ORBSCAN II–ASSISTED INTRAOCULAR LENS POWER CALCULATION FOR CATARACT SURGERY FOLLOWING MYOPIC LASER IN SITU KERATOMILEUSIS (AN AMERICAN OPHTHALMOLOGICAL SOCIETY THESIS)

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ABSTRACT

Purpose: This study tests the hypothesis that the keratometric value derived from Orbscan II mean power maps, when used in an intraocular lens (IOL) calculation formula, at a specific measurement zone, will accurately determine the power of an IOL for planned cataract surgery in patients who have undergone prior myopic laser-assisted in situ keratomileusis (LASIK).

Methods: This is a two-part study conducted in a referral practice. Experiment 1 is a prospective study of 59 eyes of 30 patients undergoing LASIK. The change in Orbscan mean power maps at five central zones (1.0, 1.5, 2.0, 2.5, and 3.0 mm) was compared with the refractive change from LASIK to determine the optimum Orbscan correlation zone. In Experiment 2, the power of the LASIK-altered cornea was measured by Orbscan and applied to IOL calculations for 17 eyes of 13 patients undergoing cataract surgery.

Results: In Experiment 1, analysis at the Orbscan 1.0-mm measurement zone demonstrated overestimation of the refractive change, whereas the 2.5-mm and 3.0-mm zones demonstrated underestimation. The 1.5-mm and 2.0-mm zones best approximated the net refractive change following LASIK. In Experiment 2, the Orbscan power at 1.5 mm was selected for IOL calculations to minimize undercorrections. The refractive error following cataract surgery ranged from −0.75 to +0.90 diopters (average, +0.05 diopters). Eight eyes were overcorrected (average, −0.52 diopters) and nine eyes were undercorrected (average, +0.54 diopters).

Conclusions: The 1.5-mm Orbscan II zone measures the effective power of the LASIK-altered cornea. When applied to an IOL calculation formula, it accurately predicts the IOL power for planned cataract surgery.

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INTRODUCTION

With 1.8 million unilateral laser vision-correction procedures performed in the United States in 2001 and trends increasing, and 2,775,000 cataract procedures performed by the end of 2004, ophthalmologists must continue to address an important factor that can affect visual acuity outcomes.[1] The literature has shown that standard techniques for determining the power of the intraocular lens (IOL) for cataract surgery in eyes that have had refractive corneal surgery are inaccurate.[2-8]

Currently, the risk of cataract following laser-assisted in situ keratomileusis (LASIK) is low because most patients are young and have healthy eyes. However, it is anticipated that the incidence of cataract will increase over time, since it is an age-related degeneration. Cataract surgery has shown itself to be very successful, even for eyes that have had prior LASIK. However, inaccuracies have been found in the standard techniques for determining the power of the IOL in eyes that have had refractive corneal surgery.[7] The difficulty lies in measuring the central curvature of these corneas. In particular, when using manual keratometry to measure the corneal power at the 3.0-mm paracentral zone and applying this measurement to IOL power calculation formulas, there is a tendency to underestimate the power of the IOL, resulting in a hyperopic postoperative refractive error.[8] Alternative methods for determining the refractive power of the cornea have been proposed.[9-14] A comparison of these various alternative techniques for determining corneal refractive power is reviewed in this paper.

The Orbscan II (Bausch & Lomb-Orbtek Inc, Rochester, New York) combines slit scanning with videokeratography using placido disks to prepare topographic maps of the cornea.[14-17] Various mathematical methods are used to generate anterior, posterior, and total power maps. Moreover, the Orbscan II is capable of measuring the normal cornea as well as the LASIK-treated cornea at variable zones. With this capability, the Orbscan II may be utilized for directly measuring the effective refractive power of the cornea altered by LASIK. This measurement can then be applied to an IOL power calculation formula to determine the optimum IOL power for cataract surgery for such eyes.

This study tests the hypothesis that the keratometric value derived from Orbscan II mean power maps, when used in an IOL calculation formula, at a specific measurement zone will accurately determine the power of an IOL for planned cataract surgery in patients who have undergone prior myopic LASIK. The hypothesis is tested by conducting two experiments.

In Experiment 1 of this study, the Orbscan II was utilized for a group of normal myopic patients scheduled to undergo LASIK. The preoperative and postoperative Orbscan II–derived mean power maps of the paracentral cornea were measured at zones from 1.0 to 3.0 mm in 0.5-mm increments. The net preoperative to postoperative mean power change at each zone was compared with the net refractive change resulting from the LASIK procedure. The first experiment was designed to determine the paracentral zone at which the net mean corneal power change most closely correlated with the net refractive change. This paracentral zone would then be designated the optimum LASIK power zone.

The accuracy in determining the power of an IOL for planned cataract surgery in patients who had undergone prior myopic LASIK was evaluated in Experiment 2 of this study. The diopter power of the cornea entered into the IOL calculation formula was derived

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from the Orbscan II mean power map at the optimum LASIK power zone, as determined in Experiment 1. Outcomes of cataract surgery for 17 eyes of 13 patients are reported. The accuracy of this measurement technique was evaluated by comparing the predicted refractive error from IOL calculations with the actual postoperative refractive outcome. The postoperative, uncorrected, and best-corrected visual acuities are also reported.

METHODS

EXPERIMENT 1

Cohort and Baseline Data

Fifty-nine eyes of 30 patients who underwent myopic LASIK between December 11, 2002, and November 12, 2003, were studied. Patients had varying degrees of myopia and astigmatism, with normal ocular examinations, and had not undergone previous ocular surgery. All patients underwent complete ocular examinations, which included measurement of manifest and cycloplegic refractions, and Orbscan II mapping of the cornea. Refractions and Orbscan II mapping were obtained in a standard fashion preoperatively and at varying times postoperatively, when the eyes were deemed stable from LASIK surgery. Follow-up ranged from 2 to 10 months. The Orbscan II mean power maps were obtained at the following paracentral zones: 1.0, 1.5, 2.0, 2.5, and 3.0 mm (Table 1).

Operative Procedure

Preoperatively all patients were provided informed consent regarding surgery and data collection for this study. LASIK surgery was performed on all eyes in a standard fashion, consistent with manufacturers' recommendations. A Hansatome microkeratome (Bausch & Lomb, Chicago, Illinois) was used for flap preparation at either 8.5 mm or 9.5 mm. The VISX S4 Excimer Laser (VISX, Santa Clara, California) was used for stromal ablation, utilizing a treatment zone of 6.5 mm with a blend zone to 8.0 mm. Treatments were performed without wave-front guided, customized ablations. All eyes healed quickly and without complications.

