Combined astigmatic keratotomy and conductive keratoplasty to correct high corneal astigmatism

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PURPOSE: To determine the safety, efficacy, and predictability of combined astigmatic keratotomy (AK) and conductive keratoplasty (CK) for treating high corneal astigmatism.

SETTING: University of California–Los Angeles, Los Angeles, California, USA.

DESIGN: Retrospective case series.

METHODS: From January 1, 2004, to December 31, 2009, AK and CK were performed in eyes with corneal astigmatism of 5.0 diopters (D) or more after keratoplasty or trauma. The uncorrected (UDVA) and corrected (CDVA) distance visual acuities, spherical equivalent (SE), defocus equivalent, mean astigmatism, efficacy index, and complications were evaluated.

RESULTS: In 11 eyes of 11 patients, the mean UDVA improved from 1.54 logMAR $\pm$ 0.50 (SD) preoperatively to 0.69 $\pm$ 0.62 logMAR 3 months postoperatively ($P < .001$) and the mean CDVA from 0.55 $\pm$ 0.62 logMAR to 0.12 $\pm$ 0.11 logMAR ($P = .028$). The mean SE and mean defocus equivalent decreased from -1.25 ± 5.06 D to 3.13 $\pm$ 3.06 D ($P = .15$) and from 7.98 $\pm$ 4.41 D to 6.97 $\pm$ 3.73 D ($P = .45$), respectively; these changes were not statistically significant. The mean absolute astigmatism decreased from 10.25 $\pm$ 4.71 D to 4.31 $\pm$ 2.34 D ($P < .001$). The mean absolute orthogonal and mean oblique astigmatism showed a statistically significant decrease. The efficacy index was 0.82. One case of wound gape after AK required suturing. No infectious keratitis, corneal perforation, or graft rejection occurred.

CONCLUSIONS: Results indicate that combined AK and CK is safe and effective for correcting high corneal astigmatism after surgery or trauma.

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Corneal astigmatism is common after corneal injury and corneal surgery such as penetrating keratoplasty (PKP). Nonsurgical management of high levels of corneal astigmatism is often limited because topographic irregularities make contact lens fitting difficult and spectacles often cause intolerable levels of aniseikonia. Surgical management of high astigmatism includes corneal wedge resection,[1] relaxing incisions with or without compression sutures,[2–4] astigmatic keratotomy (AK),[5–7] photorefractive keratectomy (PRK),[8] laser in situ keratomileusis (LASIK),[9] intrastromal corneal ring segment implantation,[10] toric intraocular lens (IOL) implantation,[11–13] and conductive keratoplasty (CK).[14–16] Photorefractive keratectomy and LASIK produce less predictable results and are limited in the amount of astigmatism they can correct.[8,9] Toric IOL implantation is also limited in how much astigmatism it can correct and carries the risks associated with intraocular surgery.

Astigmatic keratotomy involves creating a deep corneal incision, typically pairs of incisions, to cause flattening along a steep meridian. Conductive keratoplasty uses radiofrequency energy to alter the corneal curvature. Resistance to the radiofrequency current causes an increase in corneal temperature and collagen shrinkage. The change in stromal architecture results

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in steepening of the corneal meridian in the axis of treatment.[17] Using both treatments orthogonally to each other creates the potential for a synergistic effect.

To our knowledge, no study has evaluated the effects of combining AK and CK to treat high astigmatism. In this study, we report the technique, efficacy, safety, and predictability of this combined procedure.

PATIENTS AND METHODS

This retrospective case series comprised eyes treated with both AK and CK for astigmatism from January 1, 2004, to December 31, 2009. The study was approved by the Institutional Review Board, University of California, Los Angeles.

Eyes with at least 5.0 diopters (D) of astigmatism were included. All treatments were performed at least 6 months after complete suture removal in post-keratoplasty eyes, and stable topography was documented at 2 consecutive visits at least 1 month apart. Study eyes had a minimum follow-up of 3 months after the AK and CK treatments. Exclusion criteria included insufficient postoperative follow-up and a history of traumatic corneal rupture.

