Peripheral corneal relaxing incisions after excimer laser refractive surgery

Li Wang, MD, PhD, Anil Swami, MD, Douglas D. Koch, MD

Purpose: To evaluate the effectiveness of peripheral corneal relaxing incisions (PCRIs) for correcting corneal astigmatism after excimer laser refractive surgery.

Setting: Cullen Eye Institute, Baylor College of Medicine, Houston, Texas, USA.

Methods: In this retrospective case series, PCRIs were performed in 33 eyes (30 patients) that had residual astigmatism after photorefractive keratectomy or laser in situ keratomileusis according to a nomogram based on age and preoperative refractive astigmatism. Uncorrected visual acuity (UCVA) and refractive and keratometric astigmatism were evaluated, and vector analysis using the Holladay-Cravy-Koch formula was performed.

Results: The percentage of eyes with a UCVA of 20/20 or better increased significantly from 6% (2/33) preoperatively to 61% (20/33) postoperatively ($P<.001$). Refractive astigmatism was reduced significantly, and the effect was stable up to 1 year after PCRIs. The percentage of eyes within ±0.5 diopter (D) and ±1.0 D of cylinder increased by 73% and 52%, respectively (both $P<.001$). No eye lost 1 or more lines of best spectacle-corrected visual acuity.

Conclusion: Peripheral corneal relaxing incisions are an effective approach for correcting low amounts of corneal astigmatism in eyes that have had excimer laser refractive surgery.

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Astigmatism is found in 14% to 40% of the normal population and varies with patient age.[1,2] An important goal in corneal refractive surgery is to minimize postoperative corneal astigmatism after photorefractive keratectomy (PRK) and laser in situ keratomileusis (LASIK). Surgical options to treat undesired postoperative astigmatism include additional laser surgery (on the flat or steep meridians or both),[3] astigmatic keratotomy,[4] and peripheral corneal relaxing incisions (PCRIs).[5] The goal is to improve uncorrected visual acuity (UCVA) and reduce dependency on spectacle or contact lens correction.

Preliminary studies of PCRIs in cataract patients show they are effective, permit rapid postoperative recovery of vision, preserve the optical qualities of the cornea, and pose little or no risk for inducing postoperative loss of best spectacle-corrected visual acuity (BSCVA), glare, or other visual complications.[6–8] In this study, we retrospectively studied the safety, efficacy, and predictability of PCRIs for correcting astigmatism after laser refractive surgery. An improved nomogram is accordingly proposed.

Patients and Methods

Peripheral corneal relaxing incisions were performed a minimum of 3 months after PRK or LASIK. Inclusion criteria for having the procedure were patient dissatisfaction with UCVA, a refractive cylinder ≥0.75 diopter (D) stable within

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From Cullen Eye Institute, Baylor College of Medicine, Department of Ophthalmology, Houston, Texas, USA.

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Reprint requests to Douglas D. Koch, MD, Cullen Eye Institute, Baylor College of Medicine, Department of Ophthalmology, 6565 Fannin, NC205, Houston, Texas 77030, USA.

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±0.50 D on manifest refraction (MR) at least 2 weeks apart, a mean spherical equivalent cycloplegic refraction within ±0.75 D of emmetropia, no loss of BSCVA from the original procedure, and no corneal disease that might interfere with corneal wound healing. The surgical goal was improvement of UCVA to 20/25 or better and reduction of refractive cylinder to less than 0.75 D without overcorrection.

The length and number of PCRIs were chosen according to a nomogram based on age and refractive astigmatism.[7,9] Incisions were centered around the plus axis of the cylinder of the manifest refraction. To ensure correct centration of the PCRIs, 2 approaches were used: (1) When available, the meridional location of prominent landmarks on the conjunctiva or limbus was noted and drawn relative to the 6 o'clock and 12 o'clock positions. (2) If a clear landmark was not evident by slitlamp biomicroscopy, the corneal and conjunctival epithelia at the limbus at the 90 and 270 semimeridians were marked with a Sinskey hook stained with gentian-violet dye.