Data Collection

The preoperative and postoperative refractions were measured using a phoropter set for 12-mm vertex distance. The refractive errors were then vertex-adjusted to the corneal plane, aided by the computer program on the VISX S4 Laser. The spherical equivalent of this vertex-adjusted refraction was calculated in standard fashion by adding one half of the cylinder to the sphere. The refractive correction induced by the LASIK procedure was calculated by subtracting the vertex-adjusted, spherical equivalent refraction measured postoperatively from that measured preoperatively.

The keratometric values of the preoperative and postoperative Orbscan II power maps were compared at each paracentral zone. The Orbscan II–measured corneal power change, which resulted from the LASIK procedure, was calculated by subtracting the postoperative keratometric value from the preoperative value at each paracentral zone, namely, 1.0, 1.5, 2.0, 2.5, and 3.0 mm.

The LASIK-induced, refractive correction was compared with the Orbscan II–derived keratometric change at each paracentral zone. This was measured by subtracting the refractive correction from the Orbscan II keratometric change at each zone of measurement. For purposes of analysis and discussion, the difference is termed Orbscan II correlation factor. The mean Orbscan correlation factor was then calculated at each paracentral zone for all eyes studied. A perfect Orbscan correlation factor value for this study is zero and indicates that the change in the Orbscan II calculated mean power map at a given zone equals the refractive change induced by the LASIK procedure. The lower the Orbscan correlation factor, the more closely the Orbscan II power map correlates to the refractive change induced by LASIK. The mean Orbscan correlation factor was compared among the paracentral zones 1.0, 1.5, 2.0, 2.5, and 3.0 mm.

EXPERIMENT 2

Cohort and Baseline Data

This is a study of 17 eyes of 13 patients who underwent cataract surgery between October 2002 and April 2004. All patients had previously undergone myopic LASIK, were stable from the refractive surgery, and were free of other ocular disease. All patients who fit these inclusion criteria are reported in this consecutive series. The sample size for this experiment is limited to all available patients during this time interval that fit the inclusion criteria. Signed informed consents were obtained from all patients.

Prior to cataract surgery, each eye was measured for the IOL power necessary to achieve emmetropia postoperatively. Axial length measurements were obtained with the AccuSonic A-scan (Accutome, Malvern, Pennsylvania). The Orbscan II was used to measure the mean power maps of the cornea at the 1.5-mm zone (Table 1). The diopter value from this mean power map was entered into the SRK-T formula for IOL calculation purposes.[18,19] This calculation was used to guide the surgeon's selection of an IOL for surgical implantation. Four of the 13 patients contributed two eyes to the study. In these bilateral cases, each eye was measured separately. IOL power calculations and lens selection for the second eye were made independent of the results obtained in the first eye. This was done to minimize the use of interdependent data that might bias the outcomes.

Operative Procedure

Patients underwent standardized phacoemulsification cataract surgery with a self-sealing 3.0-mm scleral tunnel incision. Acrylic, foldable lenses were inserted with lens injectors or forceps, and all lenses achieved capsular fixation. A Sensar, model AR-40 lens (American Medical Optics, Santa Ana, California) was inserted in 12 eyes; an Acrysof, model SA60AT lens (Alcon, Fort Worth, Texas) was used in three eyes, and an Acrysof, model MA60AC lens (Alcon, Fort Worth, Texas) was inserted in two eyes. All patients experienced uncomplicated surgical and postoperative clinical courses, without any adverse events.

TABLE 1. NAVIGATING ORBSCAN II COMPUTER TO OBTAIN MEAN POWER MAP AT DESIRED PARACENTRAL ZONE[13]

1. Shoot Orbscan as normal.
2. Left-click gray MAX button of the keratometric map.
3. The keratometric map will now be large.
4. Left-click VIEW on the top toolbar.
5. Select OPTICAL (Snell) POWER, then select TOTAL.
6. Left-click TOOLS on the top toolbar.
7. Select STATS.
8. Select ANALYZE AREA and then select ANALYZE AREA STATISTICS.
9. Using the mouse, you will now see a cross at cursor.
10. Place the cross in the center of the map.
11. Left-click and drag the circle out to the 1.5-mm area.
12. By looking in the box at the bottom right, you will see if you are at the 1.5-mm area.
13. Release the left mouse button when you reach the 1.5-mm area.
14. Save the data to the desktop rather than printing.
15. Print the data from the desktop.

Data Collection

All eyes were measured postoperatively for uncorrected and best-corrected visual acuity, as well as manifest refractions. The postoperative, spherical equivalent, refractive error was calculated in a standard fashion as described above. Follow-up was obtained when the eyes were stable from cataract surgery and ranged from 1 to 12 months with a mean follow-up period of 3.5 months.

RESULTS

EXPERIMENT 1

Case Report (Example of Data Sampling for Analysis)

The left eye of a 31-year-old woman was analyzed by manifest refraction and using the Orbscan II both preoperatively and status post standard myopic LASIK surgery. Her preoperative, manifest refraction was −4.25+0.75×105. This provided a vertex-adjusted, spherical equivalent refractive error of −3.69 diopters at the corneal plane. The postoperative, manifest refraction was −0.25+0.75×107, which resulted in a spherical equivalent refractive error of +0.12 diopters. The change in manifest refraction from preoperative to postoperative was −3.81 diopters.

The Orbscan II mean power maps were obtained preoperatively and postoperatively and the data were analyzed at Orbscan II zones of 1.0, 1.5, 2.0, 2.5, and 3.0 mm. For this same patient, the preoperative power at 1.5-mm zone was 43.63, and the postoperative power at 1.5 mm was 39.49. The difference equals 4.14 diopters and represents the change in power measured at this zone. Similar calculations were obtained at each measurement zone. The Orbscan correlation factor is the difference between the change in Orbscan II power and the change in manifest refraction at a give zone of measurement. For this patient, the Orbscan correlation factor overestimated the refractive change at the 1.5 mm zone by +0.33 diopters (4.14 D – 3.81D). Similar calculations were performed at each Orbscan II zone. The data for all eyes were analyzed in this fashion.