Data collected included age, sex, surgeon, procedure type (combined or staged), follow-up period, uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), preoperative and postoperative manifest refraction spherical equivalent (SE), and corneal topographic astigmatism obtained using scanning-slit corneal topography (Orbscan, Bausch & Lomb). The UDVA and CDVA were measured using Snellen visual acuity charts and converted to logMAR notation for statistical analysis.

Surgical Technique

All AK and CK surgeries were performed by 1 of 2 corneal specialists (D.R.H., S.X.D.). The astigmatic keratotomy incisions were made in the area of the steep meridian, after which the CK spots were placed on the flat meridians (Figure 1). In some eyes, additional CK treatments were performed because postoperative topographic assessment showed areas of flattening amenable to additional CK spots. All procedures were performed using topical anesthesia.

Astigmatic Keratotomy The topographic axis from the scanning-slit corneal topography was used to determine treatment position. A pair of AK incisions at a 7.0 mm optical zone, inside the graft–host junction in post-PKP eyes, were created along the steep meridian using a guarded diamond blade set at 90% depth. Corneal thickness was assessed using an ultrasonic pachymeter. The topographic cylinder measurement obtained using scanning-slit corneal topography was used to determine the length of the keratotomy incisions. Each diopter of astigmatism was treated with 1 clock hour of arc length, to a maximum of 3 clock hours.

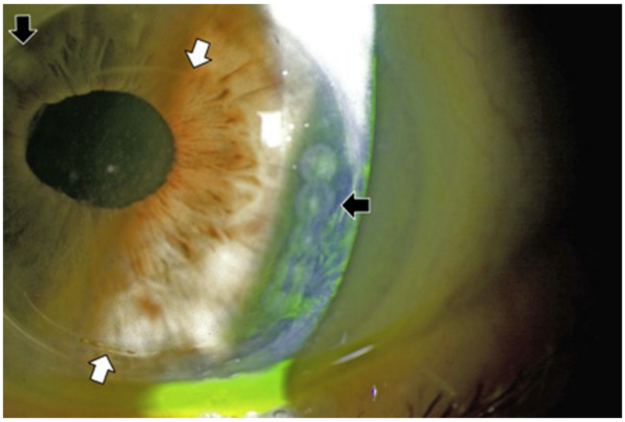

Figure 1. Slitlamp photograph showing faintly visible paired arcuate AK incisions (*white arrows*) and CK treatment spots (*black arrows*).

Conductive Keratoplasty Conductive keratoplasty using the Viewpoint CK system (Refractec, Inc.) was performed immediately after creation of the paired AK incisions or at a later date after stabilization of topography. A proprietary lid speculum hooked to a wire carrying the return current from the treatment was placed in the palpebral fissure. A coaxial, microscope-mounted ring light (keratoscope) was used to assess the preoperative astigmatism. Because of the known regression of effect with CK, the treatment goal was to flip the astigmatic axis 90 degrees and overtreat the magnitude of astigmatism by approximately 50%. A 350 kHz, 450 μm CK probe was used to apply multiple spots along the flat meridian in an iterative fashion, and the change in the appearance of the keratoscope mires guided subsequent spot application.

Initial spots were placed 1.0 mm inside the corneal graft border along the flat meridians. Gentle indentation of the cornea using the tip of the keratoplasty probe distorts the ring light in a specific direction based on the location of the indentation. This process was used to precisely locate the meridional position of the initial spot. Subsequent spots were placed on either side of the initial spot, with some placed more posterior to the initial spots or in the host corneal rim to augment the steepening effect. The number of additional spots was at the discretion of the surgeon and continued until the appropriate amount of astigmatism was induced in the opposite axis. Spots were applied using the light-touch technique, in which the cornea was indented using the probe to ensure the 450 μm tip was fully inserted in the corneal stroma. The probe was then relaxed to a neutral compression position and the footpedal was depressed, applying the treatment. As the energy was applied, constant gentle pressure was applied to the probe to ensure that the tip did not retract from the corneal stroma during stromal contraction. The amount of energy applied (60% power)

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and the duration of the application (0.6 second) were constant for all spots.