Intraoperatively, a degree gauge was aligned with the 90 and 270 semimeridians, enabling identification of the surgical meridians. Incisions were placed in the peripheral cornea just inside the anterior insertion of the conjunctival vessels with a guarded diamond knife set at a depth of 600 μm. Peripheral pachymetry along the site of the PCRI was not performed. Care was taken to avoid the corneal flap in eyes previously treated with LASIK.

All procedures were performed by the same surgeon (D.D.K.). Patients were examined at 1 day, 1 week, and 1, 3, 6, and 12 months.

The records of all patients who had PCRIs after primary refractive surgery between May 1998 and December 2001 were retrospectively reviewed. Patients with a follow-up of less than 1 month were excluded. Included in the study were 26 eyes of 24 patients who received paired 6.0 mm PCRIs, 4 eyes of 4 patients who received paired 4.5 mm PCRIs, and 3 eyes of 2 patients who received single 6.0 mm PCRIs. The analysis included (1) UCVA and BSCVA; (2) the mean arithmetic changes in refractive cylinder as measured by MR and changes in keratometric cylinder provided by the EyeSys Corneal Analysis System (version 3.2, Premier Laser Systems, Inc.) or Humphrey Atlas (version A10.1, Carl Zeiss, Inc.); (3) determination of with-the-wound (WTW) and against-the-wound (ATW) changes using the Holladay-Cravy-Koch formula[10]; for these calculations, the steep corneal meridian where the PCRIs were placed was used as the reference, ie, the "wound"; (4) analysis of aggregate refractive astigmatism[11]; (5) complications including overcorrection, which was defined as postoperative astigmatism ≥0.5 D along a meridian 60 to 120 degrees from the original steep meridian.

Factoral analysis of variation (ANOVA) was used to evaluate the effects of sex, eye (right or left), age, type (with the rule [WTR] or against the rule [ATR]/oblique), and magnitude of the preoperative astigmatism on the WTW–ATW changes in the paired 6.0 mm PCRI group. The Student *t* test and McNemar test were also used, and a probability of less than 5% ($P<.05$) was considered statistically significant.

Results

Paired 6.0 mm PCRIs

Twenty-six eyes of 24 patients received paired 6.0 mm PCRIs (Table 1).

Visual Acuity. The percentage of eyes with a UCVA of 20/20 or better increased from 8% preoperatively to 54% postoperatively and of eyes with a UCVA of 20/25 or better, from 31% to 69% (Figure 1) (both $P<.05$). No eye lost 2 or more lines of UCVA, and 12 eyes (46%) gained 2 or more lines (Figure 2).

Of the 3 eyes that lost 1 line of UCVA at the last follow-up, 1 had a mild overcorrection (see below); 1 had a UCVA of 20/32 and an MR of −1.00 +1.25 × 90 preoperatively and 20/40 and −1.25 +1.00 × 106, respectively, 6 months after PCRIs; 1 eye had a UCVA of 20/32 and an MR of −1.75 +1.50 × 76 preopera-

Table 1. Demographic summary.

PCRIs	Eyes	Age (Y)	Sex	Previous Surgery	Last Follow-up
Paired 6.0 mm	26	47 ± 8	9 men 15 women	PRK in 6 eyes LASIK in 20 eyes	1 eye at 1 mo 6 eyes at 3 mo 8 eyes at 6 mo 11 eyes at 12–20 mo
Paired 4.5 mm	4	49 ± 9	1 men 3 women	LASIK in 4 eyes	1 eye at 1 mo 2 eyes at 3 mo 1 eye at 5 mo
Single 6.0 mm	3	45 ± 12	1 men 1 women	LASIK in 3 eyes	2 eyes at 8 mo 1 eye at 12 mo

LASIK = laser in situ keratomileusis; PCRIs = peripheral corneal relaxing incisions; PRK = photorefractive keratectomy

