +58D	OD: +1D
P7	Wild-domesticated, 7 year, 9 month old, F/N	OU	OU: +58D	OS: -0.5D OD: -1.5D

Table 1. Client-owned rabbits with cataracts that underwent phacoemulsification (P1-P7). The table shows the signalment of the rabbits including their sex (F/N = female, neutered, M/N = male, neutered), if a capsular tension ring (CTR) and an intraocular lens implant (IOL) were used, and the results of postoperative retinoscopy, all of which are shown for the right eye (OD) and/or the left eye (OS). The retinoscopy results shown were obtained at 8 weeks postoperatively in all cases.

e1: $r_{post} = r_{ant} \times 0.88311$

$$\frac{6.8\ mm}{7.7\ mm} = 0.88311$$

e2: $postACD = ELP - cth_C$

e3: $ELP = ACD + \left(\frac{cth_{LC}}{2}\right)$

e4: $s1 = \frac{1000}{ref_S} - 12.00$

e5: $s1' = \frac{n'_C}{\frac{n'_{air}}{s1} + \frac{(n'_C - n'_{air})}{r_{ant}}}$

e6: $s2 = s1' - cth_C$

e7: $s2' = \frac{n'_{aqu}}{\frac{n'_C}{s2} + \frac{(n'_{aqu} - n'_C)}{r_{post}}}$

e8: $s_{IOL} = s2' - postACD$

e9: $s'_{IOL} = AXL - postACD - cth_C$

e10: $f'_{IOL} = \frac{1}{\frac{1}{s'_{IOL}} - \frac{1}{s_{IOL}}}$

e11: $P_{IOL} = \frac{n'_{aqu}}{f'_{IOL}} \times 1000.00$

Table 2. Sequential equations 1-11. (e1): Use of the Gulltrand's ratio in the calculation of the corneal curvature, where r_{ant} = preoperative measured radius of the anterior corneal curvature in mm, and r_{post} = radius of the posterior corneal curvature in mm. (e2): The prediction of the estimated lens position post-operatively (*ELP*) for human eyes. Postoperative anterior chamber depth is *postACD* and central corneal thickness is cth_c. (e3): Calculation of the estimated lens position for a rabbit eye, where the preoperative measured anterior chamber depth is *ACD* and cth_{LC} is the preoperative measured central thickness of the crystalline lens (e4): Calculation of the front focal length (FFL) of the anterior corneal surface (s1) by use of ref_s as the target

residual refractive error, which in this case is emmetropia ($ref_s = 0$). (e5): Calculation of back focal length (BFL) of the anterior corneal surface (s1’), where n'_C is the refractive index of the cornea and n'_{air} is the refractive index of air, (e6): Calculation of FFL of the posterior corneal surface (s2). (e7): Calculation of BFL where n'_{aqu} is the refractive index of the aqueous humor (s2’). (e8). Calculation of FFL of the IOL (sIOL). (e9): Calculation of BFL of the IOL, where *AXL* is the preoperative measured axial length of the eye (sIOL’). (e10): Calculation of the effective focal length of the thin IOL f'_{IOL}. (e11): Calculation of the exact IOL power P_{IOL}. The power is rounded t to the next increment in manufacturing range.

$$K = \frac{(n_C - n_{air})}{r_{ant}}$$

Table 3. The equation for conversion from corneal power *K* into corneal radius R, and vice versa. The equation converts the radius of a refracting curvature measured in mm, into a curvature power measured in diopters. Here, n_C is the refractive index of the cornea or a keratometer, n_{air} is the refractive index of air and r_{ant} is the preoperative measured radius of the anterior corneal curvature in mm.

Values used in calculations	Results with corneal R using the measured and estimated IOL positions	Results with corneal K using the measured and estimated IOL positions
Axial length = 16,396mm Preop ACD = 2,6888mm Postop ACD = 6,157mm cth LC = 7,341mm	Using an estimated IOL position (preop ACD + 0,5 * cthLC): **IOL power #1** = +29,00D with refractive error of +0,21D **IOL power #2** = +30,00D with refractive error of -0,23D	Using an estimated IOL position (preop ACD + 0,5 * cthLC): **IOL power #1** = +23,00D with refractive error of +0,13D **IOL power #2** = +24,00D with refractive error of -0,29D
cth Cornea = 0,4mm Cornea R = 4,753mm Cornea K = 73,67D Central thickness of the IOL with cthIOL = 1,5mm	Using the measured IOL position (postop ACD + 0,5 * cthIOL): **IOL power #1** = +32,00D with refractive error of +0,27D **IOL power #2** = +33,00D with refractive error of -0,13D	Using the measured IOL position (postop ACD + 0,5 * cthIOL): **IOL power #1** = +25,00D with refractive error of +0,34D **IOL power #2** = +26,00D with refractive error of -0,03D