Data Analysis

Fifty-nine eyes of 30 patients were evaluated. The patient cohort represents 41 males and 18 females, whose ages ranged from 20 to 55 with a mean of 37.8 years. Data follow-up ranged from 2 to 10 months with a mean of 6.2 months. The preoperative, vertex-adjusted, spherical equivalent, manifest refraction for all eyes studied ranged from −1.11 to −8.89 diopters and averaged −3.85 diopters (Table 2). The postoperative, spherical equivalent, manifest refraction ranged from +0.61 to −0.87 diopters and averaged −0.15 diopters (Table 2). By calculating the net refractive change preoperatively to postoperatively for each individual eye, the group of eyes studied showed a LASIK-induced refractive change ranging from −0.61 to −8.64 diopters and averaging −3.70 diopters (Table 2).

For preoperative to postoperative data comparison, the author developed a measurement, herein referred to as the Orbscan correlation factor. The Orbscan correlation factor is the difference between the change in corneal power, as measured by the Orbscan II, and the change in manifest refraction at a given zone of measurement. If the change in measured corneal power is greater than the change in manifest refraction, the Orbscan II overestimates the refractive change. Conversely, if the change in measured corneal power is less than the change in manifest refraction, the Orbscan II underestimates the refractive change.

TABLE 2 . LASIK-INDUCED REFRACTIVE CHANGE (PART 1, STUDY)

Eyes studied	59
Patient age	
Range	20 to 55
Mean	37.8
Male-female ratio	41 : 18
Follow-up data	
Range (mo)	2 to 10
Mean (mo)	6.2
SE MRx preop	
Range (diopter)	−1.11 to −8.89
Mean (diopter)	−3.85 (SD 2.08)
SE MRx postop	
Range (diopter)	+0.61 to −0.87
Mean (diopter)	−0.15 (SD 0.27)
Δ MRx (diopter)	−0.61 to −8.64
Mean (diopter)	−3.70 (SD 2.02)

SD = standard deviation; SE MRx = spherical equivalent, vertex adjusted, manifest refraction; Δ MRx = net refractive change (preoperative minus postoperative).

Table 3 reflects the data analysis that generated the Orbscan correlation factor for each zone measured, displaying the number of eyes, as well as the range, mean, and standard deviation for the Orbscan correlation factor overestimation and underestimation at each Orbscan II measurement zone. For example, the Orbscan correlation factor at the 1.5-mm zone shows an overestimation in 38 eyes ranging from 0.01 to 1.38 diopters, with an average of 0.59 diopters, and an underestimation in 21 eyes ranging from 0.01 to 1.89 diopters, with an average of −0.43 diopters. Orbscan correlation factor data at each measurement zone are also recorded in Table 3.

TABLE 3. COMPARISON OF ORBSCAN CORRELATION FACTOR AT VARIOUS PARACENTRAL ZONES

DATA ANALYSIS (59 EYES)	OCF @ 1.0 MM	OCF @ 1.5 MM	OCF @ 2.0 MM	OCF @ 2.5 MM	OCF @ 3.0 MM
ΔOrb > ΔMRx					
No. eyes	41	38	33	18	5
ΔOrb < ΔMRx					
No. eyes	18	21	26	41	54
ΔOrb > ΔMRx					
Average (D)	+0.72 (SD 0.58)	+0.59 (SD 0.36)	+0.48 (SD 0.33)	+0.34 (SD 0.23)	+0.29 (SD 0.23)
Range (D)	0.01 to 2.88	0.01 to 1.38	0.03 to 1.45	0.07 to 0.87	0.05 to 0.54
ΔOrb < ΔMRx					
Average (D)	−0.54 (SD 0.37)	−0.43 (SD 0.46)	−0.52 (SD 0.47)	−0.60 (SD 0.55)	−1.20 (SD 0.78)
Range (D)	0.03 to 1.10	0.01 to 1.89	0.06 to 2.24	0.04 to 2.48	0.01 to 3.17

ΔMRx = net refractive change (preoperative minus postoperative); ΔOrb = Net Orbscan II mean power change (preoperative minus postoperative); OCF = Orbscan correlation factor (ΔOrb minus ΔMRx). If ΔOrb > ΔMRx (positive OCF), then the Orbscan II overestimated the refractive change. If ΔOrb < ΔMRx (negative OCF), then the Orbscan II underestimated the refractive change.

Figure 1 compares the Orbscan correlation factor overestimation and underestimation at each Orbscan II measurement zone. The range and mean error at each zone are shown and suggest that the range of overestimation is inversely proportional to the size of the Orbscan II measurement zone: the smaller the zone, the greater the range of overestimation. In contrast, the range of underestimation is proportional to the size of the Orbscan II zone: the larger the zone size, the greater the range of under estimation. The Orbscan correlation factor data are further elucidated in Figure 2, which compares the proportionate number of eyes that were overestimated and underestimated at each measurement zone. The inverse relationship between zone size and percentage of overestimation is once again evident. As zone size diminishes, the percent of overestimation increases. There is a direct correlation between zone size and underestimation, in that as the measurement zone size increases, the percentage of underestimation also increases.

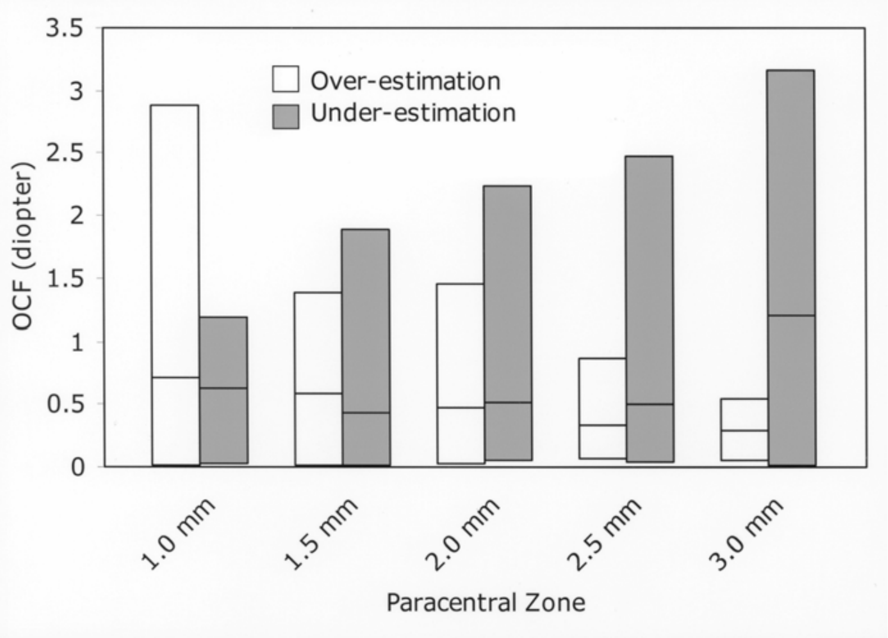

FIGURE 1

Comparison Orbscan correlation factor at measurement zones (Part 1, study). The Orbscan correlation factor (OCF) compares the net refractive change from LASIK (preoperative minus postoperative) with the net change in Orbscan mean power maps (preoperative minus postoperative). The bar graph compares the OCF overestimation and underestimation at each Orbscan measurement zone. The range and mean OCF measurement for each group are shown.

