

Effect of intraoperative aberrometry on the rate of postoperative enhancement: Retrospective study

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PURPOSE: To determine whether the use of intraoperative wavefront aberrometry reduces the frequency of postoperative laser enhancements over the rate in cases in which aberrometry was not used.

SETTING: Private surgical center and private practice, Eugene, Oregon, USA.

METHODS: This was a retrospective case-control chart review of patients who chose to have correction of preexisting corneal astigmatism by limbal relaxing incisions (LRIs) at the time of cataract surgery or refractive lens exchange. In the aberrometry group, an ORange wavefront aberrometer was used intraoperatively to measure total ocular refractive cylinder after intraocular lens implantation and to guide LRI enhancement. A group in which the aberrometer was not used served as the control.

RESULTS: The control group had 37 eyes and the aberrometry group, 30 eyes. The excimer laser enhancement rate was 3.3% in the aberrometry group and 16.2% in the control group. The mean postoperative cylinder was 0.48 diopter (D) in the control group and 0.37 D in the aberrometry group. Residual cylindrical refractive error, not sphere, determined the patients' decision to have enhancement.

CONCLUSION: The use of intraoperative wavefront aberrometry to measure and enhance the effect of LRIs produced a nonsignificant trend that led to a 5.7-fold reduction in the odds ratio of subsequent excimer laser enhancement.

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An astigmatically neutral postoperative result is a major goal of modern small-incision phacoemulsification and refractive lens surgery. Careful planning of incision location, addition of limbal relaxing incisions (LRIs) intraoperatively,^{1–8} and implantation of toric

intraocular lenses (IOLs) to treat higher levels of preoperative astigmatism have contributed toward achieving that goal.^{9–11} Limbal relaxing incisions are widely used for low dioptric corrections.¹² They preserve the optical qualities of the cornea, are easy to perform, do not cause significant patient discomfort, and are sufficiently effective for lower levels of astigmatism. The limbal location of these incisions results in a consistent 1:1 coupling ratio¹³ that causes little change in spherical equivalent (SE) and eliminates the need to change IOL power. Osher¹⁴ and Gills¹ were early advocates of LRIs.

Successfully placed LRIs reduce cylinder without overcorrection or axis shift. Determining the exact location of the cylinder, however, is often challenging. Keratometry, refraction, and corneal topography may not correlate. Of these, corneal topography has been the most helpful and is most often used to guide the surgical plan and evaluate postoperative results.

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However, real-time information about the refractive status during cataract surgery could aid in the correct placement of LRIs and prevent the need for postoperative enhancement surgery; it might also be able to automatically take into account surgically induced astigmatism from clear corneal incisions (CCIs).

Patients who opt to have astigmatism correction at the time of cataract surgery, with or without presbyopia-correcting IOL implantation, may not be satisfied with the results if they continue to require spectacle correction because of a residual refractive error. These patients may seek further refinement of their refractive status through an enhancement procedure. Enhancement procedures for residual myopia, hyperopia, or astigmatism are often performed with the excimer laser. Although generally effective, enhancements incur tangible and intangible costs to the patient and the surgeon. This study was performed to determine whether use of an intraoperative wavefront aberrometer reduced the frequency of postoperative enhancements over that in cases in which the aberrometer was not used.

PATIENTS AND METHODS

This retrospective case-control chart review comprised patients who opted to have correction of preexisting corneal astigmatism by LRIs at the time of cataract surgery or refractive lens exchange (RLE) by the same surgeon (M.P.) between May 2007 and June 2009. The nature of the procedure was explained to all participating patients, and they all signed informed consent forms before having the procedure. Exclusion criteria were ocular disease other than cataract, previous eye surgery including keratorefractive surgery, abnormal corneal topography, and intraoperative or postoperative complications that might limit visual acuity. A standardized surgical LRI technique was used throughout the study period.

The patients were divided into 2 groups. The control group comprised patients who had LRIs but no wavefront measurements. The aberrometry group consisted of patients treated with LRIs who had intraoperative wavefront measurements and therefore may or may not have had an intraoperative LRI extension based on the wavefront measurements.

Wavefront Aberrometry Device

Beginning in August 2008, the ORange intraoperative wavefront aberrometer (WaveTec Vision Systems, Inc.) was used to measure total ocular refractive cylinder after IOL implantation and to guide LRI enhancement; a few cases did not have intraoperative aberrometry because the device was not available. The aberrometer uses Talbot moiré interferometry,^{15,16} which is based on 2 transmission grids spaced a specific distance apart and rotated relative to each other. The spectacle correction in an aberrated ocular wavefront is determined using Fourier transform calculation and is represented in the resulting interferogram. The aberrometer attaches to the surgical microscope and gives on-demand readings of sphere, cylinder, and axis in approximately 2 to

5 seconds. It has a dynamic range of -5.00 to $+20.00$ diopters (D).