Patient Assessment

All patients were treated postoperatively with fluoroquinolone drops (Vigamox) 4 times a day for 1 week and topical prednisolone acetate 1.0% (Pred Forte) 4 times a day for 1 week, twice a day for the second week, and once a day for the third week. Patients were examined regularly, and the data 3 months after the last intervention was recorded. The efficacy index was calculated as the ratio of the mean postoperative UDVA and mean preoperative CDVA.[18] The safety index was calculated as the ratio of the mean postoperative CDVA and mean preoperative CDVA.[18]

Analysis of Astigmatism

Previous studies[5,6,19] have described a method for analyzing astigmatism correction. This analysis is represented by a double-angle polar plot, given that a cycle of astigmatism is completed in 180 degrees. The double-angle polar plot was set so that the 3 o'clock position represented the 0-degree axis and the 180-degree axis, with the 9 o'clock position at 90 degrees. Surgically induced refractive changes that were astigmatically neutral had a centroid overlying the center of the plot.

Because the cylinder magnitude and the axis are not independent orthogonal parameters, the polar values of astigmatism vectors were converted to the Cartesian coordinate system to be analyzed correctly using standard statistical analysis. The cylinder magnitude was converted to the Cartesian system using the following equations:

$$x = C \times \cos(2a)$$

$$y = C \times \sin(2a)$$

where C is the cylinder and a is the axis.

The mean set of x (x_m) and y (y_m) values were then independently calculated and converted back to polar values to represent the mean astigmatism vector (centroid) using the equations

$$\mathrm{C} = \left(x_m^2 + y_m^2\right)^{0.5}$$

and

$$\mathrm{A} = 0.5 \times \tan^{-1}\left(\frac{y_m}{x_m}\right)$$

where A is the angle. If $x_m > 0$ and $y_m > 0$, then the axis equals the angle. If $x_m < 0$, then the axis equals the angle plus 90 degrees. If $x_m > 0$ and $y_m < 0$, then the axis equals the angle plus 180 degrees.

The standard deviation (SD) of the mean astigmatism vector(s) was calculated as the geometric mean of the SDs of the x and y components and was represented as an ellipse surrounding the centroid and derived as

$$s_m = \left(s_x s_y\right)^{0.5}$$

The defocus equivalent has been shown to correlate more closely with the actual UDVA than with the SE.[20] The defocus equivalent was calculated as

$$\mathrm{E_D} = M_{SE} + 0.5(M_C)$$

where $\mathrm{E_D}$ is the defocus equivalent, M_{SE} is the magnitude of the SE, and M_C is the magnitude of the cylinder.

Statistical Analysis

Statistical analysis was performed using the Wilcoxon signed-rank test. The P values of continuous variables were calculated using paired t test, and P values less than 0.05 were considered statistically significant.

RESULTS

The study evaluated 11 eyes of 11 patients (6 men, 5 women; aged 33 to 86 years). Ten eyes had post-keratoplasty astigmatism (9 PKP and 1 deep anterior lamellar keratoplasty), and 1 developed astigmatism after a traumatic LASIK flap avulsion. In the first 2 eyes to have surgery, AK was performed first and CK followed 4 to 9 weeks later. In the other 9 eyes, AK and CK were performed consecutively on the same day. Two eyes had additional CK treatments, and 1 eye had a repeat AK. The mean follow-up was 7.6 months ± 6 (SD) (range 3 to 17 months).

Table 1 shows the preoperative and postoperative data. Figure 2 shows the pretreatment and post-treatment tomography of 1 eye in which sequential AK and CK were performed and whose magnitude of astigmatism was reduced from 13.9 D to 3.0 D.

In 8 eyes (73%), the defocus equivalent improved postoperatively. Figure 3 shows a trend toward improved postoperative defocus equivalent in eyes with a preoperative defocus equivalent of 6.34 D or higher. The 3 eyes with a worse defocus equivalent postoperatively had a preoperative defocus equivalent of less than 5.00 D. Of these 3 eyes, the CDVA improved in 2 and was unchanged in 1.