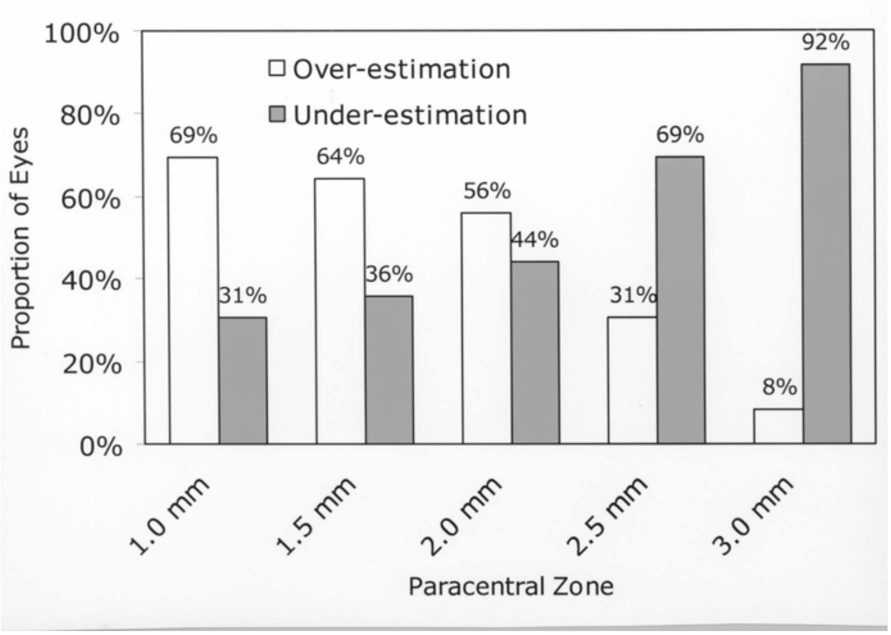

FIGURE 2

Proportionate distribution of eyes at Orbscan measurement zones (Part 1, study). The bar graph compares the proportionate distribution of eyes for Orbscan correlation factor overestimation and underestimation at each Orbscan measurement zone.

Analysis of variance (ANOVA), using a within-subject design, showed that different measurement zones yield significantly different results in terms of Orbscan correlation factor (F = 70.4: $P < .01$). Figure 3 shows Bland-Altman plots for each of the five measurement zones. The areas between the upper and lower dotted lines correspond to the 95% limits of agreement between manifest refraction and Orbscan II results. The Orbscan correlation factor is plotted against the average of the refractive changes, as determined by manifest refraction and Orbscan II power measurement. The Orbscan correlation factor is closest to 0 for the 1.5-mm and 2.0-mm zones. The 95% limits of agreement between manifest refraction and Orbscan II results for the 1.5-mm zone were determined to be between −1.01 D and +1.47 D. The middle dotted line of Figure 3 corresponds to the average bias, which was +0.23 D for the 1.5-mm zone. This bias appeared independent of the amount of refractive changes for the 1.0-mm, 1.5-mm, and 2.0-mm zones, whereas bias for the 2.5-mm and 3.0-mm zones varies significantly with the amount of refractive change. It is important to note that bias and 95% limits of agreement clearly deteriorate for zone settings 1.0 mm, 2.5 mm, and 3.0 mm. Of interest, the accuracy of the Orbscan correlation factor results at the 1.5-mm measurement zone did not vary with the preoperative, spherical equivalent (r = 0.08) or cylinder (r = 0.004).

A preliminary analysis of the Orbscan correlation factor data suggested both Orbscan II measurement zones of 1.5 mm or 2.0 mm could be utilized for determining the mean power of the cornea for IOL calculation purposes; however, further analysis showed subtle differences between these two zones. Figure 1 shows the range and mean Orbscan correlation factor for the 2.0-mm zone group (underestimation) is greater than the 1.5-mm zone. The group of overestimation Orbscan correlation factor is greater for the 1.5-mm zone than the 2.0-mm zone. Figure 2 further highlights these differences.

A greater percentage of eyes for the 1.5-mm and 2.0-mm zones overestimated the refractive error compared to underestimation. The percent overestimation was greater for the 1.5-mm zone (64%) than for the 2.0-mm zone (56%), and the percent underestimation was greater for the 2.0-mm zone (44%) than for the 1.5-mm zone (36%). This suggests that using measurements from the 1.5-mm zone presents less risk of undercorrection than use of the 2.0-mm zone. It is noteworthy that undercorrection results in postoperative hyperopia. To minimize the risk of inducing a hyperopic error after cataract surgery, the 1.5-mm zone was selected as the optimum Orbscan correlation zone for corneal power measurements in Experiment 2 of this study.

EXPERIMENT 2

Case Report (Example of Data Sampling for Analysis)

The patient was a 42-year-old man who underwent LASIK 4 years previously (right eye, first patient, Table 4). Prior to cataract surgery, the Orbscan II was utilized to measure the mean power of the cornea at the 1.5-mm zone, and the axial length of the eye was measured by A-scan biometry. These data were entered into the SRK-T formula for IOL power calculations. Measurements suggested a +20.54 diopter IOL was needed to achieve emmetropia.