Patient Counseling

All suitable candidates were counseled about the expected benefits and potential risks of LRIs to correct preexisting astigmatism and the potential for reduced spectacle dependence postoperatively. Patients were also counseled about toric IOLs; patients who chose this option were not included in this review. Patients were also informed of the availability of presbyopia-correcting IOLs, including the multifocal and accommodative designs that became available during the review period. The informed consent process included several informational videos about the general risks and benefits of cataract surgery as well as specific video presentations related to several IOL options.

Patients were fully informed of the additional charges for the services associated with these procedures, which are not covered by Medicare or commercial health insurers in the United States. With the integration of the intraoperative aberrometer into the LRI procedure, the increased facility fee the surgical center charged for LRIs was carried through to cover the additional costs. Patients were also told that if an enhancement procedure was indicated to correct residual refractive error after the initial refractive RLE or cataract surgery, there would be an additional charge for the enhancement that would equal the amount the facility charged the surgeon for performing the procedure.

Biometry and Intraocular Lens Power Calculation

Throughout the study period, a single standardized approach was used for biometry and IOL power calculation. The IOLMaster partial coherence interferometry device (Carl Zeiss Meditec) was used for axial length, anterior chamber depth, and corneal white-to-white measurements.¹⁷ Along with these measurements, simulated keratometry values from the EyeSys corneal topography system (Tracey Technologies) were input into the Holladay IOL Consultant software program.¹⁸ The Holladay 2 formula was used to calculate IOL power.

Surgical Technique

The surgical technique was standardized throughout the study period.

Phacoemulsification Phacoemulsification was performed using a previously described biaxial microincision technique.¹⁹ Briefly, 2 trapezoidal CCIs (1.4 mm) were constructed temporally, allowing introduction of a 20-gauge, 30-degree beveled phaco tip and an irrigating chopper. The location of the 2 incisions varied depending on the anticipated location of the LRIs. In all cases, the capsulorhexis was designed to be round, centered, and smaller in diameter than the IOL optic. Phacoemulsification proceeded with a vertical chop technique. The IOL was inserted through a third temporal trapezoidal CCI; the CCI diameter was 2.2 to 2.8 mm depending on the size required for IOL implantation.

Limbal Relaxing Incisions Axial maps obtained from the corneal topography system served as the basis for planning the incisions. The extent and placement of the arcs was based on a modification of the Nichamin nomogram⁴

Table 1. Preoperative baseline characteristics by group.

Parameter	Control Group (n = 37 Eyes)		Aberrometry Group (n = 30 Eyes)	
	Mean	Interquartile Range (25%-75%)	Mean	Interquartile Range (25%-75%)
Age (y)	63.5	56-70	61.5	56-69
ΔK (D)	1.5	1.0-1.9	1.3	0.74-1.7
Steep axis (degrees)	83	67-103	87	68-99
Pachymetry (μm)	679	648-709	668	638-694

ΔK = delta keratometry value

(Supplement A, available at www.jcrsjournal.org). The critical parameters for arc design and construction included axis verification, optical zone size, arc length, and incision depth.

After topography was performed to show the location of the steep axis, corneal pachymetry was measured (Cornea-Gage Plus, Sonogage) at the 10.0 mm optical zone at both ends and at points on either side of the axis. Before the patient was transferred to the operating room, the 12 o'clock and 6 o'clock positions were marked with a surgical pen on the adjacent conjunctiva with the patient sitting upright and fixating on a distant target.

Following a standard topical anesthesia and preoperative antibiotic prophylaxis protocol, the eye was prepped and draped for surgery (M. Packer, MD, et al., "Perfecting Your Protocol for Infection Prophylaxis," Ophthalmology Management, March 2008, pages 27-34. Available at: <http://www.opthmanagement.com/article.aspx?article=101484>. Accessed January 22, 2010). The planned arcs of the relaxing incisions were initially marked with a Ruminson astigmatic gauge and marker (Rhein Medical, Inc.) to allow placement of the biaxial microincisions for lens extraction outside these areas.

Lens extraction was through 2 symmetric temporal 1.2 to 1.4 mm trapezoidal CCI's. In the case of against-the-rule astigmatism, the temporal arc was constructed before the incision for IOL insertion. Otherwise, both arcs were constructed after IOL insertion. The eye was inflated with an ophthalmic viscoelastic device (OVD) and the 10.0 mm

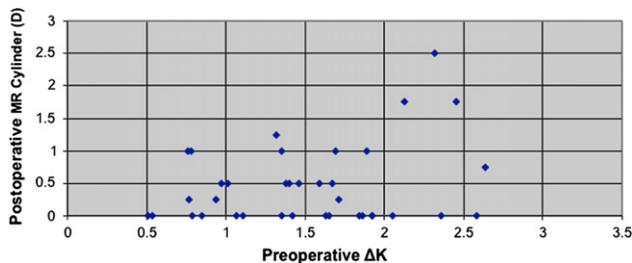


Figure 1. Preoperative ΔK versus postoperative manifest refractive cylinder in the control group (ΔK = delta keratometry value; MR = manifest refractive).