Figure 4 shows a close correlation between the intended orthogonal astigmatic correction and the surgically induced orthogonal astigmatic correction, with a slight undercorrection for minus cylinder. Figure 5 shows the relationship between the intended and surgically induced oblique astigmatic correction. On average, undercorrection was achieved for the minus and plus cylinders.

The double-angle polar plot shows a shift of the postoperative centroid toward the neutral point. There was a large shift toward the neutral point vertically, representing a mean postoperative decrease in oblique astigmatism. The reduction in absolute astigmatism is represented in the graph Figure 6 by the smaller ellipse after surgery.

Efficacy

The postoperative UDVA was 20/70 or better in 6 eyes (54%). The efficacy index was 0.82.

Table 1. Parameters before and after AK and CK.

Parameter	Mean ± SD Preoperative	Mean ± SD Postoperative	*P* Value*
CDVA (logMAR)	0.55 ± 0.62	0.12 ± 0.11	.028†
UDVA (logMAR)	1.54 ± 0.50	0.69 ± 0.62	<.001†
Spherical equivalent (D)	−1.25 ± 5.06	−3.13 ± 3.06	.15
Defocus equivalent (D)	7.98 ± 4.41	6.97 ± 3.73	.45
Absolute astigmatism (D)	10.25 ± 4.71	4.31 ± 2.34	<.001†
Absolute orthogonal astigmatism (D)	7.38 ± 3.95	2.73 ± 1.82	.003†
Absolute oblique astigmatism (D)	6.15 ± 4.53	2.98 ± 2.14	.013†
Mean astigmatism vector	3.06 ± 7.91 × 42	0.88 ± 3.53 × 22	—

CDVA = corrected distance visual acuity; UDVA = uncorrected distance visual acuity
*Paired *t* test
†Statistically significant

Safety

Nine eyes (82%) gained 1 or more lines of CDVA, 1 eye (9%) had no change in CDVA, and 1 eye (9%) lost 1 line of CDVA. The safety index was 1.63. There was 1 episode of wound gape after AK that required suturing. There were no other complications, such as infectious keratitis, corneal perforation, or episodes of graft rejection.

DISCUSSION

Astigmatic keratotomy involves creating paired corneal stromal relaxing incisions and is commonly performed to correct astigmatism after PKP. Conductive keratoplasty uses radiofrequency energy to induce collagen shrinkage and resultant corneal steepening. Xu et al.[15] reported a decrease in keratometric astigmatism from 4.15 ± 2.4 D preoperatively to 1.66 ± 1.44 D 6 months after CK for compound astigmatism after corneal trauma or incision. Hersh et al.[21] used CK for complications after LASIK and PRK and reported a 54% reduction in astigmatism. Traditional augmented relaxing corneal incisions for the treatment of astigmatism involve the use of AK and the orthogonal placement of compression sutures. Pairing AK