The surgeon selected a +21.0 diopter lens for surgery. The SRK-T formula predicted that a +21.0 diopter lens would induce −0.38 diopters of myopia; therefore, the refractive error induced by the selection of the IOL was −0.38 diopters. The patient's uncorrected visual acuity was 20/20 3 months postoperatively, and the manifest refraction measured −0.50+0.50×110; therefore, the postoperative spherical equivalent was −0.25 diopters. Due to the fact that some of this refractive error was induced by the available IOL selected, the true error caused by the IOL calculation technique was obtained by subtracting the refractive error of the IOL from the postoperative correction. The resultant refractive error is +0.13 diopter [−0.25− (−0.38)].

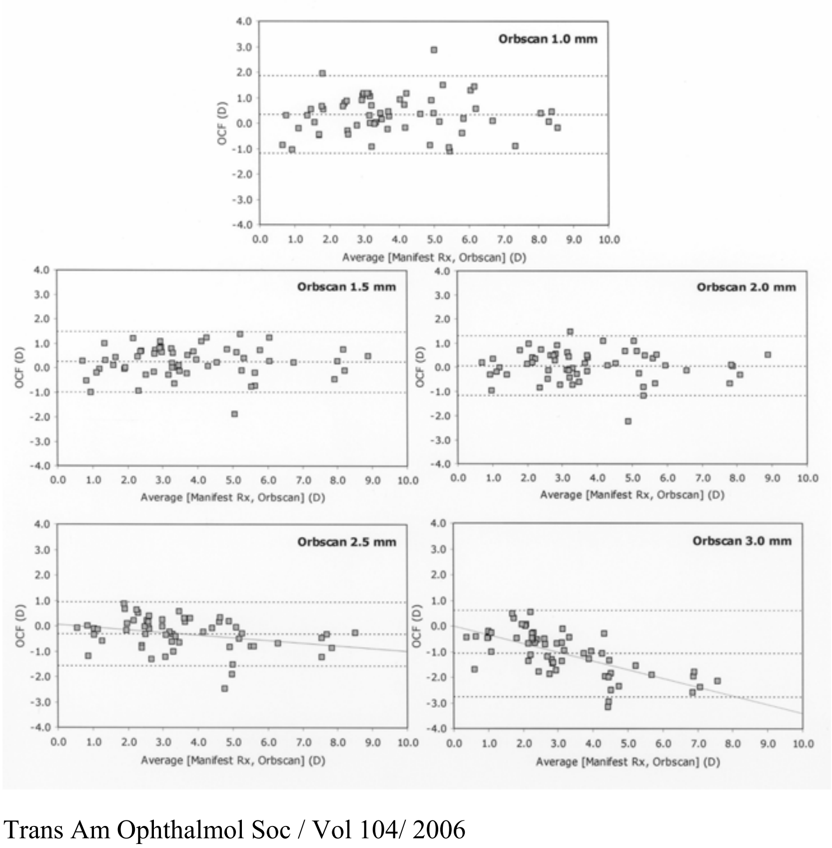

FIGURE 3

Bland-Altman plots comparing Orbscan correlation factor (OCF) at Orbscan measurement zones (Part 1, study). Bland-Altman plots of analysis of variance (ANOVA), using a within-subjects design, are shown for each Orbscan measurement zone. The OCF is plotted against the average of the refractive changes as determined by manifest refraction and Orbscan II mean power maps. For each zone, the areas between the upper and lower dotted lines correspond to the 95% limits of agreement between manifest refraction and Orbscan II results. The middle dotted line corresponds to the average bias.

In this example, the postoperative, manifest refraction, spherical equivalent showed −0.25 diopters of myopia; however, the actual, resultant error attributable to the IOL power calculation technique was +0.13 diopters of hyperopia. Data for all eyes were analyzed in this fashion.

TABLE 4. VISUAL AND REFRACTIVE RESULTS FOLLOWING CATARACT SURGERY (PART 2, STUDY)

PATIENT	EYE	IOL(D)	VA SC	VA CC	MRX POSTOP	LASIK–PHACO	PHACO–DATA
42 M	OD	21	20/20	20/15	–0.50+0.50×110	4 yr	3 mo
	OS	20.5	20/20	20/15	–1.25+0.50×70	4 yr	1 mo
55 F	OD	20	20/30	20/15	–1.25+0.50×60	4 yr	12 mo
	OS	21	20/40	20/20	–1.25 sphere	4 yr	2 mo
41 M	OD	18.5	20/15	20/15	Plano+0.25×105	1 yr	5 mo
	OS	19.5	20/20	20/15	–0.25+0.50×5	3 yr	2 mo
54 M	OD	20.5	20/25	20/20	–1.00+1.00×38	2 yr	2 mo
65 M	OD	21.5	20/20	20/15	–0.75+1.00×99	9 mo	5 mo
	OS	19	20/40	20/15	–1.75+0.75×165	9 mo	7 mo
71 M	OS	21.5	20/25	20/15	–0.50+0.75×65	20 mo	3 mo
62 F	OS	18	20/25	20/20	+0.50+0.50×70	4 yr	1 mo
60 M	OD	21.5	20/30	20/15	–0.75 sphere	2 yr	2 mo
48 F	OD	20	20/20	20/15	–1.25+0.75×110	3 yr	1 mo
53 M	OD*	16	20/20	20/20	Plano	2 yr	5 mo
57 M	OD	19	20/40	20/20	–0.25+1.00×55	2 yr	2 mo
48 M	OD*	17.5	20/30	20/20	–1.75+1.00×45	3 yr	2 mo
54 F	OS	17.5	20/30	20/20	–1.25+1.00×150	4 yr	3 mo

D = diopter; MRx = manifest refraction; VA cc = visual acuity with correction; VA sc = visual acuity without correction.
*History of retinal detachment prior to cataract surgery.

Data Analysis

In the second experiment, 17 eyes of 13 patients were analyzed. The patient cohort represented nine males and four females, whose ages ranged from 41 to 71 years of age (average age, 55). There was a history of retinal detachment surgery prior to the cataract surgery in two patients; however, there was no history of prior ocular surgery other than LASIK in 15 eyes. The time interval between LASIK and cataract surgery ranged from 9 months to 4 years (average, 2.67 years).

Eleven eyes were myopic postoperatively, four eyes were hyperopic, and two were emmetropic. The spherical equivalent, postoperative refractive ranged from −1.38 to +0.75 diopters and averaged –0.47 diopters (Table 5). The 95% confidence interval is −1.69 to +0.75 diopters.