Table 2. Postoperative results by group.

Parameter	Control Group (n = 37 Eyes)	Aberrometry Group (n = 30 Eyes)
Sphere (D)		
Mean	-0.27	-0.33
Range	-2.00 to 0.75	-1.75 to 1.00
Within, n (%)	26 (70.3)	22 (73.3)
±0.50	34 (91.9)	27 (90.0)
±1.00		
MRSE (D)		
Mean	0.00	-0.15
Range	-1.13 to 1.00	-1.38 to 1.00
Within, n (%)		
±0.50	30 (81.8)	24 (80.0)
±1.00	36 (97.2)	28 (93.0)
MR cylinder (D)		
Mean	0.48	0.37
Range	0.00 to 2.50	0.00 to 1.25
Within, n (%)		
±0.50	27 (73)	23 (77)
±1.00	33 (89)	29 (97)
±1.25	34 (92)	30 (100)
UDVA		
Median UCVA	20/25	20/25
Range	20/20 to 20/60	20/15 to 20/50

MR = manifest refraction; MRSE = manifest refraction spherical equivalent; UDVA = uncorrected distance visual acuity

zone marked with an optical zone marker. The eye was fixed with a large-diameter short-handled Fine-Thornton ring (Rhein Medical, Inc.). The ocular surface was lubricated with OVD and the diamond blade (Stealth Triamond, Mastel Precision) adjusted to 90% of the measured pachymetry. Care was taken to hold the blade 90 degrees to the corneal surface and to completely and accurately incise the arc. The incisions were probed and rinsed with a balanced salt solution on a 30-gauge cannula to ensure the absence of skip areas or bridging fibers between the incision walls.

Wavefront Measurement The first wavefront measurement was obtained after IOL insertion and before completion of the LRIs. The anterior chamber and capsular bag were

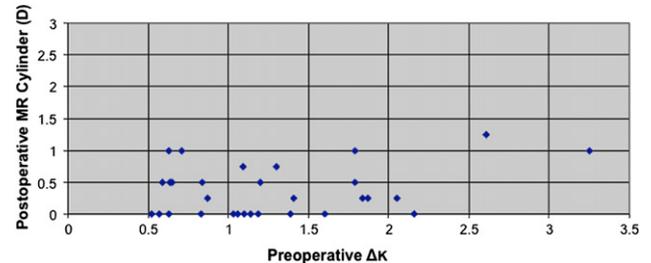


Figure 2. Preoperative ΔK versus postoperative manifest refractive cylinder in the aberrometry group.

