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CLINICAL ARTICLE

The effect of elective phacofragmentation on central corneal thickness in the dog

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Abstract

Objective To characterize the short- and intermediate-term effects of elective phacofragmentation on central corneal thickness (CCT) in the dog.

Methods Forty-three dogs (66 eyes) undergoing elective phacofragmentation cataract surgery over an 8-month period at a single private ophthalmology referral clinic were enrolled in the study. Central corneal thickness was measured by ultrasonic pachymetry just prior to surgery, 1 day following surgery, 1 week postoperatively, 1 month postoperatively, and more than 2 months postoperatively. Statistical comparisons were made using descriptive and inferential statistical methods with a level of significance set at $P < 0.05$.

Results The initial mean CCT of 611 μm increased dramatically to 741 μm 1 day postphacofragmentation. Mean CCT remained slightly elevated (666 μm) at 1 week postoperatively, but became indistinguishable from preoperative measurements by 1 month postsurgery (626 μm) and remained so at the > 2-month time period (618 μm). The change over time and trends remained statistically significant and remarkably similar, even when adjusted separately for age, gender, surgeon status, diabetic status, cataract type, and total surgery time (all $P < 0.0001$). Corneas of diabetic dogs were thicker than those of nondiabetic dogs at all time periods, and the overall effect of diabetic status was significant ($P = 0.016$). There was a sharper increase from the preoperative to 1-day postoperative CCT in the diabetic group compared to the nondiabetic group. The mean CCT of the pseudophakic group took longer to return to baseline than the aphakic group. The mean CCT of the foldable intraocular lens (IOL) group took longer to return to baseline than both the rigid IOL and aphakic groups. Dogs with documented in-hospital postoperative intraocular pressure spikes (> 25 mmHg) developed a greater 1-day postsurgical increase in CCT. It appears that there was a sharper decrease in mean CCT from 1 month to more than 2 months postoperatively in the postoperative hypertension group.

Conclusions Elective phacofragmentation cataract surgery results in an increase in CCT in dogs, but this increase is transient. Particular care may be indicated to protect the endothelium of diabetic patients undergoing phacofragmentation. These data do not clearly support an advantage of the small-incision cataract surgery made possible by the use of foldable IOLs.

Key Words: cataract, corneal thickness, dog, pachymetry, phacofragmentation

INTRODUCTION

Iatrogenic corneal endothelial damage caused by elective surgical procedures, such as cataract surgery via phacofragmentation, deserves careful consideration. Human ophthalmology researchers have characterized the effects of ultrasound energy from phacofragmentation on corneal thickness and endothelial cell density.[1] A moderate decrease in endothelial cell density

was found to result from a single episode of phacofragmentation, but this appeared to only transiently compromise endothelial cell function, presumably because the endothelial cell count did not fall below critical physiological density.[1]

Normal corneal thickness measurements in several veterinary species, including the dog, have been determined via ultrasonic pachymetry and/or specular microscopy.[2–9] Nonetheless, documentation of the effects of iatrogenic injury on corneal thickness is lacking in the veterinary literature. Specifically, the effects of cataract surgery on the endothelium and corneal thickness of the dog have not been considered since 1983,[10] and significant changes in standard canine cataract surgery protocols have occurred since this time. The goal of this study was to quantify the short- and intermediate-term effects of phacofragmentation on corneal thickness in the dog undergoing routine phacoemulsification cataract surgery.

MATERIALS AND METHODS

Patient selection

Forty-three dogs (66 eyes) undergoing elective phacofragmentation cataract surgery at a single private veterinary ophthalmology referral facility between March and November 2003 were enrolled in the study. All patients underwent a complete initial ophthalmic examination. Scotopic flash electroretinogram (ERG) and ocular ultrasound testing with results considered satisfactory to the attending clinician were required preoperatively for each enrolled eye. Preanesthetic blood screening, including a blood glucose measurement at minimum, was required of all participants. Direct gonioscopic examination was performed on the majority of surgical candidates preoperatively using a Koeppe goniolens (Ocular Instruments, Bellevue, WA, USA) and handheld slit-lamp biomicroscope (Kowa SL-2 or SL-14, Kowa Company, Ltd, Tokyo, Japan).

Surgical and medical protocols

Following initial preoperative examination, patients were treated as necessary to control phacolytic uveitis. Surgical intervention was delayed for diabetic dogs until satisfactory blood glucose regulation was achieved based on blood glucose curve or per referring veterinarian. Four days prior to surgery, topical antibiotic–steroid combination therapy using 0.3% gentamicin-1.0% prednisolone acetate ophthalmic solution (Pred-G®, Allergan Inc., Irvine, CA, USA) four times daily was initiated. This protocol replaced any previous topical steroid medications, but was often additive to topical nonsteroidal medications, particularly for diabetic patients. On the day of surgery, 0.3% gentamicin-1.0% prednisolone acetate ophthalmic solution was applied to the surgery eye(s) once, followed by flurbiprofen (Pacifica Pharma, Irvine, CA, USA) q30 min during the 2 h prior to induction. Tropicamide 1% (Falcon Pharmaceuticals, Ft. Worth, TX, USA) was administered twice and 2.5% phenylephrine (Akorn Inc., Buffalo Grove, IL, USA) once during the final hour prior to induction. Typically, patients were premedicated with an opioid or neuroleptanalgesic combination. They were induced with IV propofol (Propoflo, Abbott Laboratories, Abbott Park, IL, USA) and maintained with inhalant isoflurane (Attane™ isoflurine USP, Minrad Inc., Bethlehem, PA, USA) adminsistered via endotracheal tube. Injections of flunixin meglumine (FluMeglumine 50 mg/mL, Phoenix Pharmaceuticals, St. Joseph, MO, USA) and cefazolin sodium (Sandoz Inc., Broomfield, CO, USA) were administered IV immediately following induction and prior to surgical manipulation.