For all eyes studied, the predicted refractive error induced by the IOL ranged from −0.03 to –1.13 diopters and averaged –0.53 diopters (Table 5). The resultant refraction ranged from −0.75 to +0.90 diopters and averaged +0.05 diopters (Tables 5 and 6). The 95% confidence interval is −1.11 to +1.20 diopters.

The data for the resultant refractive error was also analyzed for eyes overcorrected and undercorrected. These are not two separate groups but rather are part of the same continuum, and this division was made for purposes of comparison. Eight eyes were overcorrected with an average of −0.52 diopters, and nine eyes were undercorrected with an average of +0.54 diopters (Table 6). Assuming the cohort represented a random sample from a normally distributed population, the confidence interval of achieving a refractive outcome within ±1.00 diopter is 91% and ±0.50 diopter was 60%.

For the 17 eyes studied, 14 (82%) achieved 20/30 or better without correction. The worst uncorrected vision was 20/40. Seven of the 17 eyes (41%) achieved 20/20 or better, uncorrected. With correction, 10 of the 17 eyes (59%) saw 20/15, and all eyes were correctable to 20/20 or better (Table 4).

Prior to interpreting the significance of the refractive outcome, two factors had to be considered. The first related to the fact that the IOL power selected for surgery may not have been chosen to achieve emmetropia; therefore, the refractive error induced by the calculation technique is the difference between the actual, postoperative refraction and the desired refractive outcome. The second factor related to the fact that there is an inherent error induced by the IOL selected. This is because IOL powers are available in 0.5-diopter increments while the SRK-T formula can calculate the IOL power necessary to achieve emmetropia or any desired refractive outcome to 0.01 diopter. There is a refractive error induced by the selection of a given IOL (referred to as refractive error of the IOL), which represents the difference between the power necessary to achieve the desired refractive outcome and the power of

TABLE 5. REFRACTIVE ERROR AFTER CATARACT SURGERY (PART 2, STUDY)

PATIENT	EYE	PORE (D)	RE/IOL (D)	RRE (D)
42 M	OD	–0.25	–0.91	+0.66
	OS	–1.00	–0.77	–0.33
55 F	OD	–1.00	–0.25	–0.75
	OS	–1.25	–1.10	–0.15
41 M	OD	+0.12	–0.19	+0.31
	OS	Plano	–0.26	+0.26
54 M	OD	–0.50	–0.91	+0.41
65 M	OD	–0.25	–1.13	+0.88
	OS	–1.38	–0.86	–0.52
71 M	OS	+0.12	–0.65	+0.77
62 F	OS	+0.75	–0.15	+0.90
60 M	OD	–0.75	–0.03	–0.72
48 F	OD	–0.87	–0.38	–0.49
53 M	OD	Plano	–0.43	+0.43
57 M	OD	+0.25	–0.03	+0.28
48 M	OD	–1.25	–0.74	–0.51
54 F	OS	–0.75	–0.19	–0.66

D = diopters (spherical equivalent); PORE = postoperative refractive error; RE/IOL = refractive error induced by the selected IOL (predicted); RRE = resultant refractive error (PORE minus RE/IOL). The resultant refractive error (RRE) more accurately reflects the error of the IOL measurement technique.

TABLE 6. RESULTANT REFRACTIVE ERROR AFTER CATARACT SURGERY*

Overall (No. eyes)	17
Mean (diopter)	+0.05 (SD 0.59)
Range (diopter)	–0.75 to +0.90
Overcorrection, myopia (No. eyes)	8
Mean (diopter)	–0.52 (SD 0.20)
Range (diopter)	–0.15 to –0.75
Undercorrection, hyperopia (No. eyes)	9
Mean (diopter)	+0.54 (SD 0.26)
Range (diopter)	+0.28 to +0.90

SD = standard deviation.
*Resultant refractive error equals the postoperative refractive error minus the refractive error induced by the selection of an available intraocular lens.

available lenses. To assess the accuracy of the IOL calculations, this induced refractive error of the IOL must be subtracted from the postoperative refraction. The resultant refractive error more accurately reflects the error of the IOL measurement technique.

DISCUSSION

Physicians are increasingly confronted with patients in need of cataract surgery who have previously undergone refractive surgery, especially LASIK. Prior to the development of cataracts, these patients enjoyed excellent, uncorrected visual acuity. As they approach cataract surgery, they anticipate the restoration of clear and uncorrected vision. To achieve this, the surgeon must properly select the IOL power to ensure minimal residual refractive error after cataract surgery.

Intraocular lens power calculation formulas, such as the SRK-T formula, require proper measurement of the diopter power of the cornea and of the axial length of the globe as well as knowledge of the final position of the IOL in the eye. Various studies have shown that there is a tendency to underestimate the IOL power for patients undergoing cataract surgery who have previously had LASIK.[2-8] This causes an effective residual refractive error, which is hyperopic. This hyperopia may be problematic enough that further corrective surgery may be necessary. Odenthal and associates[8] found that seven of 15 eyes that underwent cataract surgery subsequent to PRK required IOL exchange or piggybacking of a secondary IOL to correct the hyperopia. The problem is with the method of IOL power calculation and in particular, the technique of measuring the effective refractive power of the cornea.[5,11-13,19]

Manual keratometry has been the standard for measuring the anterior curvature of the cornea and has served well in IOL calculation formulas involving normal, unaltered corneas. However, manual keratometers measure the radius of curvature at the 3-mm paracentral zone. When keratometric measurements of the LASIK-altered cornea are applied to IOL calculation formulas, it may not be appropriate to assume that the 3-mm zone of measurement accurately reflects the mean corneal power in these eyes.[20] Because manual keratometry is inaccurate, various alternate techniques have been developed to assist in the selection of the IOL power for these patients and may serve as historical controls for the second experiment in this study. Some of these techniques require knowledge of the pre-LASIK keratometry and refractive error. These include a historically derived method and the Feiz-Mannis method.[6-10,13]

With the historically derived method, the net diopters of refractive correction resulting from the LASIK procedure, when subtracted from the pre-LASIK keratometry, are used to estimate the resultant keratometry of the post-LASIK cornea.[6,8,13] Studies have shown that the historically derived calculations accurately predict the effective power of the LASIK-treated cornea.[6,8] However, the data of pre-LASIK keratometry and amount of refractive correction achieved by the LASIK procedure may not always be available for these patients. In the event of a long time interval between the LASIK procedure and the necessary cataract surgery, the patient's records may no longer be available; therefore, this technique is of limited application. The author does encourage LASIK surgeons to provide patients with the pre-LASIK data of keratometry and refractive correction achieved by the LASIK procedure as a reference point of the treatment parameters. This would be similar to the current practice of providing a card identifying an IOL that has been implanted in a patient's eye. This LASIK data could prove useful for future IOL power calculations should the patient require future cataract surgery.