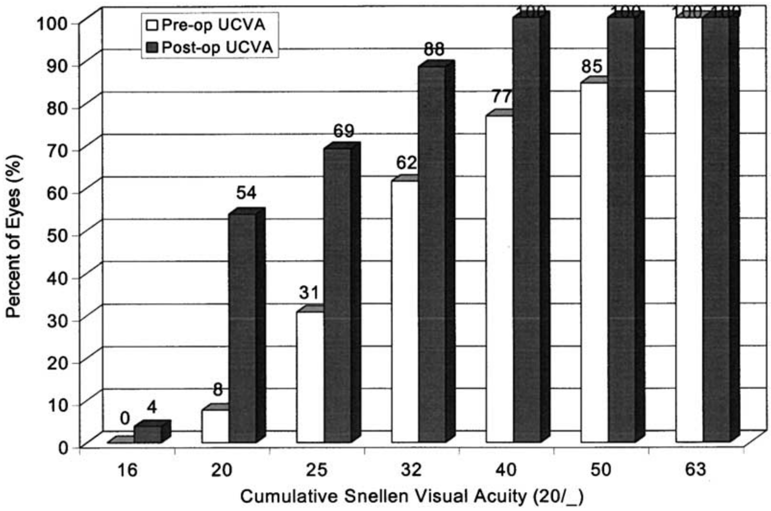

Figure 1. (Wang) Cumulative Snellen UCVA preoperatively and postoperatively. The percentage of eyes with a UCVA of 20/20 or better increased by 46% and of eyes with a UCVA of 20/25 or better, by 38%.

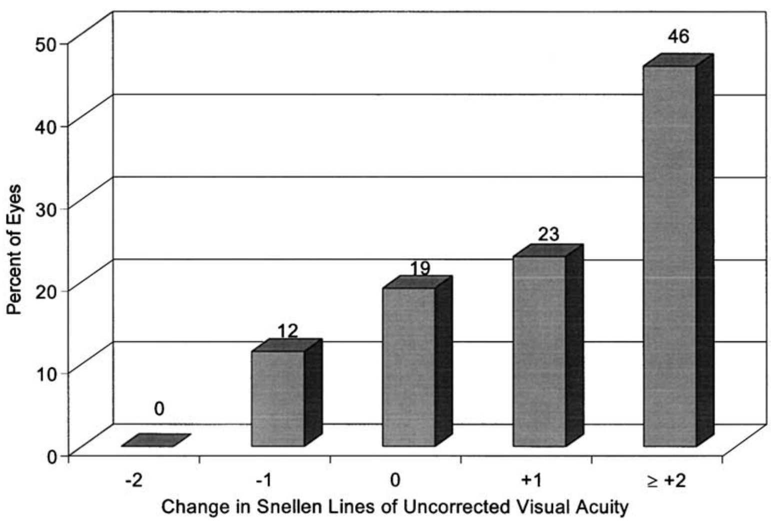

Figure 2. (Wang) Change in Snellen lines of UCVA. No eye lost 2 or more lines of UCVA, and 12 eyes (46%) gained 2 or more lines.

tively and 20/40 and $-1.25 +0.50 \times 90$, respectively, at 3 months.

Of the 5 eyes that had the same UCVA as preoperatively at the last follow-up, 2 had a UCVA of 20/20 before and after PCRIs. Two had a UCVA of 20/25 preoperatively, 20/16 at 3 to 6 months, and 20/25 at 12 months; however, the refractive cylinder was reduced by 0.75 D. One eye had a UCVA of 20/32 and a refractive cylinder of 1.00 D after PRK and before PCRIs; the refractive cylinder was 0.75 D at 6 months

Table 2. Preoperative and postoperative refractive and keratometric astigmatism in eyes that received paired 6.0 mm PCRIs.