All surgeries were performed at the same facility using the same AMO Diplomax phacoemulsification unit (Allergan). Phacofragmentation was performed by several surgeons and therefore techniques varied slightly. With few exceptions, the following protocol was followed. Anterior chamber entrance was achieved with a 2.8-mm disposable keratome. A continuous curvilinear anterior capsulorrhexis was performed, and a one-handed phacoemulsification technique performed through the capsular window. A commercially available 1% sodium hyaluronate viscoelastic solution (Hylartin V, Pharmacia & Upjohn, MI, USA) was injected as needed to maintain the anterior chamber and facilitate intraocular lens (IOL) placement. The viscoelastic material was always aspirated prior to corneal closure using an irrigation/aspiration handpiece. Lactated Ringer's Solution (Abbott Laboratory) was used both as the intraocular irrigating and extraocular wetting solutions. The sole additive used within the irrigating solution was 1000 U/L heparin (Baxter Healthcare Corporation, Deerfield, IL, USA).

All surgeons had the option of placing a commercially available posterior chamber 'in the bag' 41D artificial canine IOL. A rigid polymethyl-methacrylate lens (The Cutting Edge Division, Keragenix Inc., Diamond Springs, CA, USA) and a foldable acrylic lens (Corneal, Aventix Animal Health, Paris, France) were available and selected based on surgeon preference. The original 2.8 mm corneal incision had to be enlarged with curved corneal section scissors in all cases for placement of the IOL. Acetylcholine chloride (Miochol-E, Novartis Ophthalmics, Duluth, GA, USA) and 0.01% carbachol (Alcon Laboratories Inc., Ft. Worth, TX, USA) were available for intraoperative use at the surgeon's discretion and were used routinely. Corneal closure in all eyes was achieved with 9-0 coated polyglactin 910 (Vicryl®, Ethicon Inc., Sommerville, NJ, USA) or 10–0 nylon (Ethicon Inc.) in either a simple continuous or symmetrical double-sawtooth pattern.

Injections of 1.2 mg betamethasone (betamethasone acetate/sodium phosphate 3 mg/3 mg/mL, Wedgewood Pharmacy, Swedesboro, NJ, USA) were routinely administered subconjunctivally to the operated eyes immediately postoperatively. Initial postoperative medical protocols varied, but typically included continuation of the topical antibiotic–anti-inflammatory combination, a systemic nonsteroidal or steroidal agent, an oral antibiotic, and a topical or systemic carbonic anhydrase inhibitor.

Study protocol

Patient data were recorded for each participant, including age, sex, breed, weight, and diabetic status. Surgical data recorded included eye operated, cataract classification, surgeon status, effective phacoemulsification time, total surgery time (TST), type of IOL if placed, volume of fluid infused, incision size, and volume of viscoelastic injected. Cataracts were classified as immature, mature, or hypermature. The single incipient cataract operated was included in the immature group for purposes of statistical analysis. TST was defined as the time from entry into the anterior chamber to completion of corneal incision closure for each eye. Because of technical difficulties and inconsistencies in the values recorded, effective phacoemulsification time and volume of fluid and viscoelastic infused could not be included in any statistical analyses. Postoperative intraocular pressure (IOP) of each operated eye was measured using an applanation tonometer (Tono-Pen or Tono-Pen XL, Medtronic Solan, Jacksonville, FL, USA) 1 h following surgery and just prior to discharge from the hospital (within 6 h of surgery). The patients were divided into hypertensive (IOP = 25 mmHg) and normotensive (IOP < 25 mmHg) groups, based on the greater of the two postoperative IOP measurements.

Initial central corneal thickness (CCT) of each operated eye was measured preoperatively on the day of cataract surgery. Follow-up examinations and CCT measurements were routinely scheduled for 1 day, 1 week, 1 month, and > 2 months following cataract surgery. Except for the initial follow-up, CCT measurement at 1 day postoperatively, minor deviations from this schedule were allowed. Measurements were made on unsedated patients following the instillation of a single drop of 0.5% proparacaine hydrochloride (Falcon Pharmaceuticals, Fort Worth, TX, USA). The minimum possible manual restraint was used to immobilize the patient for the procedure.

Equipment

Central corneal thickness was measured using a 20-MHz ultrasonic pachymeter (SP-3000, Tomey Corporation, Nishi-Ku, Nagoya, Japan) following the manufacturer's instructions. The velocity of ultrasound through the cornea was set at 1630 m/s. The manufacturer states the unit is accurate to within ± 5 μm. Each corneal thickness measurement using this unit is an internal average of 10 individual measurements. Three mean CCT measurements were obtained from each axial cornea at each time period, and a mean and standard deviation (SD) of the three measurements was calculated automatically by the pachymetry unit.