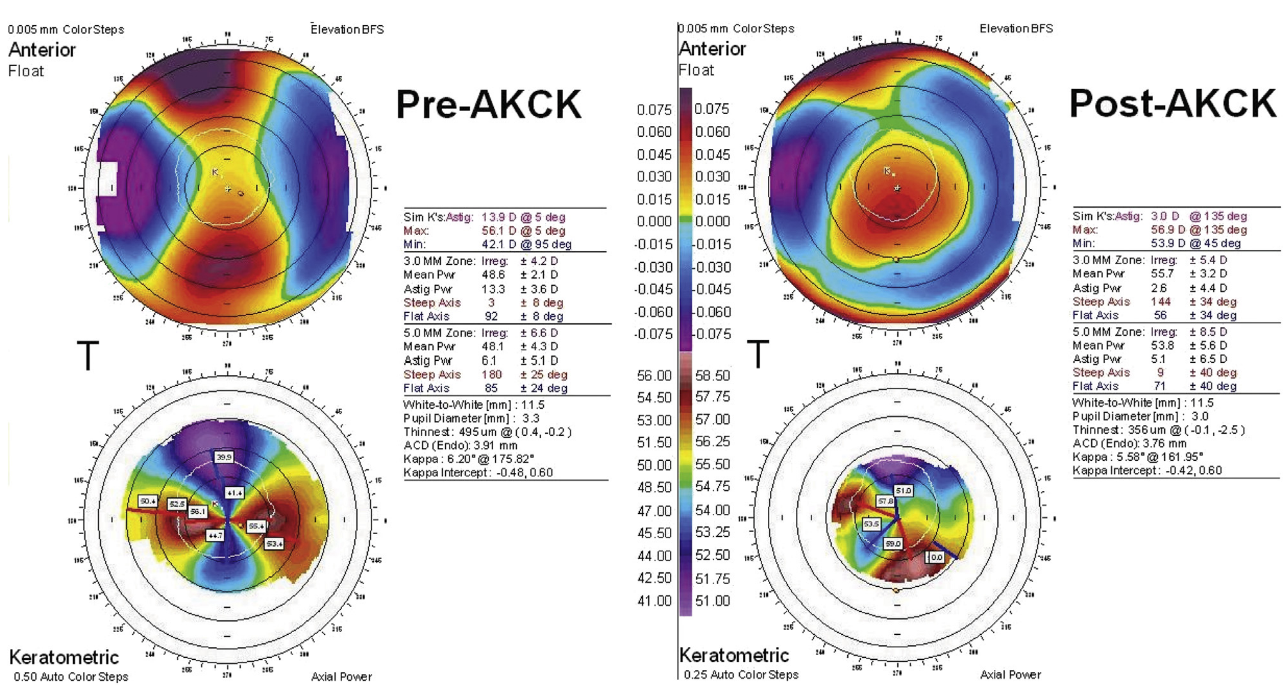

Figure 2. Preoperative and postoperative scanning slit-beam tomography scans showing the anterior float and keratometry maps. Note the significant decrease in astigmatism and change in the axis after AK and CK (AKCK = combined astigmatic keratotomy and conductive keratoplasty; T = temporal).

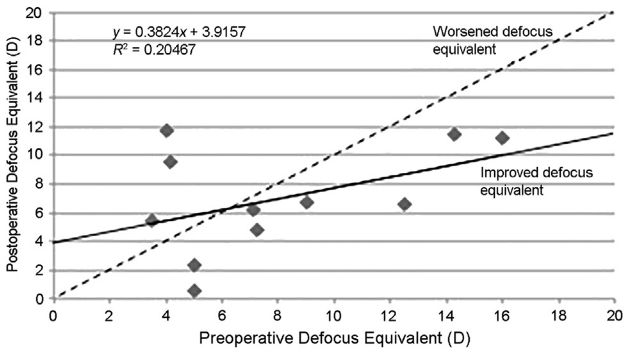

Figure 3. Postoperative defocus equivalent versus preoperative defocus equivalent. The solid line represents linear regression of the data points, and the dotted lines represent no change in defocus equivalent. Points above the dotted line show worsened defocus equivalent, and points below the dotted line show improved defocus equivalent.

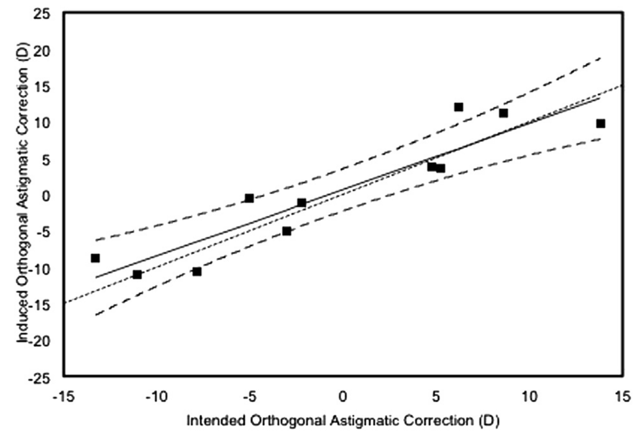

Figure 4. Comparison of surgically induced orthogonal astigmatic correction versus intended orthogonal astigmatic correction. The solid line represents linear regression of all the treatments. The single dotted line represents surgically induced orthogonal astigmatic correction equal to the intended orthogonal astigmatic correction. The paired dashed lines flanking the solid line indicate the 95% confidence interval (CI).

with CK is expected to have a similar augmented effect for reducing high levels of corneal astigmatism.