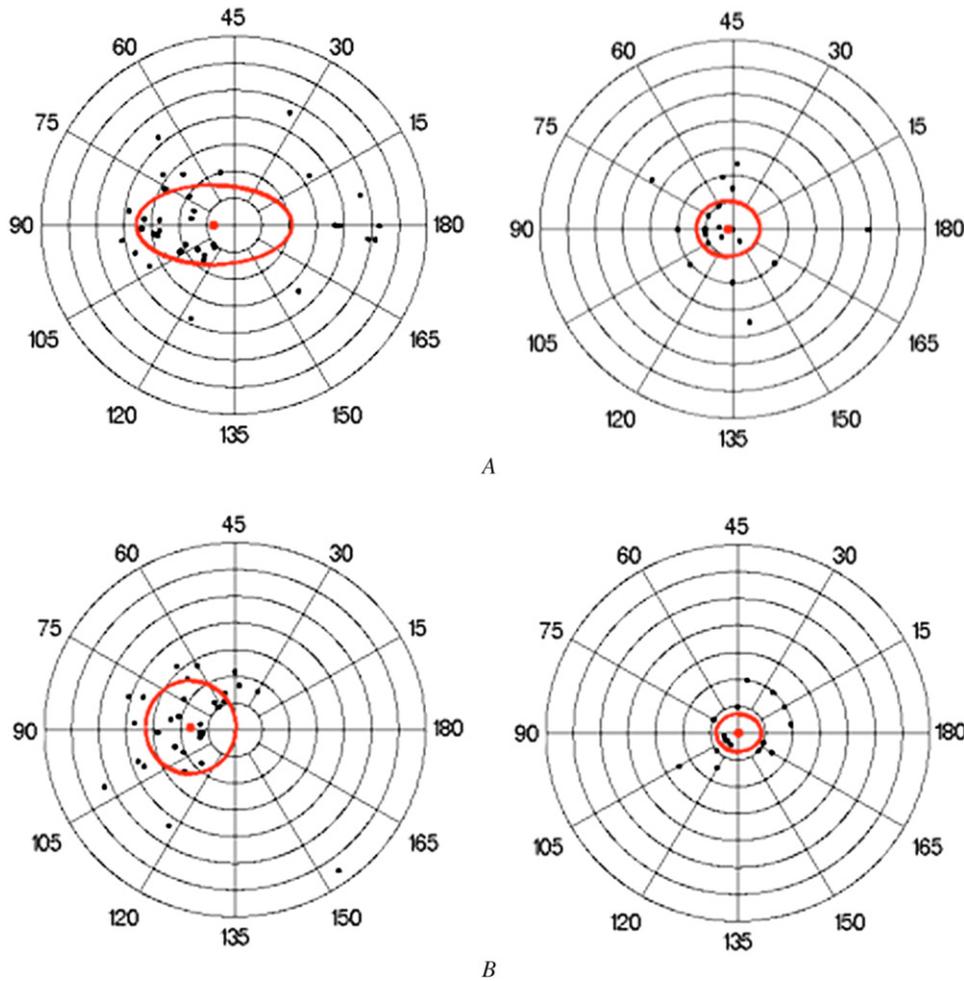


Figure 3. A: Double-angle plot of ΔK (left) and postoperative manifest refractive cylinder (right) in the control group. B: Double-angle plot of preoperative ΔK (left) and postoperative (right) manifest refractive cylinder in the aberrometry group. In all plots, each ring represents 0.50 D and the centroids (red dots) represent the preoperative and postoperative cylinders.

filled with OVD to maintain an intraocular pressure of 25 mm Hg or higher by palpation. Lens tilt and decentration were minimized by visual inspection of the Purkinje images. Initial LRIs were performed based on corneal topography and the modified Nichamin nomogram, after which a second wavefront measurement was obtained. Enhancement was performed by extending the arcs symmetrically if the measured axis was within approximately ± 15 degrees of the expected axis based on corneal topography and SIA ($+0.50 @ 90$) and the magnitude of residual cylinder was 1.00 D or higher. A third wavefront measurement was taken after

enhancement. If a second enhancement was performed based on the same criteria, a final wavefront was obtained. Irrigation and aspiration of the OVD from the anterior chamber was performed as usual, and all incisions were checked to ensure a negative Seidel test.

The postoperative regimen in all cases included topical medication, including a fourth-generation fluoroquinolone antibiotic, steroidal, and nonsteroidal antiinflammatory drops. After a 1-day postoperative check, patients were routinely examined again at 1 month and approximately 3 to 6 months.

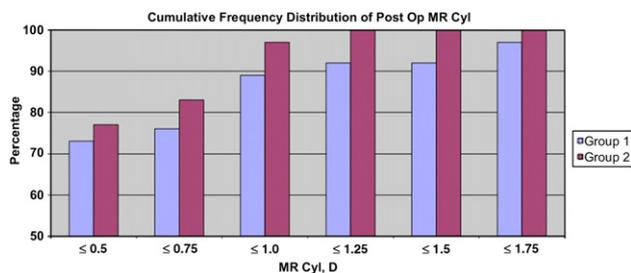


Figure 4. Percentage of eyes with postoperative cylinder (Group 1 = control group; Group 2 = aberrometry group; MR = manifest refractive).

Postoperative Enhancement

Patients reporting blurred vision or problems with vision were evaluated for possible enhancement at 1 month. Significant residual refractive error was considered to be ± 0.50 D or greater sphere, 0.75 D or greater cylinder, or both. Candidates for enhancement were followed at 2- to 3-week intervals to determine refractive stability and were offered an excimer laser procedure at cost for up to 1 year after cataract surgery. Laser in situ keratomileusis (LASIK) was preferred unless the condition of the ocular surface suggested that photorefractive keratectomy (PRK) would produce a better outcome. Enhancement procedures were performed at the patient's earliest convenience once stability was documented.

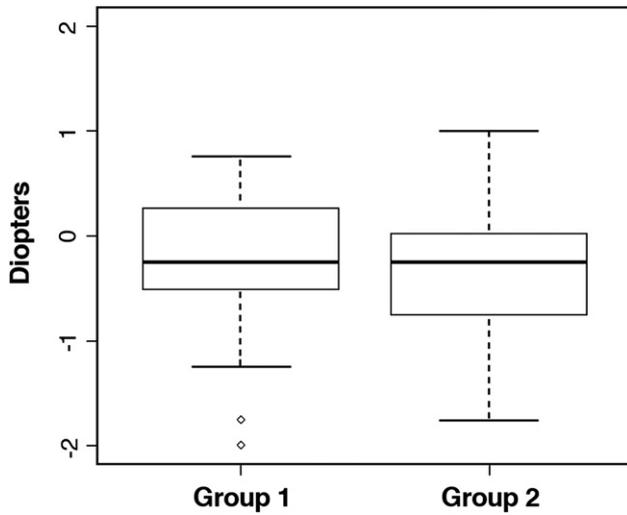


Figure 5. Box plot of postoperative sphere. The boxes contain 50% of the data. The upper edge of the box indicates the 75th percentile of the data set and the lower edge, the 25th percentile. The range of the middle 2 quartiles is the interquartile range. The line in the box indicates the median value. The ends of the vertical lines indicate the minimum and maximum data values. The triangles represent outlier values (Group 1 = control group; Group 2 = aberrometry group).