The Feiz-Mannis method of calculation utilizes standard keratometry and biometry and a nomogram-based IOL power adjustment on the resultant refractive correction from the previous LASIK procedure.[9,10] It does not require knowledge of the pre-LASIK keratometry. Excellent refractive outcomes have been demonstrated when applied to IOL power calculations for cataract surgery.[9,10] Of 19 eyes studied, 63.2% were within 0.5 diopter of the intended spherical equivalent. This technique was also compared with the clinical history method, with the finding that the nomogram-based calculation technique was more accurate than the clinical history method, where the correct IOL power was accurately predicted in only 37.5% of the cases studied.[10] The authors point out that the refractive change from LASIK must not include any refractive change induced by the cataract. This nomogram-based technique is also limited by the need to access the historical data of LASIK-achieved refractive outcomes.

Shammas and associates[11] developed formulas to adjust the post-LASIK keratometry and compared these calculations with the historically derived method of determining the effective power of the cornea. One formula adjusted the post-LASIK keratometry by subtracting −0.23 diopter for every diopter of myopia corrected by the LASIK. The second formula used a regression equation of the post-LASIK keratometry and was independent of the amount of refractive error from the LASIK. The authors found that for both techniques, the adjusted keratometry correlated well with the historically derived method of calculation.[11] The study was performed on eyes that underwent LASIK, but the validity of this model for applications to cataract surgery has yet to be tested.

Calculation techniques that do not require pre-LASIK data are more practical. These include refraction techniques over contact lenses and direct measurements using Orbscan topography.[14,16,20,21]

With the contact lens method, the corneal power represents the sum of the contact lens base curve, lens power, and overrefraction minus the spherical equivalent of the manifest refraction without a contact lens.[13,21,22] However, the lack of visual clarity caused by the cataract makes it difficult to assess the end point in the refraction, and the cataract may induce an unusual refractive error. This can lead to difficulty in extrapolating the effective refractive power of the cornea by contact lens trial.

Wang and associates[13] studied several techniques to measure the power of the cornea for IOL calculation formulas for eyes undergoing cataract surgery. They used single-K and double-K versions of IOL formulas and compared corneal power values obtained by the Feiz-Mannis method, clinical history, contact lens overrefraction, and the Maloney method for IOL calculations.[13,23] Furthermore, an adjusted effective refractive power calculation methodology was utilized, which was termed EffRPadj.[13] This calculation is obtained by multiplying the LASIK-induced refractive change by 0.15 diopter and subtracting this value from the measured EffRP, which is displayed in the Holladay Diagnostic Summary of the EyeSys Corneal Analysis System.[13] The investigators found the most accurate method of calculation was the combination of the double-K formula and corneal values derived from EffRPadj, with refractive outcomes of cataract surgery averaging −0.61 ± 0.79 diopter (range, −2.0 to 1.0 diopter).[13]

LASIK corrects myopia by flattening the central cornea, thereby reducing the diopter power of the cornea. However, this flattening is not uniform. The greatest degree of flattening is found most centrally, and there is a gradual steepening toward the periphery of the treatment zone, which in turn converts the normal prolate convexity of the anterior cornea to an oblate convexity.[24] As a result, the mean refractive power of the cornea is reduced and the effective refractive zone shifts.[24] Corneal topographers may be used to measure the various zones of the cornea.[15]

The Orbscan II combines slit scanning with videokeratography using placido disks to prepare topographic maps of the cornea.[14-17] Various mathematical methods are used to generate anterior, posterior, and total power maps. It is also capable of providing optical pachymetry, differential, and best-fit sphere elevation maps, as well as spherical equivalent mean power maps. With Orbscan II technology, the cornea may be analyzed from areas as small as the central 40 μm to 10 mm diameter and at any preselected area in between. With this in mind, the Orbscan II may be harnessed as a direct measurement technique to calculate the power of the central cornea after myopic LASIK.

Sonego-Krone and associates[14] used the Orbscan II corneal power maps to measure the corneal power after myopic LASIK. They evaluated measurement zones from 1.0 mm to 6.0 mm in 1-mm increments and found the total-mean power map derived at 2.0 mm best reflects the keratometric power of the LASIK-altered cornea.[14] It should be noted that the 1.5-mm zone was not tested. The study concluded the Orbscan II total-mean and total-optical power maps accurately assess the corneal power after myopic LASIK independent of preoperative data or correcting factors.[14] This technique was suggested for improvement of IOL calculation; however, the methodology was not applied to patients undergoing cataract surgery.

Cheng and associates[16] compared the results of measuring corneal keratometry after LASIK using historically derived data and Orbscan II calculations. The post-LASIK refractive corneal power was measured by subtracting the surgically induced, spherical equivalent, spectacle plane, refractive change from the pre-LASIK keratometry. Orbscan II measurements of the anterior and posterior corneal surfaces were then utilized to calculate the effective corneal power using the Gaussian optics formula.[16] A high correlation was found between the K-value obtained by these two calculations, with the mean difference between the two methods of 0.13 diopters (P = .06).[16] The study concluded the Orbscan II would be useful in measuring the effective power of the cornea in patients with no preoperative LASIK treatment data.[16]

In Experiment 1, Orbscan II was utilized to evaluate the corneas of a group of cataract-free patients who underwent standard myopic LASIK. The difference between the pre-LASIK and post-LASIK Orbscan II–derived mean power maps at various central zones between 1.0 and 3.0 mm was compared with the LASIK-induced refractive change. This was measured by subtracting the refractive correction from the Orbscan II mean power change at each zone of measurement (termed the Orbscan correlation factor). A perfect Orbscan correlation factor value was designated as zero (0) and is an indication that the change in the Orbscan II calculated mean power map at a given zone of measurement correlates exactly with the refractive change induced by the LASIK procedure. The closer to zero the Orbscan correlation factor, the more closely the Orbscan II power map correlated to the refractive change induced by LASIK.