Follow-up	Number of Eyes	Refractive Cylinder (D)		Keratometric Cylinder (D)	
		Mean	Range	Mean	Range
Preop	26	1.17 ± 0.23	0.75 to 1.50	1.31 ± 0.63	0.62 to 3.62
1 wk	24	0.48 ± 0.38*	0 to 1.50	1.05 ± 0.68	0.04 to 2.50
1 mo	13	0.48 ± 0.36*	0 to 1.25	0.86 ± 0.48*	0.04 to 1.64
3 mo	14	0.46 ± 0.19*	0 to 0.75	1.00 ± 0.67	0 to 2.62
6 mo	12	0.54 ± 0.40*	0 to 1.00	1.03 ± 0.74*	0.19 to 2.87
12 mo	11	0.45 ± 0.49*	0 to 1.50	0.87 ± 0.69	0.13 to 2.25

PCRIs = peripheral corneal relaxing incisions
*Statistically significant reduction ($P<.05$)

Table 3. Change in WTW and ATW (Holladay-Cravy-Koch formula) by paired 6.0 mm PCRIs along the PCRI meridian at postoperative follow-ups.

Follow-up	Number of Eyes	WTW (D)	ATW (D)	WTW–ATW (D)
1 wk	24	−0.71 ± 0.52	0.31 ± 0.48	−1.01 ± 0.47
1 mo	13	−0.67 ± 0.64	0.38 ± 0.53	−1.06 ± 0.43
3 mo	14	−0.73 ± 0.27	0.23 ± 0.41	−0.96 ± 0.36
6 mo	12	−0.37 ± 0.47	0.50 ± 0.40	−0.87 ± 0.44
12 mo	11	−0.36 ± 0.53	0.52 ± 0.42	−0.88 ± 0.43

ATW = against the wound; WTW = with the wound

and 1.50 D at 13 months after paired 6.0 mm PCRIs. Paired 4.5 mm PCRIs were performed, and the UCVA was 20/16 at 6 months.

No eye lost 1 or more lines of BSCVA.

Mean Arithmetic Changes in Refractive and Keratometric Astigmatism. The refractive cylinder was significantly reduced by 0.57 D to 0.75 D from 1 week to more than 1 year (Table 2) ($P<.01$). The keratometric cylinder was significantly reduced at 1 and 6 months ($P<.05$), and the mean reduction ranged from 0.28 D to 0.38 D (Table 2).

At the last follow-up, the percentage of eyes with a refractive cylinder ≤0.5 D improved from 0% preoperatively to 69% postoperatively and the percentage with ≤1.0 D, from 38% to 96%, respectively (both $P<.001$).

Changes in WTW and ATW by Holladay-Cravy-Koch Formula. The mean WTW–ATW changes were −1.06 D, −0.96 D, −0.87 D, and −0.88 D at 1, 3, 6, and 12 months, respectively (Table 3). At the last follow-up, the mean WTW–ATW changes were −0.84 D ± 0.45 (SD) in 19 eyes with preoperative WTR astigmatism and −1.13 ± 0.23 D in 7 eyes with preoperative ATR/oblique astigmatism. Factoral ANOVA revealed that the WTW–ATW values at the last follow-up increased with increasing age: $F_{1,20} = 5.038$, $P = .036$.

Analysis of Aggregate Refractive Astigmatism. In all eyes at the last follow-up, the paired 6.0 mm PCRIs reduced the preoperative mean refractive astigmatism of 0.64 ± 0.69 D × 92° to 0.24 ± 0.41 D × 115° postoperatively (Figure 3), with a mean reduction of 0.49 ± 0.68 D × 82°.

Complications. One eye (3.8%) that received paired 6.0 mm PCRIs was overcorrected. The MR was −0.50 +1.00 × 50 preoperatively and −0.25 +0.50 × 141 at 4 months. The WTW–ATW change along the preoperative steep meridian was 1.04 D.

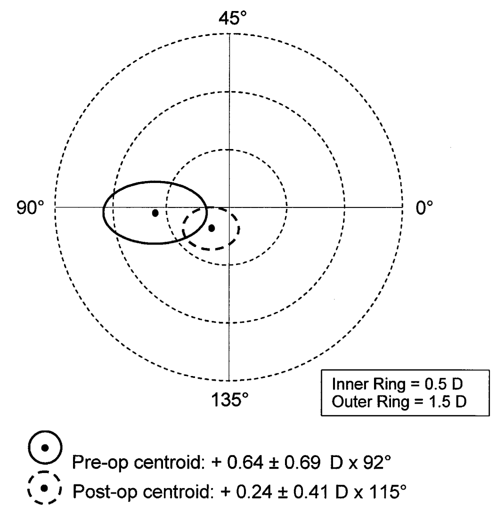

Figure 3. (Wang) Aggregate vector analysis of refractive astigmatism before and after paired 6.0 mm PCRIs. Black dots represent centroids or means, and elliptical areas surrounding the centroids represent the standard deviation.