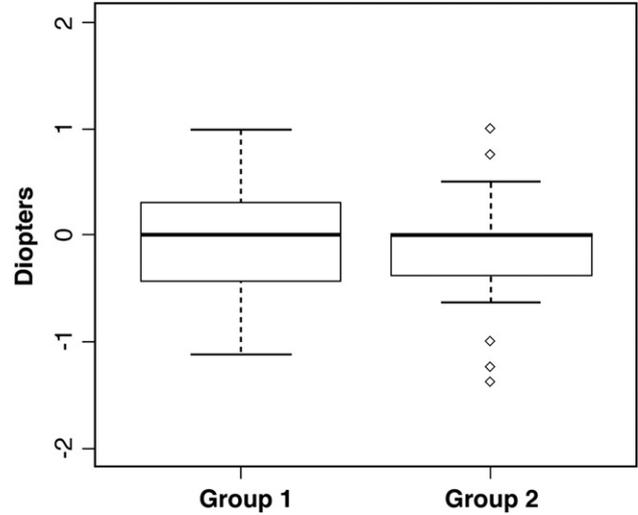


Figure 7. Box plot of postoperative MRSE. The boxes contain 50% of the data. The upper edge of the box indicates the 75th percentile of the data set and the lower edge, the 25th percentile. The range of the middle 2 quartiles is the interquartile range. The line in the box indicates the median value. The ends of the vertical lines indicate the minimum and maximum data values. The triangles represent outlier values (Group 1 = control group; Group 2 = aberrometry group).

Statistical Analysis

In general, the key preoperative variables that determine a given eye’s response to LRIs include the patient’s age, magnitude of keratometric astigmatism, peripheral corneal pachymetry, and axis of astigmatism. These variables were considered in determining the baseline comparability of the 2 groups (control and aberrometry). A general estimating equation model (GEE) was used in evaluating a correlated endpoint that resulted from taking measures from both eyes. General estimating equation modeling permits estimation of treatment effects (and covariates) using 1 of a variety of correlational structures from the dependent variables being analyzed; in the case of 2 endpoints (ie, from right eye and left eye in the same person), a symmetric matrix is necessary. Different link functions permit analysis of binary

and continuous (among others) endpoints. For the modeling used in this study, a logistic link function was used to assess the effect of treatment on the occurrence of subsequent enhancement, which was assigned to a binary enhanced or not enhanced. The model included follow-up exposure time as a covariate. Given the small sample size, covariates were not included in the GEE modeling.

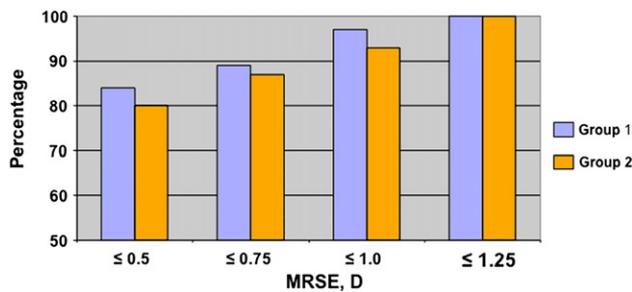


Figure 6. Cumulative frequency distribution of MRSE (Group 1 = control group; Group 2 = aberrometry group).

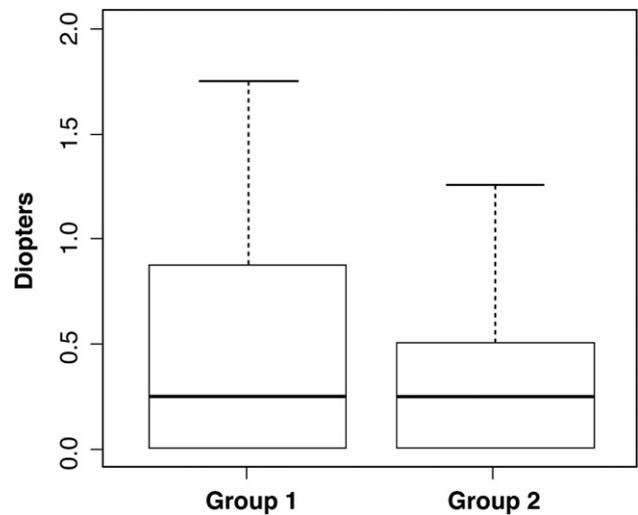


Figure 8. Box plot of manifest refractive cylinder 1 month postoperatively. The boxes contain 50% of the data. The upper edge of the box indicates the 75th percentile of the data set and the lower edge, the 25th percentile. The range of the middle 2 quartiles is the interquartile range. The line in the box indicates the median value. The ends of the vertical lines indicate the minimum and maximum data values (Group 1 = control group; Group 2 = aberrometry group).