If the change in Orbscan II power was greater than the change in manifest refraction, then the Orbscan II overestimated the refractive change (Δ Orbscan II > Δ manifest refraction). In the event the change in Orbscan II power was less than the change in manifest refraction, the Orbscan II underestimated the refractive change (Δ Orbscan II < Δ manifest refraction). The Orbscan correlation factor predicted a high degree of underestimation at measurement zone 3.0 mm (54 of 59 eyes, 92%) and at zone 2.5 mm (41 of 59 eyes, 69%) (Figure 2). Meanwhile, the Orbscan correlation factor predicted a high degree of overestimation at measurement zone 1.0 mm (41 of 59 eyes, 69%). The Orbscan correlation factor at measurement zones 1.5 and 2.0 mm were more balanced, but both predicted a tendency for overestimation (38 of 59 eyes, 64% at zone 1.5 mm; and 33 of 59 eyes or 56% at zone 2.0 mm) (Figure 2).

Further evaluation of the Orbscan correlation factor data examined the range and mean of overestimation and underestimation at each zone of measurement. Again, the measurement zone at 1.0 mm revealed a broad range of overestimation, whereas the 2.5-mm and 3.0-mm zones showed a broad range of underestimation (Figure 1). The average Orbscan correlation factor overestimation at 1.5 mm was +0.59 diopters and at 2.0 mm was +0.48 diopters, whereas the average Orbscan correlation factor underestimation at 1.5 mm was −0.43 diopters and at 2.0 diopters was −0.52 diopters (Figure 1). Furthermore, the range of overestimation and underestimation at the 2.0-mm zone was greater than at the 1.5-mm zone (Figure 1).

From this experiment, it may be concluded that the change in Orbscan II mean power maps derived at measurement zones 1.5 mm and 2.0 mm most closely correlated with the change in refractive error resulting from LASIK surgery. This would suggest that the Orbscan II–derived corneal power map at either the 1.5-mm or 2.0-mm zone could be used as the keratometric value in an IOL calculation formula to determine the power of an IOL for planned cataract surgery for eyes that have undergone prior LASIK. However, to minimize the range of underestimation, and thus the degree of the resultant postoperative hyperopia, the author selected the 1.5-mm zone as the optimum Orbscan II measurement zone for subsequent IOL calculation purposes.

In the first experiment, the underestimation predicted by the Orbscan correlation factor at 3.0 mm suggested that the corneal power measured by Orbscan II at this zone would be higher than the effective keratometric value of the LASIK-altered cornea. When such a keratometry value was entered into an IOL calculation formula, the predicted IOL power needed to achieve emmetropia was too low. This helps explain the tendency for resultant hyperopic refractive errors after cataract surgery for post-LASIK eyes when manual keratometry is used to measure the corneal power at the 3.0-mm zone.

In Experiment 2 of this study, the conclusions from Experiment 1 were tested. The hypothesis was that the keratometric value derived from Orbscan II mean power maps at measurement zone 1.5 mm, when used in an IOL calculation formula, would accurately determine the power of an IOL for planned cataract surgery in patients who have undergone prior myopic LASIK.

The Orbscan II–derived mean power maps at 1.5 mm were utilized to estimate the diopter power of the cornea, and the SRK-T formula was used to calculate the IOL power needed to achieve emmetropia. Following the cataract surgery, the postoperative refraction expressed as the spherical equivalent ranged from +0.75 to –1.38 diopters with an average of –0.47 diopters. Eleven of 17 eyes were myopic, four eyes were hyperopic, and two eyes were emmetropic.

As previously stated, an error is induced by the selection of a given IOL. This represents the difference between the power (calculated to 0.01 diopters) necessary to achieve a desired refractive outcome, such as emmetropia, and the power of available lenses (0.5-diopter increments). The IOL-induced refractive error should be taken into consideration when assessing the accuracy of the IOL power calculation technique. The refractive error induced by the IOL was subtracted from the postoperative refraction in the second experiment. The resultant refractive error more accurately reflects the error of the IOL measurement technique. The resultant refractive error ranged from –0.75 to +0.90 diopters, with an overall average of +0.05 diopters (Table 6). Eight eyes were overcorrected an average of –0.52 diopters, and nine eyes were undercorrected an average of +0.54 diopters (Table 6). From this analysis, it may be concluded that the IOL calculation technique tested in Experiment 1 is accurate.

It should be noted that two eyes had a history of retinal detachment surgery prior to the cataract surgery. Postoperatively, one eye achieved emmetropia and the other eye had a spherical equivalent refraction of –1.25 diopters. The resultant refractive error using Orbscan II at 1.5 mm was +0.43 diopters for one eye and –0.50 diopters for the other eye. Therefore, this Orbscan II–derived IOL calculation technique may be applied to eyes that have had prior retinal detachment surgery in addition to prior LASIK.

As expected, the uncorrected visual acuity was excellent with 14 (82%) of 17 eyes 20/30 or better and seven (41%) of 17 eyes 20/20 or better. All eyes achieved 20/20 or better with correction. The IOLs selected by this technique proved to be accurate in providing the desired refractive outcome after cataract surgery.

Although this study has shown that Orbscan II measurement of the 1.5-mm paracentral corneal zone yields accurate corneal power measurements in eyes that have undergone myopic LASIK, further studies are needed to determine if this technique applies to eyes that have undergone hyperopic LASIK. The effective cornea measurement zone for eyes that have had hyperopic LASIK may be different than the myopic LASIK-treated cornea, and future research should determine the optimum zone for Orbscan II measurements in these patients.[25] Other refractive procedures, such as radial keratotomy, can also induce flattening of the central cornea, and additional research is necessary to determine the accuracy of this Orbscan II technique for IOL power calculation in these eyes.[26]

CONCLUSION

These two experiments proved the hypothesis that the keratometric value derived from Orbscan II mean power maps, when used in an IOL calculation formula, at a specific measurement zone, namely 1.5 mm, will accurately determine the power of an IOL for planned cataract surgery in patients who have undergone prior myopic LASIK. The specific measurement was identified as the Orbscan II–derived mean power of the cornea at 1.5 mm. This represents a direct and simple technique to measure the effective keratometric value of the cornea in patients who have had prior myopic LASIK. When applied to IOL calculation formulas, such as the SRK-T formula, it affords an accurate measurement of IOL power for planned cataract surgery. Patients can achieve excellent uncorrected visual acuity with minimal induced refractive error using this method.

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