One eye had a superonasal macroperforation at the 120-degree meridian following PCRIs due to the first use of a new knife, and 2 sutures were placed. At 3 months, the manifest cylinder was reduced by 0.75 D and the UCVA gained 2 lines.

No eye had other postoperative complications.

Paired 4.5 mm PCRIs

Four eyes of 4 patients received paired 4.5 mm PCRIs (Table 1) for treatment of ATR astigmatism.

Preoperatively, the UCVA was 20/32 in 3 eyes and 20/25 in 1 eye. After PCRIs, it was 20/16 in 1 eye, 20/20 in 1 eye, and 20/25 in 2 eyes. All eyes gained at least 1 line of UCVA. No eye lost 1 or more lines of BSCVA.

Table 4. Refractive and keratometric cylinder changes and WTW–ATW changes induced by paired 4.5 mm and single 6.0 mm PCRIs.

PCRIs	Number of Eyes	Scalar Reduction in Refractive Cylinder (D)	Scalar Reduction in Keratometric Cylinder (D)	WTW (D)	ATW (D)	WTW–ATW (D)
Paired 4.5 mm	4	0.75 ± 0.35*	0.29 ± 0.30	−0.78 ± 0.20	0.03 ± 0.38	−0.80 ± 0.29
Single 6.0 mm	3	0.83 ± 0.14*	0.50 ± 0.45	−0.48 ± 0.31	0.48 ± 0.37	−0.96 ± 0.18

*Statistically significant reduction ($P<.05$)

The refractive cylinder was significantly reduced by 0.75 D ($P<.05$), and the keratometric cylinder was reduced by 0.29 D (Table 4). No eye had a refractive cylinder ≤0.5 D preoperatively compared with 3 eyes (75%) postoperatively.

The mean WTW–ATW change was −0.80 D (Table 4).

No eye was overcorrected or had postoperative complications.

Single 6.0 mm PCRIs

Three eyes of 2 patients received single 6.0 mm PCRIs (Table 1). Preoperatively, the UCVA was 20/25 in 2 eyes and 20/32 in 1 eye; after PCRIs, the UCVA was 20/20 in all 3 eyes. No eye lost 1 or more lines of BSCVA.

The refractive cylinder was significantly reduced by 0.83 D ($P<.05$), and the keratometric cylinder was reduced by 0.50 D (Table 4). No eye had a refractive cylinder ≤0.50 D before PCRIs; all 3 eyes had a refractive cylinder ≤0.50 D or less after PCRIs.

The mean WTW–ATW change was −0.96 D (Table 4).

No eye was overcorrected or had postoperative complications.

Nomogram

The results were used to modify the nomogram based on age and preexisting refractive astigmatism, as shown in Table 5.

Table 5. Current nomogram for PCRIs to correct refractive astigmatism after refractive surgery.

Astigmatism (D)	Age (Y)	Number	Length (Degree)
WTR			
0.75–1.00	<65	2	45
	≥65	1	45
1.25–1.75	<65	2	60
	≥65	2	45
≥2.00	<65	2	80
	≥65	2	60
ATR/oblique			
0.75–1.00	—	1	45
1.25–2.00	<65	2	50
	≥65	2	40
≥2.00	<65	2	55
	≥65	2	45

ATR = against the rule; WTR = with the rule

Discussion

Astigmatism present after refractive surgery is surgically induced[12,13] or residual because of undercorrection of preexisting astigmatism. Patients with ≥0.75 D of astigmatism may be candidates for some form of astigmatic correction. As indicated by our inclusion criteria, we believe that the major determinants for astigmatic correction are the patient's desire for better UCVA, a UCVA that is generally less than 20/25, and evidence based on the MR that the refractive cylinder is the cause of the suboptimal vision. In this regard, we often place trial lenses before the patient's affected eye to ascertain whether the anticipated cylindrical correction will alleviate the visual complaint.