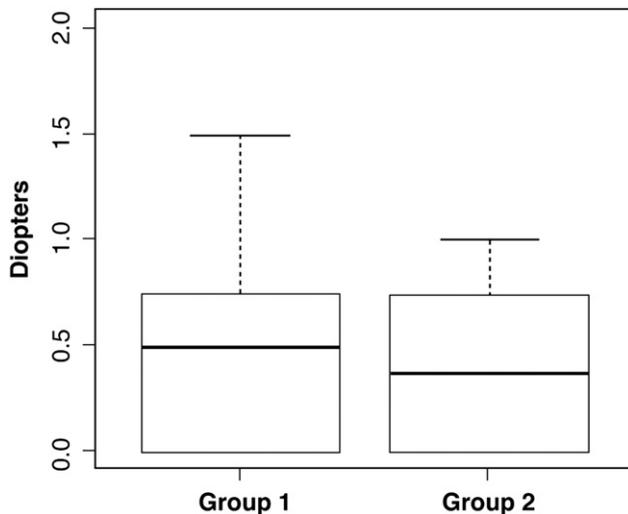


Figure 9. Box plot of manifest refractive cylinder 6 months postoperatively. The boxes contain 50% of the data. The upper edge of the box indicates the 75th percentile of the data set and the lower edge, the 25th percentile. The range of the middle 2 quartiles is the interquartile range. The line in the box indicates the median value. The ends of the vertical lines indicate the minimum and maximum data values (Group 1 = control group; Group 2 = aberrometry group).

RESULTS

The control group comprised 37 eyes of 27 patients and the aberrometry group, 30 eyes of 21 patients. Table 1 shows the preoperative baseline characteristics by group. There were no statistically significant differences between the 2 groups in any preoperative parameter. A monofocal IOL was implanted in 18 eyes in the control group and 14 eyes in the aberrometry group, a multifocal IOL in 11 eyes and 6 eyes, respectively, and an accommodating IOL in 8 eyes and 10 eyes, respectively.

The mean postoperative follow-up was 6 ± 2.5 months (range 1 to 19 months) in the control group and 3 ± 2.5 months (range 1 to 9 months) in the aberrometry group; the difference between the groups was not statistically significant ($P = .61$). No patient in either group was excluded because of an intraoperative or postoperative complication that might limit visual acuity.

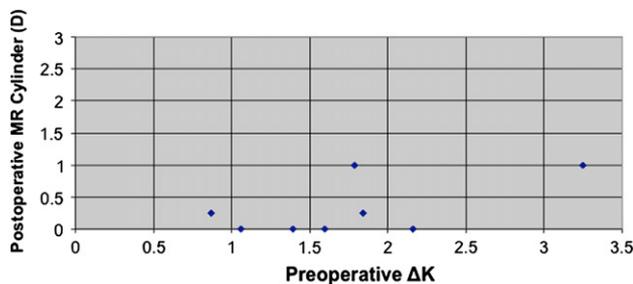


Figure 10. Preoperative ΔK versus postoperative cylinder in eyes in the aberrometry group that had LRI enhancement (ΔK = delta keratometry value; MR = manifest refractive).

Table 2 shows postoperative results in the 2 groups. There were no statistically significant differences between the groups in postoperative parameters.

One month postoperatively (66 eyes), the mean manifest refractive cylinder in all eyes was 0.42 D (range 0.00 to 2.50 D), the median Snellen uncorrected distance visual acuity (UDVA) was 20/25 (range 20/15 to 20/60), and the median corrected distance visual acuity (CDVA) was 20/20 (range 20/15 to 20/40). At a mean of 7 months (34 eyes), the mean manifest refractive cylinder was 0.59 D, the median UDVA was 20/25 (range 20/20 to 20/50), and the median CDVA was 20/20 (range 20/15 to 20/30).

In the control group, eyes with higher preoperative delta keratometry values (ΔK) had higher levels of postoperative manifest refractive cylinder (Figure 1). At a mean of 9 months (20 eyes), the mean cylinder was 0.53 D, the median UDVA was 20/25 (range 20/20 to 20/50), and the median CDVA was 20/20 (range 20/15 to 20/30).

In the aberrometry group, eyes with higher preoperative ΔK values had higher levels of postoperative manifest refractive cylinder (Figure 2). At a mean of 5 months (14 eyes), the mean refractive cylinder was 0.41 D.