Exclusion/disenrollment

Mean CCT measurements from an individual visit that provided an SD > 10% were excluded from the study. A small number of dogs developed corneal ulcers following cataract surgery. Pachymetry measurements were not included unless an intact epithelium was present on the day of measurement. Some follow-up CCT measurements were missed as a result of poor client compliance or because re-examinations were performed at a satellite clinic at which ultrasonic pachymetry was unavailable. Any eye for which a corneal thickness measurement was not available for at least three of the five time periods for any of the previously mentioned reasons was disenrolled from the study. A total of five eyes were disenrolled based on this criterion.

Statistics

All analyses were carried out using SPSS for Windows (SPSS 12.0, SPSS Inc., Chicago, IL, USA). Descriptive and inferential statistical methods were employed. Significance was based on a two-sided alpha level of 0.05. Repeated measures analysis of variance (ANOVA) was used to compare the distribution of CCT over time and between groups such as age and sex. Repeated measures analyses of covariance was used to compare the distribution of CCT over time and between groups after adjusting for other variables such as weight and surgery time. Individuals that were missing one or more data points did not contribute to the repeated measures analyses. Chi-squared analysis or Fisher's exact tests were used, as appropriate, to compare the basic characteristics of the individuals included vs. those that were excluded, in order to determine whether this produced a biased sample.

Because the 66 eyes evaluated came from only 43 animals, the observations were not all independent. To determine the extent, if any, to which this had an impact, the analyses were ran a second time on one eye only. The eye to be included in the second analysis from the dogs that underwent surgery in both eyes was selected at random.

RESULTS

Forty-three dogs (66 eyes) undergoing elective cataract surgery were included in the study. The dogs ranged in age from < 1 to 13 years of age with a mean age of 6.5 years. They were approximately evenly distributed with respect to sex (21 females and 22 males). A wide range of breeds were represented. The American Cocker spaniel (8 dogs/12 eyes), poodle (6 dogs/9 eyes), Labrador Retriever (5 dogs/9 eyes), and Bichon Frise (4 dogs/7 eyes) breeds were over-represented. Equal numbers of unilateral and bilateral surgeries were performed (22 each). One dog underwent consecutive unilateral surgeries. Thirty-seven cataracts (56.1%) were classified as mature, 17 (25.8%) as hypermature, 11 (16.7%) as immature, and 1 (1.5%) as incipient. Twenty-one percent of the cataracts (in 16% of the dogs) appeared to be secondary to diabetes mellitus, based on a firm diagnosis of diabetes and history of the rapid onset of bilateral, mature, usually intumescent cataracts. Diplomates of the American College of Veterinary Ophthalmologists (ACVO) performed cataract surgery alone on 30/66 (45.5%) eyes, whereas ACVO non-diplomates were the primary surgeons on the remaining 36/66 eyes (54.5%). Rigid intraocular lenses (IOLs) were placed in 45/66 eyes (69.7%), foldable IOLs placed in 14/66 eyes (21.2%), and 6/66 eyes (9.1%) were left aphakic. Reasons for

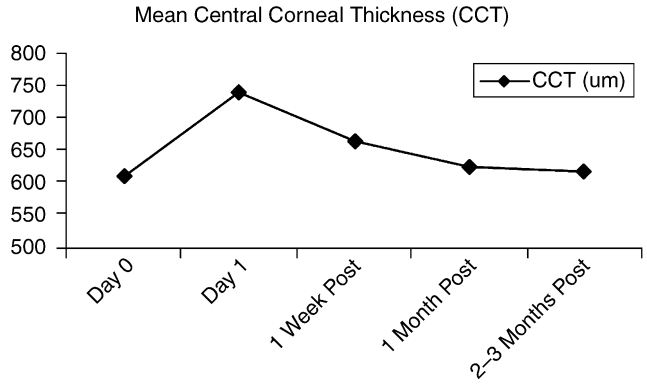

Figure 1. Overall variation in mean central corneal thickness (CCT) over the study period. Note the dramatic elevation by 1 day postoperatively, followed by return to near baseline by 1 month postoperatively.

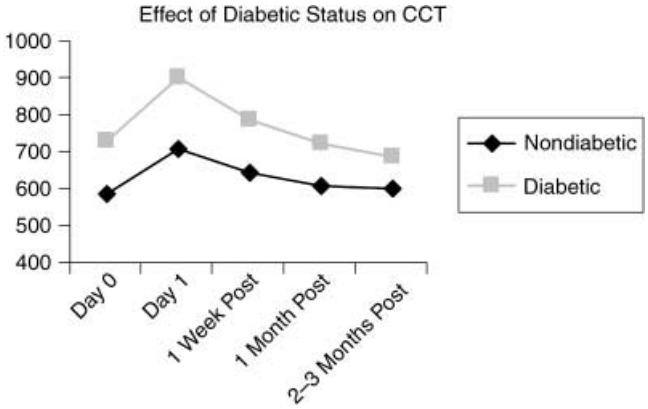

Figure 2. Variation in mean CCT of diabetes patients over the study period, compared to nondiabetic patients. Note the sharper increase from the preoperative to 1 day postoperative CCT in the diabetic group, with ultimate return of CCT to below baseline levels by the greater than 2 months postoperative time period.