We analyzed the results of combined AK and CK after PKP and trauma. Our results indicate that AK–CK is an effective method of reducing high levels of astigmatism.

The UDVA and the CDVA improved significantly postoperatively, and the mean CDVA improved by 3 lines (Snellen). Although the change in SE was not statistically significant, the myopic shift was similar to the results reported by Javadi et al.[4] after augmented relaxing incisions for post-keratoplasty astigmatism.

The defocus equivalent is a measure of surgical success and correlates better with UDVA than with SE.[20] Although it was not statistically significant, there was a trend toward improvement in the postoperative defocus equivalent and a decrease in the diameter of the blur circle. Eyes with a higher preoperative defocus equivalent had an improved postoperative defocus equivalent, indicating better success with higher amounts of astigmatism. All eyes with a worse defocus equivalent postoperatively had improved or unchanged CDVA postoperatively.

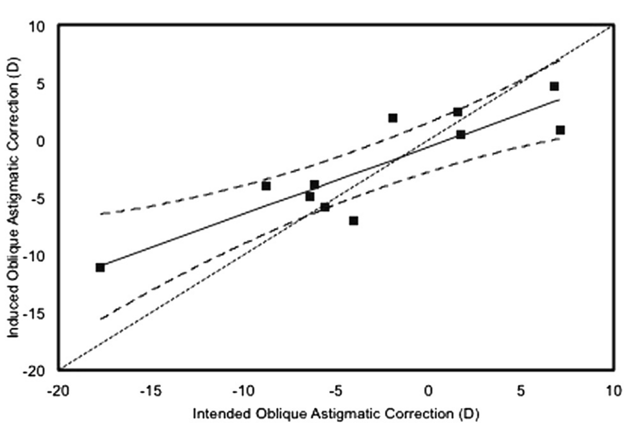

Figure 5. Surgically induced oblique astigmatic correction versus intended oblique astigmatic correction. The solid line represents linear regression of all treatments. The single dotted line represents surgically induced oblique astigmatism equal to the intended oblique astigmatic correction. The paired dashed lines flanking the solid line indicate the 95% CI.

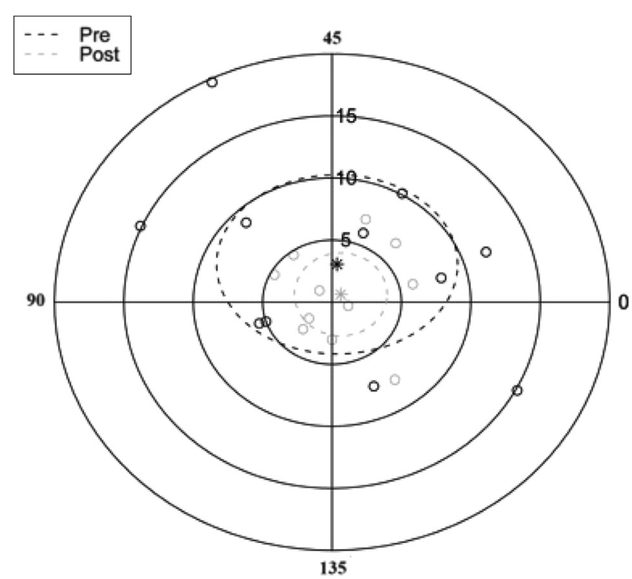

Figure 6. Preoperative and postoperative keratometric astigmatism. The black and gray circles represent the preoperative and postoperative astigmatism values, respectively. The dashed circles represent 1 SD around the mean astigmatism vector (*asterisks*). The center of the plot represents the astigmatically neutral point.