Figure 3 shows double-angle plots of the preoperative ΔK and postoperative manifest refractive cylinder in both groups. The mean preoperative cylinder was 0.365 D in the control group and 0.813 D in the aberrometry group and the mean postoperative cylinder, 0.084 D and 0.019 D, respectively. Neither group had an axis shift.

Figure 4 shows the cumulative frequency distribution of postoperative manifest refractive cylinder in the 2 groups. Postoperatively, the control group had higher postoperative cylinder than the aberrometry group. In contrast, the means and distributions of manifest refractive sphere and SE were similar between the 2 groups. Figure 5 shows a box plot of postoperative sphere and Figure 6, a box plot of the postoperative manifest refraction spherical equivalent (MRSE). Figure 7 shows the cumulative frequency distribution of MRSE. Eyes in the aberrometry group had lower levels of postoperatively cylinder (≤ 1.0 D) than eyes in the control group. Figure 8 shows a box plot of manifest refractive cylinder 1 month postoperatively and Figure 9, at 6 months.

Eight eyes (6 patients) in the aberrometry group had intraoperative enhancement with extended LRIs based on intraoperative aberrometry measurements. The mean age of the 6 patients was 62.2 ± 12.5 years. In the 8 eyes, the mean preoperative ΔK was 1.75 D (0.87 to 3.25 D) with a mean steep axis of 82 degrees and the mean preoperative 10.0 mm pachymetry at the steep axis was 655 μm . The mean postoperative

Table 3. Characteristics of eyes that had laser enhancement.

Group and Patient	Preop ΔK	MR Before Enhancement	Eye	UDVA	IOL Model/Power (D)
Control					
1	2.32 @ 148	-2.00 +2.50 × 180	L	20/70	Z9002, 22.0
2	1.63 @ 88	-0.25 +1.00 × 90	R	20/30	NXG1, 13.5
2	2.05 @ 86	-0.25 +1.25 × 90	L	20/30	SN6AD3, 14.0
3	2.13 @ 115	-1.75 +1.25 × 43	R	20/40	AT50SE, 18.0
3	1.32 @ 67	-1.25 +1.75 × 106	L	20/40	AT50SE, 19.0
4	0.76 @ 67	-0.50 +1.00 × 90	L	20/50	AT52SE, 16.0
Aberrometry					
5	2.61 @ 78	-1.25 +1.25 × 75	L	20/25	ZCBOO, 27.0

ΔK = delta keratometry value; MR = manifest refraction; UDVA = uncorrected distance visual acuity

SE was 0.063 D (range -0.375 to 1.00 D) and the mean manifest refractive cylinder at 29 days, 0.31 D (range 0.00 to 1.00 D). The median UDVA was 20/25 (range 20/20 to 20/40) and the median CDVA, 20/20 (range 20/15 to 20/30). The mean postoperative cylinder at 6 months (n = 4) was 0.31 D (range 0.00 to 0.75 D). Eyes with a ΔK value of 1.50 D or less preoperatively had a mean cylinder of 0.25 D after LRI enhancement (Figure 10).

Overall, laser enhancements were performed in 7 eyes (3 LASIK, 4 PRK) of 5 patients, for a rate of 10.4% (Table 3). One enhancement was performed 2 months after cataract surgery, 3 were performed at 3 months, 1 was performed at 5 months, and 2 were performed at 11 months. The mean time from primary surgery to enhancement was 8 months (range 2 to 11 months). No eye with postoperative refractive cylinder of 0.75 D or less had laser enhancement. Two eyes (2 patients) in the control group with 1.00 D of postoperative refractive cylinder had laser enhancement. Seven eyes of 7 patients (4 in control group; 3 in aberrometry group) with a postoperative refractive cylinder of 1.00 D did not have laser enhancement. Two of the 3 eyes in the aberrometry group had intraoperative LRI enhancements. One eye of 1 patient in the control group with more than 1.00 D of postoperative refractive cylinder did not have laser enhancement. The postoperative refraction was -1.00 +1.75 × 40, the UDVA

was 20/25, and the CDVA was 20/20. Figure 11 shows the preoperative ΔK versus the postoperative manifest refractive cylinder in eyes that had laser enhancement.