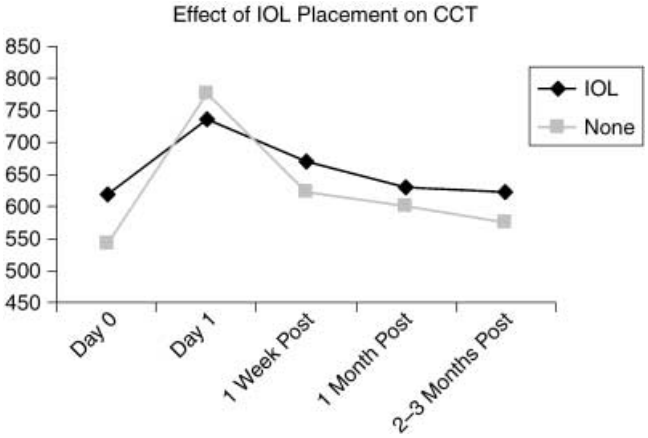

Figure 3. Change in CCT over time after adjusting for IOL placement. Note that CCT of the pseudophakic group declined more gradually than the aphakic group.

aphakia included the presence of a large posterior capsulotomy (two eyes), a radial capsular tear (one eye), and subluxation of the capsular bag (two eyes). The reason was unreported for one eye. Postoperative IOP spikes (> 25 mmHg) were documented in-hospital in 18% of the enroled eyes. Of the postoperative hypertensive group, 10/12 had rigid IOLs placed, 8/12 had mature cataracts removed, and only 3/12 belonged to diabetic patients.

Only 35 of the 66 eyes included in the study had complete data representing CCT at all five time periods. Therefore, only data for these 35 eyes were used in the repeated measures ANOVA. Chi-squared analysis was used to show that there was no significant difference between individuals included in the analysis and those excluded. The repeated measures ANOVA demonstrated that there was a statistically significant change in CCT over the five time periods ($P < 0.0001$). The greatest difference occurred between the preoperative and 1 day postoperative time periods. The preoperative CCT ranged from 480 μm to 788 μm, with a mean of 611 μm. One day following elective phacofragmentation, mean CCT had increased to 741 μm (range: 519–950 μm). By 1 week following surgery, mean CCT had declined, but remained above baseline at 666 μm (range: 514–950 μm). By 1 month postoperatively, the mean CCT decreased to near preoperative values at 626 μm (range: 483–916 μm), and remained so for the > 2-month postoperative measurement at 618 μm (range: 500–858 μm) (Fig. 1). The change in CCT over time remained significant, and the trends similar, when adjusted separately for age, gender, surgeon status, cataract type, and TST (all $P < 0.0001$).

On the other hand, the mean CCT for diabetic dogs over all time periods was significantly greater at 764 μm than the mean CCT for nondiabetics at 629 μm ($P = 0.016$). The mean CCT of diabetic eyes at each time period was greater than that of nondiabetic eyes at the corresponding time point. The pattern of variation in CCT over time also varied slightly for the diabetic group. There was a sharper increase from the preoperative to 1 day postoperative CCT in the diabetic group compared to the nondiabetic group (Fig. 2). By the more than 2 months postoperative visit, however, the diabetic corneas had compensated for the sharper rise in thickness by returning to 645 μm, which is below the baseline CCT for diabetics of 657 μm.

There was a significant change in CCT over time after adjusting for IOL placement ($P < 0.0001$) and type of IOL placed ($P < 0.0001$). The interaction effect between time and IOL placement was significant ($P = 0.044$). The CCT of the pseudophakic group overall appeared slower to decline than the aphakic group (Fig. 3). The interaction effect between time and type of IOL placed was significant at $P = 0.021$. Interestingly, the CCT of the foldable IOL group took longer to return to baseline than either the rigid IOL or aphakic group (Fig. 4). The interaction effect between time and postoperative IOP was also significant ($P = 0.001$). It appears that there was a sharper initial postoperative increase in CCT and later a sharper decrease in mean CCT

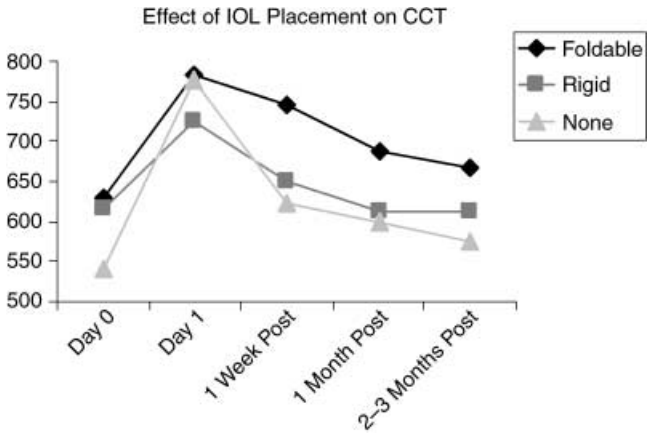

Figure 4. Change in CCT over time after adjusting for type of IOL placed. An unexpected finding was that the CCT of the foldable IOL group took longer to return to baseline than either the rigid IOL or aphakic group.