The mean absolute astigmatism decreased significantly, from 10.25 $\pm$ 4.71 D preoperatively to 4.31 $\pm$ 2.34 D postoperatively. The combined procedure yielded a greater reduction in astigmatism than other current surgical treatments such as AK alone, PRK, or LASIK.[6,8,22] Forseto et al.[23] performed LASIK in 22 eyes after keratoplasty and reported a reduction in mean astigmatism from -4.24 ± 2.28 D to -1.79 ± 1.12 D. In 12 eyes after keratoplasty, Webber et al.[9] reported a reduction in astigmatism from -6.61 D to -3.39 D after LASIK. Bilgihan et al.[8] reported 6 cases of grade 2 to grade 3 corneal haze in the eyes of 16 post-keratoplasty patients after PRK for -4.47 ± 1.39 D and -5.62 ± 2.88 D of mean sphere and cylinder, respectively. Our study yielded a reduction in keratometric astigmatism similar to the results of augmented relaxing incisions.[4] However, corneal wedge resection can cause a greater reduction in astigmatism. In a study by Ezra et al.,[1] astigmatism decreased by a mean of 12.9 D (range 6.3 to 25.4 D).

Predictability might be defined as how close the correlation is between the intended and induced astigmatism correction.[6] In the present study, the intended orthogonal astigmatism was closely correlated with the induced orthogonal astigmatism, with slight undercorrection for minus cylinder (Figure 4). For oblique astigmatism, an increase in minus and plus cylinder was correlated with an increase in undercorrection for both (Figure 5). However, the double-angle polar plot in Figure 6 shows a shift toward the neutral point vertically, indicating a mean decrease in oblique astigmatism postoperatively. The mean astigmatism vector was reduced by 2.18 D and was brought closer to the neutral point. The smaller ellipse shows an overall reduction in mean absolute astigmatism.

There was 1 episode of wound gape; however, there were no other complications such as perforation, infectious keratitis, or graft rejection. Studies[5,6] have reported corneal perforation after manual AK and episodes of graft rejection after femtosecond laser–assisted AK. Studies[24,25] have found that there is no added risk for complications with CK.

The results in our study suggest that combined AK and CK is a safe, predictable, and effective method for reducing high corneal astigmatism. Absolute astigmatic correction was greater with this combined method than with other surgical procedures for astigmatism correction. Our results are comparable to those of augmented relaxing incisions and toric IOL implantation. Augmented relaxing incisions carry an additional risk for perforation and development of suture abscess,[4] and IOL implantation increases the risk for endothelial cell loss and graft failure after PKP. Tahzib et al.[12] reported a 34.8% loss of endothelial cells 4 years after implantation of Artisan toric IOLs (Ophtec BV) and 2 cases of irreversible graft rejection. Tehrani and Dick[13] reported endothelial cell loss of 3.2% in myopic eyes and 2.88% in hyperopic eyes after implantation of a toric iris-fixated phakic IOL. Intrastromal corneal ring segment implantation has also been reported to effectively treat post-keratoplasty astigmatism; however, the amount of correction from this technique is very limited and the procedure has potential complications, such as stromal neovascularization and infectious keratitis.[10,26]

The limitations of this study include its small sample, its retrospective nature, and its limited follow-up (3 months). However, recent studies have shown that postoperative astigmatic changes after AK[6] and CK[15] stabilize after 3 months and are minimal to none thereafter. In addition, we were unable to evaluate whether simultaneous or consecutive AK–CK treatment was more effective. A future controlled prospective study of this might help prove the effectiveness of a combined treatment of AK and CK. A study examining femtosecond laser–assisted AK with CK also is warranted. Studies[5,6,27] have shown advantages of femtosecond laser–assisted AK over manual AK, including its precise geometry and depth of incision, significant improvement in UDVA and CDVA, and lack of episodes of perforation. Its effectiveness, safety, and relative predictability make the combined use of AK and CK a useful surgical option to correct high corneal astigmatism.

WHAT WAS KNOWN

- High astigmatism after corneal surgery (eg, PKP) or trauma can be corrected using a variety of methods, among them AK or CK.

WHAT THIS PAPER ADDS

- The combined AK–CK procedure provided a greater reduction in astigmatism and a statistically significant improvement in CDVA and UDVA postoperatively than other surgical treatments directed at astigmatism correction (eg, AK alone, PRK, LASIK).
- Astigmatic keratotomy and CK together effectively reduced high corneal astigmatism after surgery or trauma with a low risk for complications.

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