Surgical options for reducing astigmatism include additional excimer laser ablation, astigmatic keratotomy, and PCRIs. Excimer laser retreatment has been shown to be a safe and effective approach. However, there are complications associated with reablating eyes that have had surface ablation[14] and with lifting or recutting LASIK flaps.[15] Furthermore, excimer laser correction of astigmatism along the flat meridian can produce a hyperopic shift.[16] As a result, we generally reserve excimer laser retreatments for astigmatism for eyes whose spherical equivalent is undercorrected or overcorrected.

Astigmatic keratotomy is another acceptable option, and corrections of 3.0 D or more can be achieved in eyes with naturally occurring or postoperative astigmatism.[17] Kapadia and coauthors[4] report that paired arcuate transverse incisions (Casebeer-Lindstrom nomogram) with a 7.0 mm diameter optical zone after PRK effectively reduce astigmatism and improve visual outcome. The major disadvantage of astigmatic keratotomy is that incisions are made closer to the center of the cornea than is done with PCRIs; this requires cutting through the LASIK flap. With the current accuracy of excimer laser surgery, residual astigmatism in excess of 2.0 D is uncommon and to date, we have not encountered eyes in which PCRIs did not provide adequate correction.

In light of the limitations of alternative approaches, PCRIs seem to be an excellent option. The goal of PCRIs is to safely and effectively reduce the astigmatism present after PRK or LASIK. In our patients, there was a statistically (and clinically) significant increase in UCVA; the percentage of eyes with a UCVA of 20/20 increased from 6% to 61%. There was also a significant reduction in the refractive cylinder and a corresponding significant increase in the percentage of eyes within ±0.5 D (from 0% to 73%) and ±1.0 D (from 45% to 97%) of the refractive cylinder. The effect was stable up to 1 year, and there was no loss of BSCVA. No patient reported postoperative distortion in vision, glare, or discomfort.

Of the 3 eyes that lost 1 line of UCVA, 1 eye was overcorrected. According to the revised monogram, a single 45-degree PCRI is recommended for preoperative oblique astigmatism of 1.0 D rather than the paired 6.0 mm PCRIs that were performed. The second eye's loss of UCVA was due to myopic regression. In the third eye, the UCVA decreased from 20/32 to 20/40 despite an improvement in manifest cylinder from $-1.75 + 1.50 \times 76$ to $-1.25 + 0.50 \times 90$; the change in UCVA might have been due to loss of myopic astigmatism.

We did not measure the peripheral pachymetry along the site of the PCRIs. The macroperforation in 1 case was due to the first use of a new knife; this knife has a slender footplate, which permits rocking the blade that can lead to increased incisional depth. It was not used thereafter. Our experience generally suggests that a guarded diamond knife set at a depth of 600 μm is safe; however, the risk for perforation could presumably be further reduced by performing intraoperative pachymetry.

Factoral ANOVA revealed that only age had a significant effect on the WTW–ATW change. Although we did not detect a significant effect of WTR or ATR/oblique astigmatism in this study, our current nomogram differentiates between WTR and ATR/oblique preoperative astigmatism. In studies of PCRIs in virgin eyes and eyes having cataract surgery, we found that horizontal PCRIs have more effect on the WTW–ATW change than vertical PCRIs. Data from a large series of patients are required to assess the effects of horizontal and vertical PCRIs in eyes after LASIK and PRK. Also, to minimize the risk for overcorrection in eyes with small corneal diameters, we changed our new nomogram to measure the PCRI length by degrees rather than by millimeters. The conversion from millimeters to degrees was performed based on a corneal diameter of 11.5 mm; 4.5 mm in length equals 45 degrees and 6.0 mm equals 60 degrees.

In summary, our results suggest that PCRIs are a practical, effective, and easily performed method for correcting astigmatism after excimer laser refractive surgery. We modified the nomogram based on the data in this study and believe that more effective results can be expected under the guidance of the improved nomogram.

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