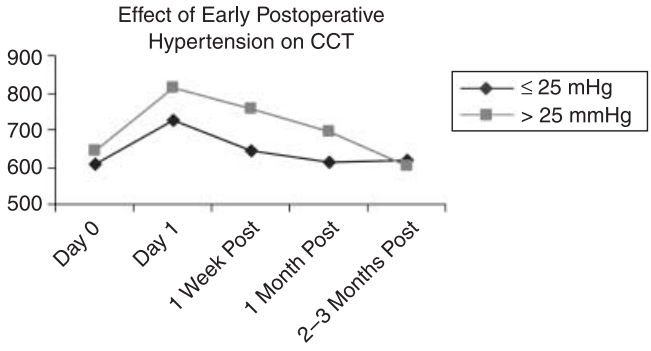

Figure 5. Interaction effect between time and postoperative IOP. Note the sharper initial postoperative increase in CCT and later a sharper decrease in mean CCT from the 1-month postoperative time period to the greater than 2 months time period in the > 25 mmHg postoperative IOP group compared to the normotensive group.

from the 1-month time period to the greater than 2 months time period in the > 25 mmHg postoperative IOP group (Fig. 5).

DISCUSSION

The mean preoperative CCT of eyes enrolled in the study was 611 μm. This number is greater than that of 562 μm reported by Gilger *et al.* as an average of central, superior peripheral, and temporal peripheral corneal thickness in normal dogs.[3] This seems especially significant when taking into account that CCT in dogs is reported to be thinner than peripheral corneal thickness when measured by ultrasonic pachymetry.[3,11] A possible explanation for this discrepancy could be the presence of preoperative phacolytic uveitis, with transient endothelial pump damage and resultant mild or subclinical corneal edema. However, when only non-diabetic study eyes are considered, the preoperative mean CCT becomes 587 μm, which is more consistent with previous data. The apparent bias induced by diabetic status will be discussed later in further detail.

Mean CCT consistently increased dramatically from baseline by 1 day following cataract surgery in the study dogs. Several factors likely contributed to this increase. Among them, endothelial damage secondary to the corneal incision, placement of an IOL, prolonged blood–aqueous barrier (BAB) breakdown, phacofragmentation factors, and postoperative hypertension, will be further discussed. Full-thickness iatrogenic corneal damage from the corneal entrance wound likely contributed significantly to the acutely elevated corneal thickness. Even a peripheral corneal incision can cause diffuse corneal edema affecting CCT via exposure of the corneal stroma to aqueous humor and irrigating and wetting solutions.[12]

Surprisingly, eyes fitted with rigid polymethyl-methacrylate (PMMA) lenses, which required larger corneal incisions than the foldable acrylic lenses, did not have a significantly greater peak CCT 1 day postoperatively. In fact, eyes fitted with foldable IOLs had a slightly sharper postoperative rise in CCT and were slower to return to baseline CCT ($P = 0.021$). It was not surprising to us that the mean CCT of pseudophakic patients increased more dramatically than that of aphakics. It was unexpected, however, that the foldable IOL group took longer to return toward baseline than the rigid IOL group.

We expected that three important factors would be improved by use of the newer foldable IOLs. TST and corneal incision size should both have been decreased through use of this technique, when compared to rigid PMMA lens placement. PMMA is also a hydrophobic material, which reportedly damages corneal endothelium through direct contact more than hydrophilic lens materials.[13] Nonetheless, it is possible that the endothelium is more likely to be directly injured by the use of the sizeable IOL introducer to place the foldable lens through a small corneal incision. This difference was reported previously when the same model of silicone IOL was placed in either flat or folded configuration in human eyes.[14] The foldable lenses were newly available to these surgeons during the study period. Although the learning process was subjectively rapid, it is possible that the endothelium was damaged more severely during this period than it might have been with surgeons already experienced with the technique. Overall, these findings do not clearly support an advantage of the small-incision cataract surgery made possible by the use of foldable IOLs.

Another contributor to the elevated postoperative CCT is likely surgically induced (or prolonged) BAB breakdown. This breakdown is consistently present following intraocular surgery.[15] Iridocyclitis appears to commonly cause a secondary endothelial inflammatory process.[16] Inflamed corneal endothelial cells are enzymatically less able to maintain deturgescence.[17]

In addition, phacoemulsification-induced endothelial cell loss or damage contributes to elevation in postoperative CCT. The high-intensity ultrasonic phacoemulsification

process results in the production of acoustic cavitation bubbles and subsequent free radical formation.[18–20] The amount of free radicals and degree of endothelial damage appear to be correlated with ultrasound power.[19] Phacoemulsification time and volume of irrigation fluid infused undoubtedly influence the degree of damage induced by the phacoemulsification process. It may be expected that differences in TST may be positively correlated with differences in phacoemulsification time, and the effects of difference in TST were found to be insignificant here. Nonetheless, it is regrettable that the actual values for phacoemulsification time and volume fluid infused were not accurately recorded. Viscoelastic solutions have been shown to act as free radical scavengers[19,21,22] and have proven direct endothelial protective effects against the mechanical effects of ultrasound, turbulence, air bubbles, and anterior chamber lens fragments during cataract surgery.[23,24] Primarily dispersive viscoelastics, such as chondroitin sulfate, are considered to have more endothelial-protective (coatability) effects than are their primarily cohesive counterparts, like hyaluronic acid. Although a 1% sodium hyaluronate product is currently the most commonly used viscoelastic substance in veterinary ophthalmology for practical reasons,[24] combination products exist that attempt to maximize the advantages of both dispersive and cohesive properties. Choice of corneal and intraocular irrigating solutions may also have an effect on corneal thickness.[25,26] Although all available viscoelastics and irrigating solutions may not be equal in their endothelial-sparing and protective effects,[25–29] the differences, at least in healthy corneas, may also not be as great as previously suggested.[24,30–36] In any case, the use of these substances was consistent within this study, and compatible with commonly applied veterinary protocols.