In the control group, the excimer laser enhancement rate was 16.2%. The mean age of the 6 patients having enhancement was 59.8 ± 3.7 years. The mean preoperative ΔK was 1.70 D (range 0.76 to 2.32 D) with a mean steep axis of 95 degrees, and the mean preoperative 10.0 mm pachymetry at the steep axis was 664 μm. One of the eyes had a monofocal IOL, 2 had a multifocal IOL, and 3 had an accommodating IOL. The mean postoperative SE before enhancement was -0.27 D (range -1.13 to 0.375 D) and the mean manifest refractive cylinder at 1 month after primary surgery, 1.45 D (range 1.00 to 2.50 D). Four of the eyes had mixed astigmatism, and 2 had myopic astigmatism. The MRSE was ±0.50 D or less in all eyes with mixed astigmatism. In one eye with mixed astigmatism and 1 eye with myopic astigmatism (patient 3, left eye; patient 4), the postoperative manifest refractive cylinder exceeded the preoperative keratometric cylinder. Both were left eyes with oblique preoperative keratometric cylinder at 67 degrees, and both developed an increased magnitude of with-the-rule astigmatism. Before excimer laser enhancement, the median UDVA was 20/40 (20/25 to 20/70) and the median CDVA, 20/20. The mean manifest cylinder 7 to 16 months after laser enhancement was 0.95 D. The median UDVA improved to 20/30 (20/25 to 20/50) and the median CDVA, to 20/20 (20/15 to 20/20).

One eye of a 58-year-old patient in the aberrometry group had excimer laser enhancement (Table 3), for a rate of 3.3%. The preoperative 10.0 mm pachymetry at the steep axis was 658 μm. The eye had a monofocal IOL and did not have intraoperative LRI enhancement. After PRK, the UDVA improved from 20/25 to 20/20 (no refraction performed).

The general estimating equation model showed that the odds ratio of a laser enhancement without intraoperative wavefront aberrometry was 5.71 (P =

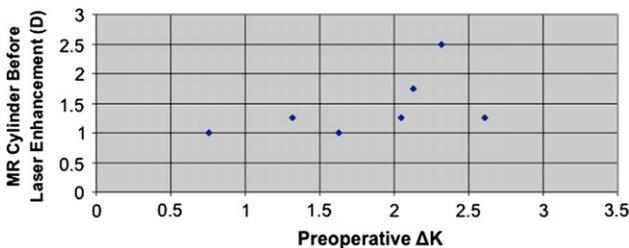


Figure 11. Preoperative ΔK versus postoperative cylinder in eyes having laser enhancement (ΔK = delta keratometry value; MR = manifest refractive).

.12). Because analysis of the baseline characteristics and length of follow-up did not show significant differences, the model was not adjusted for covariates. Calculation of the association between the measured manifest refractive cylinder at 1 month and later time points showed a Pearson correlation coefficient of 0.65 ($P = .0025$).

DISCUSSION

This small retrospective case-control study found that using intraoperative wavefront aberrometry to measure and enhance the effect of LRIs reduced the odds of later excimer laser more than 5-fold. Although the effect was not statistically significant ($P = .12$), it appears to represent a trend. With 7 excimer laser enhancements in the entire population, there was not adequate power to detect significant differences. Further research, in particular a prospective randomized study, is indicated to validate the significance of the effect of intraoperative wavefront aberrometry.

The decision to proceed with a laser enhancement is generally complex, involving the patient's current level of satisfaction with his or her degree of spectacle independence, tolerance of blur due to refractive error (including the balance between the spherical and cylindrical components of the refraction), acceptance of additional surgical risk, and enthusiasm for the potential benefits of enhancement surgery. In some countries, the decision also depends on the patient's ability and willingness to pay the additional price of the enhancement procedure. In addition, postoperative satisfaction hinges on an implicit comparison with the patient's preoperative state. For some patients who were uncertain about having an enhancement, the present study's 1-year follow-up deadline for obtaining the enhancement at cost may have played a decisive role in the timing of the procedure.

The intraoperative wavefront aberrometer used in this study was developed to improve astigmatism correction during cataract surgery. The device has found applications in the construction and enhancement of peripheral corneal relaxing incisions and accurate rotational placement of toric IOLs. The system uses Talbot moiré technology,^{15,16} which has a more robust measurement capability than Hartmann-Shack or Tscherning aberrometry.

During the study, the only significant alteration in procedure or technique was the introduction of the wavefront aberrometer. Intraocular lens power calculation and surgical technique did not vary. Although the decision to proceed with an enhancement procedure is complex and multifactorial, residual refractive error remains the critical determinant. In examining the characteristics of the 2 groups, the relatively

identical postoperative SE manifest refractive errors indicate that sphere was usually not the source of patient dissatisfaction. In 2 eyes having enhancement (patient 1 and patient 3, right eyes), the myopic SE did play a role in the overall refractive error; in the other 5 eyes, the cylindrical component alone resulted in the patients' decision to have an enhancement.

In this series, a residual manifest refractive cylinder of 1.00 D appeared to be a watershed in the decision to have a postoperative enhancement procedure. Most patients (7 of 9) with 1.00 D residual astigmatism decided not to proceed with an enhancement, and no patient with less than 1.00 D had an enhancement. On the other hand, only 1 patient with a postoperative refractive cylinder greater than 1.00 D did not choose to have laser enhancement. Therefore, it appears as though reducing postoperative refractive cylinder to 0.75 D or less may be an effective strategy to avoid postoperative enhancement procedures.

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