Table 4. Results of the proprietary predictive formula showing the values used in the calculation and the results using the corneal power (K) and the corneal radius (R), as well as the measured IOL position, which refers to the position of the IOL in the wild cadaver rabbit eye that underwent sham phacoemulsification, and the estimated IOL position, which was based on the ultrasound measurement of the center of the natural lens measured in wild rabbit cadaver eyes. The corneal power (K) indicates the power of a single-surfaced cornea based on the measurement of the anterior corneal radius. The corneal radius (R) used assumed the curvature of the anterior corneal surface was known.

Patient	Weight	APGA OS/OD		EGA OD/OS		APLA OS/OD		ELA OS/OD	
P1	2.81 kg	17.3	17.8	16.8	17.8	7.7	8.1	10.7	11.2
P2	2.27 kg	17.0	17.8	19.5	18.3	7.2	5.9	11.0	9.0
P3	2.10 kg	16.7	16.7	19.4	19.2	7.2	5.8	10.5	9.7
P4	2.50 kg	17.1	17.9	19.6	19.1	9.8	8.5	11.6	11.8
P5	1.80 kg	16.3	16.2	17.6	18.7	7.8	7.5	11.4	11.0
P6	2.70 kg	17.4	17.5	18.7	19.0	7.4	7.8	11.9	12.1
P7	2.30 kg	17.9	17.6	19.2	18.8	8.5	9.9	12.1	12.5
Avg.	**2.35Kg**	**17.23mm**		**17.40mm**		**7.79mm**		**11.18mm**	

Table 5. Ocular measurements (in mm) from B-mode ultrasonography of the client-owned rabbits with cataracts that underwent phacoemulsification. Anterior-posterior globe axis (APGA), equatorial globe axis (EGA), anterior-posterior lens axis (APLA) and equatorial lens axis (ELA). All the measurements of length are expressed in mm.

Control	Signalment	Retinoscopy OD	Retinoscopy OS
C1	Dwarf lop, 5 month old, F	0D	-0.5D
C2	Dwarf lop, 5 month old, M	0D	-0.5D
C3	Dwarf lop, 3 year old, F	-1D	-0.5D
C4	Dwarf lop, 6 year old, M	+0.5D	-2.5D
C5	Dwarf lop, 6 year old, M/N	+0.5D	0D
C6	Dwarf lop, 6 year old, F	+0.5D	+0.5D
C7	Dwarf lop, 3 month old, F	+1D	+0.5D
C8	Dwarf lop, 1 year old, F	+0.5D	+0.5D
C9	Dwarf lop, 4 year old, M	+0.5D	+0.5D
C10	Rex, 3 year old, M	+1D	+1D

Table 6. Dwarf-lop rabbit population without ocular problems on ophthalmic exam that underwent retinoscopy in the vertical axis and served as controls.

Figure

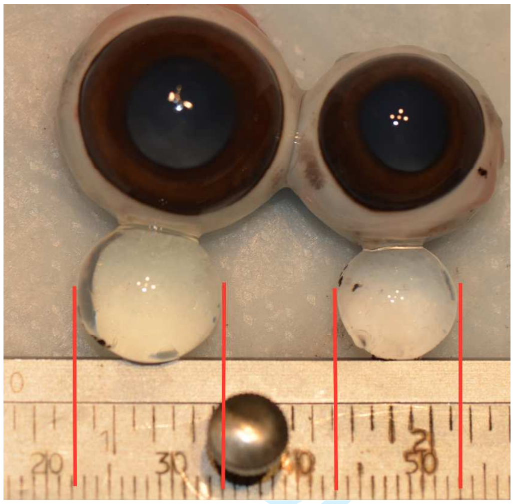

Figure 1. Image showing the dissected lens from the eyes of two wild rabbit cadavers. The complete companion eye of each extracted lens is shown above the extracted lenses. The diameter of the lens in the left of the image measured approximately 12mm and the diameter of the lens in the right of the image measured approximately 10mm.