Postoperative IOP spikes were also considered as a source of endothelial damage contributing to the postcataract surgery rise in CCT.[37] Documented postoperative IOP spikes (> 25 mmHg) in the hospital appeared to result in a greater rise in postoperative CCT and delay early return to baseline CCT, although the hypertensive group appeared to 'catch up' through a sharper decline in CCT over the 1 month to the greater than 2 months time period. While it is tempting to contribute the prolonged recovery to the elevation of IOP and subsequent endothelial damage, other factors could have contributed to this pattern. For instance, all documented postoperative pressure spikes were initially treated, and the method varied by clinician and severity of pressure elevation. Many dogs, both with and without documented postoperative ocular hypertensive episodes, were prescribed antiglaucoma agents for varying periods of time. To the authors' knowledge, the effects of the various available antiglaucoma drugs on corneal thickness have not been documented in the dog. Carbonic anhydrase inhibitors, in particular, have the potential to affect the corneal endothelial pump mechanisms. The effect of at least one topical carbonic anhydrase inhibitor, dorzolamide, on human CCT has been explored, but results have been equivocal.[38,39]

Overall mean CCT returned to approximately preoperative thickness within 1 month. This finding is consistent with the time frame described for basic corneal wound repair with re-establishment of a complete anterior and posterior corneal barrier to the imbibition of excess fluid. Although BAB breakdown often takes prolonged periods of time to re-establish itself, it is reasonable to expect that clinical control of anterior uveitis and IOP could be achieved in the majority of patients over this time period through medical management and removal of cataract. These findings are consistent with the restoration of an enzymatically functional and physiologically adequate endothelial cell monolayer. They do not suggest that the endothelial cell density or structure was unaffected. In fact, a recent large human study revealed a 10% reduction in endothelial cell count from preoperative to 1 year postcataract surgery.[40] Another human trial suggested an even greater (16%) decrease in endothelial cell concentration postoperatively.[1] Provided the remaining endothelial cell count remains within the physiological range and the endothelium is healthy, the numerical density is not expected to be directly correlated with CCT.[1,12,41,42] Future directions of study in dogs should include specular microscopy to measure endothelial cell density postcataract surgery.

The CCT change over time was significant for both the diabetic and nondiabetic groups ($P < 0.0001$), but the mean CCT of the diabetic group was greater at all time points than that of the nondiabetic group. The overall effect of diabetes on corneal thickness was also significant ($P = 0.016$). This is consistent with some reports on persistently hyperglycemic rabbits and humans,[43–46] but contradictory to others.[47,48] Diabetic human corneas have been reported to have a decreased ability to recover from transient insults,[49,50] apparently as a result of endothelial enzymatic dysfunctions. This corresponds with the pattern of corneal thickness recovery seen here. This finding also offers further support of an endothelial inflammatory component as a result of the acute and severe anterior uveitis often seen secondary to rapid onset, intumescent diabetic cataracts in dogs. The anterior uveitis in diabetic patients may be slower to respond to symptomatic treatment as a result of differences in medical management protocols. One of the greatest differences in postoperative medical protocols identified here reflects a reluctance to treat diabetic patients with systemic corticosteroids. It would be interesting to follow these patients for a prolonged period to determine whether the expected senile increase in corneal thicknesses[3,11] of apahakic and pseudophakic diabetics is more rapid than in their nondiabetic counterparts.

In spite of the absence of clinical corneal edema by the end of the study period and the return of CCT to preoperative values over the study period, the apparently greater potential for diabetic corneas to decompensate following stress suggests that particular care should be taken to protect the corneal endothelium of diabetic dogs during cataract surgery. This is particularly true because adult corneal endothelial cells appear to lack appreciative regenerative

capacity. Endothelial insults are therefore likely cumulative over a lifetime, and special care may be especially indicated for diabetic patients. Precise recommendations would require further in-depth study, but may include use of more expensive viscoelastic and irrigation solution combinations, such as Viscoat® (Alcon) and BSS Plus® (Alcon), perhaps combined with placement of a rigid IOL and perioperative treatment with antiglaucoma agents.

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REFERENCES

1. Ventura AC, Walti R, Bohnke M. Corneal thickness and endothelial density before and after cataract surgery. *British Journal of Ophthalmology* 2001; **85**: 18–20.
2. Schoster J, Wickman L, Stuhr C. The use of ultrasonic pachymetry and computer enhancement to illustrate the collective corneal thickness profile of 25 cats. *Veterinary and Comparative Ophthalmology* 1995; **5**: 68–73.
3. Gilger BC, Whitley RD, McLaughlin SA *et al.* Canine corneal thickness measured by ultrasonic pachymetry. *American Journal of Veterinary Research* 1991; **52**: 1570–1572.
4. Gilger BC, Wright JC, Whitley RD *et al.* Corneal thickness measured by ultrasonic pachymetry in cats. *American Journal of Veterinary Research* 1993; **54**: 228–230.
5. McLaughlin SA, Grizzle J, Whiteley H. Ophthalmic examination of normal light-adapted and dark-adapted channel catfish, *Ictalurus punctatus*. *Veterinary and Comparative Ophthalmology* 1996; **6**: 248–251.
6. Ramsey DT, Hauptman JG, Petersen-Jones SM. Corneal thickness, intraocular pressure, and optical corneal diameter in Rocky Mountain horses with cornea globosa or clinically normal corneas. *American Journal of Veterinary Research* 1999; **60**: 1317–1321.
7. Andrew SE, Willis AM, Anderson DE. Density of corneal endothelial cells, corneal thickness, and corneal diameters in normal eyes of llamas and alpacas. *American Journal of Veterinary Research* 2002; **63**: 326–329.
8. Ollivier FJ, Brooks DE, Komaromy AM *et al.* Corneal thickness and endothelial cell density measured by non-contact specular microscopy and pachymetry in Rhesus macaques (*Macaca mulatta*) with laser-induced ocular hypertension. *Experimental Eye Research* 2003; **76**: 671–677.
9. Moodie KL, Hashizume N, Houston DL *et al.* Postnatal development of corneal curvature and thickness in the cat. *Veterinary Ophthalmology* 2001; **4**: 267–272.
10. Gwin RM, Warren JK, Samuelson DA *et al.* Effects of phacoemulsification and extracapsular lens removal on corneal thickness and endothelial cell density in the dog. *Investigative Ophthalmology and Visual Science* 1983; **24**: 227–236.
11. Gwin RM, Lerner I, Warren JK *et al.* Decrease in canine corneal endothelial cell density and increase in corneal thickness as functions of age. *Investigative Ophthalmology and Visual Science* 1982; **22**: 267–271.
12. Amon M, Menapace R, Radax U *et al.* Endothelial cell density and corneal pachometry after no-stitch, small-incision cataract surgery. *Documenta Ophthalmologica* 1992; **81**: 301–307.
13. Tehrani M, Dick HB, Wolters B *et al.* Material properties of various intraocular lenses in an experimental study. *Ophthalmologica* 2004; **218**: 57–63.
14. Levy JH, Pisacano AM. Clinical endothelial cell loss following phacoemulsification and silicone or polymethylmethacrylate lens implantation. *Journal of Cataract and Refractive Surgery* 1988; **14**: 299–302.
15. Carlson KH, Cameron JD, Lindstrom RL. Assessment of the blood–aqueous barrier by fluorophotometry following poly (methyl methacrylate), silicone, and hydrogel lens implantation in rabbit eyes. *Journal of Cataract and Refractive Surgery* 1993; **19**: 9–15.
16. Brooks AM, Grant G, Gillies WE. Reversible corneal endothelial cell changes in diseases of the anterior segment. *Australian and New Zealand Journal of Ophthalmology* 1987; **15**: 283–289.
17. Macdonald JM, Geroski DH, Edelhauser HF. Effect of inflammation on the corneal endothelial pump and barrier. *Current Eye Research* 1987; **6**: 1125–1132.
18. Topaz M, Motiei M, Assia E *et al.* Acoustic cavitation in phacoemulsification: chemical effects, modes of action and cavitation index. *Ultrasound in Medicine and Biology* 2002; **28**: 775–784.
19. Holst A, Rolfsen W, Svensson B *et al.* Formation of free radicals during phacoemulsification. *Current Eye Research* 1993; **12**: 359–365.
20. Shimmura S, Tsubota K, Oguchi Y *et al.* Oxiradical-dependent photoemission induced by a phacoemulsification probe. *Investigative Ophthalmology and Visual Science* 1992; **33**: 2904–2907.
21. Artola A, Alio JL, Bellot JL *et al.* Protective properties of viscoelastic substances (sodium hyaluronate and 2% hydroxymethylcellulose) against experimental free radical damage to the corneal endothelium. *Cornea* 1993; **12**: 109–114.
22. Camillieri G, Nastasi A, Gulino P *et al.* Effects of hyaluronan on free radical formation, corneal endothelium damage, and inflammation parameters after phacoemulsification in rabbits. *Journal of Ocular Pharmacology and Therapeutics* 2004; **20**: 151–157.
23. Wilkie DA, Willis AM. Viscoelastic materials in veterinary ophthalmology. *Veterinary Ophthalmology* 1999; **2**: 147–153.
24. Kim EK, Cristol SM, Kang SJ *et al.* Viscoelastic protection from endothelial damage by air bubbles. *Journal of Cataract and Refractive Surgery* 2002; **28**: 1047–1053.
25. Glasser DB, Matsuda M, Ellis JG *et al.* Effects of intraocular irrigating solutions on the corneal endothelium after *in vivo* anterior chamber irrigation. *American Journal of Ophthalmology* 1985; **99**: 321–328.
26. Joussen AM, Barth U, Cubuk H *et al.* Effect of irrigating solution and irrigation temperature on the cornea and pupil during phacoemulsification. *Journal of Cataract and Refractive Surgery* 2000; **26**: 392–397.
27. Emre S, Akkin C, Afrashi F *et al.* Effect of corneal wetting solutions on corneal thickness during ophthalmic surgery. *Journal of Cataract and Refractive Surgery* 2002; **28**: 149–151.
28. Cameron MD, Poyer JF, Aust SD. Identification of free radicals produced during phacoemulsification. *Journal of Cataract and Refractive Surgery* 2001; **27**: 463–470.
29. Matsuda M, Kinoshita S, Ohashi Y *et al.* Comparison of the effects of intraocular irrigating solutions on the corneal endothelium in intraocular lens implantation. *British Journal of Ophthalmology* 1991; **75**: 476–479.
30. Maar N, Graebe A, Schild G *et al.* Influence of viscoelastic substances used in cataract surgery on corneal metabolism and endothelial morphology: comparison of Healon and Viscoat. *Journal of Cataract and Refractive Surgery* 2001; **27**: 1756–1761.

31. Kiss B, Findl O, Menapace R *et al.* Corneal endothelial cell protection with a dispersive viscoelastic material and an irrigating solution during phacoemulsification: low-cost versus expensive combination. *Journal of Cataract and Refractive Surgery* 2003; **29**: 733–740.
32. Miller KM, Colvard DM. Randomized clinical comparison of Healon GV and Viscoat. *Journal of Cataract and Refractive Surgery* 1999; **25**: 1630–1636.
33. Schwenn O, Dick HB, Krummenauer F *et al.* Healon 5 versus Viscoat during cataract surgery: intraocular pressure, laser flare and corneal changes. *Graefes Archives of Clinical and Experimental Ophthalmology* 2000; **238**: 861–867.
34. Rosenfeld SI, Waltman SR, Olk RJ *et al.* Comparison of intraocular irrigating solutions in pars plana vitrectomy. *Ophthalmology* 1986; **93**: 109–115.
35. Gerding PA Jr, McLaughlin SA, Brightman AH *et al.* Effects of intracameral injection of viscoelastic solutions on corneal endothelium in dogs. *American Journal of Veterinary Research* 1990; **51**: 1086–1088.
36. Nasisse MP, Cook CS, Harling DE. Response of the canine corneal endothelium to intraocular irrigation with saline solution, balanced salt solution, and balanced salt solution with glutathione. *American Journal of Veterinary Research* 1986; **47**: 2261–2265.
37. Gagnon MM, Boisjoly HM, Brunette I *et al.* Corneal endothelial cell density in glaucoma. *Cornea* 1997; **16**: 314–318.
38. Inoue K, Okugawa K, Oshika T *et al.* Influence of dorzolamide on corneal endothelium. *Japan Journal of Ophthalmology* 2003; **47**: 129–133.
39. Kaminski S, Hommer A, Koyuncu D *et al.* Influence of dorzolamide on corneal thickness, endothelial cell count and corneal sensibility. *Acta Ophthalmologica Scandinavica* 1998; **76**: 78–79.
40. Bourne RR, Minassian DC, Dart JK *et al.* Effect of cataract surgery on the corneal endothelium: modern phacoemulsification compared with extracapsular cataract surgery. *Ophthalmology* 2004; **111**: 679–685.
41. Cheng H, Bates AK, Wood L *et al.* Positive correlation of corneal thickness and endothelial cell loss. Serial measurements after cataract surgery. *Archives of Ophthalmology* 1988; **106**: 920–922.
42. Maurice DM. The location of the fluid pump in the cornea. *Journal of Physiology* 1972; **221**: 43–54.
43. Herse P, Adams L. Effect of hyperglycemia duration on rabbit corneal thickness and endothelial ATPase activity. *Acta Ophthalmologica Scandinavica* 1995; **73**: 158–161.
44. Busted N, Olsen T, Schmitz O. Clinical observations on the corneal thickness and the corneal endothelium in diabetes mellitus. *British Journal of Ophthalmology* 1981; **65**: 687–690.
45. Olsen T, Busted N. Corneal thickness in eyes with diabetic and nondiabetic neovascularisation. *British Journal of Ophthalmology* 1981; **65**: 691–693.
46. Rosenberg ME, Tervo TM, Immonen IJ *et al.* Corneal structure and sensitivity in type 1 diabetes mellitus. *Investigative Ophthalmology and Visual Science* 2000; **41**: 2915–2921.
47. Inoue K, Kato S, Inoue Y *et al.* The corneal endothelium and thickness in type II diabetes mellitus. *Japan Journal of Ophthalmology* 2002; **46**: 65–69.
48. Keoleian GM, Pach JM, Hodge DO *et al.* Structural and functional studies of the corneal endothelium in diabetes mellitus. *American Journal of Ophthalmology* 1992; **113**: 64–70.
49. Saini JS, Mittal S. *In vivo* assessment of corneal endothelial function in diabetes mellitus. *Archives of Ophthalmology* 1996; **114**: 649–653.
50. Ziadi M, Moiroux P, d'Athis P *et al.* Assessment of induced corneal hypoxia in diabetic patients. *Cornea* 2002; **21**: 453–457.