

# Geometric Customization of Optical and Transition Zone Parameters for Treatment of Compound Myopic Astigmatism With the NIDEK EC-5000 Excimer Laser

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## ABSTRACT

**PURPOSE:** To compare the refractive outcome of two ablation zone designs using LASIK for the correction of compound myopic astigmatism.

**METHODS:** This retrospective study compared refractive outcomes in two groups of patients undergoing LASIK. In the circular treatment group, 45 eyes were corrected with circular optical and transition zones of 6 mm and 6.5 mm, respectively. In the customized treatment group, 45 eyes were corrected with optical and transition zones enlarged along the flat axis to 6.5 mm and 7.5 mm, respectively. *P* values <.05 were considered statistically significant.

**RESULTS:** Mean preoperative spherical equivalent refraction was  $-5.36 \pm 2.02$  diopters (D) and  $-5.36 \pm 2.13$  D for the circular and customized treatment groups, respectively. Mean postoperative spherical equivalent refraction was  $-0.09 \pm 0.74$  D and  $-0.11 \pm 0.42$  D for the circular and customized treatment groups, respectively. Mean cylinder was  $0.49 \pm 0.39$  D and  $0.22 \pm 0.43$  D for the circular and customized treatment groups, respectively ( $P < .001$ ). Postoperative blur strength index was  $0.68 \pm 0.44$  D and  $0.39 \pm 0.27$  D in the circular and customized treatment groups, respectively ( $P < .001$ ). Uncorrected visual acuity was significantly better in the customized treatment group compared with the circular treatment group ( $P < .05$ ). The gain in lines of best spectacle-corrected visual acuity was significantly greater in the customized treatment group compared with the circular treatment group ( $P < .001$ ).

**CONCLUSIONS:** An elliptical ablation zone for treating compound myopic astigmatism results in better efficacy, safety, and lower tissue removal than a circular treatment zone. This may be due to the geometric optimization provided by the enlargement of the optical and transition zones along the flat meridian. [*J Refract Surg.* 2007;23:924-930.]

The main component of refractive astigmatism is corneal toricity.<sup>1</sup> Laser in situ keratomileusis (LASIK) for astigmatism is a subtractive surgical technique that aims to reduce corneal toricity by removing a toric lenticule from the corneal stroma. To avoid undercorrection, this surgical technique imposes geometric constraints that involve the alignment of the corneal surface to the laser delivery system, combined with the smooth blending of steep edges of variable depth induced at the periphery of the optical zone. However, these two conditions are not always met and may account for the undercorrection of astigmatism and overcorrection of sphere following astigmatic treatment.

To overcome these geometric constraints, a variety of treatments have been proposed, including the use of larger transition zones along the initial flatter meridian<sup>2</sup> or a reduction of the volume of tissue removed during laser ablation, as well as various strategies for treating mixed and compound astigmatism.<sup>3,4</sup> In previous studies, we have reported the geometric features of the ablated lenticules that correct for pure and compound astigmatism.<sup>4,5</sup>

In sequential strategies to correct for compound myopic astigmatism, the spherical and cylindrical components of the refractive error are treated successively. For example, in compound myopic astigmatism (eg,  $-3.00 -2.00 \times 90^\circ$ ), the negative cylindrical ablation ( $-2.00 \times 90^\circ$ ) is followed by ablation of the myopic sphere ( $-3.00$ ). This treatment strategy results in flattening the toric cornea centrally as a result of the myopic spherical ablation, and it reduces corneal toricity as a result of the cylindrical ablation. However, corneal curvature increases concomitantly at the junction of the optical and transition zones due to the spherical ablation, and abrupt

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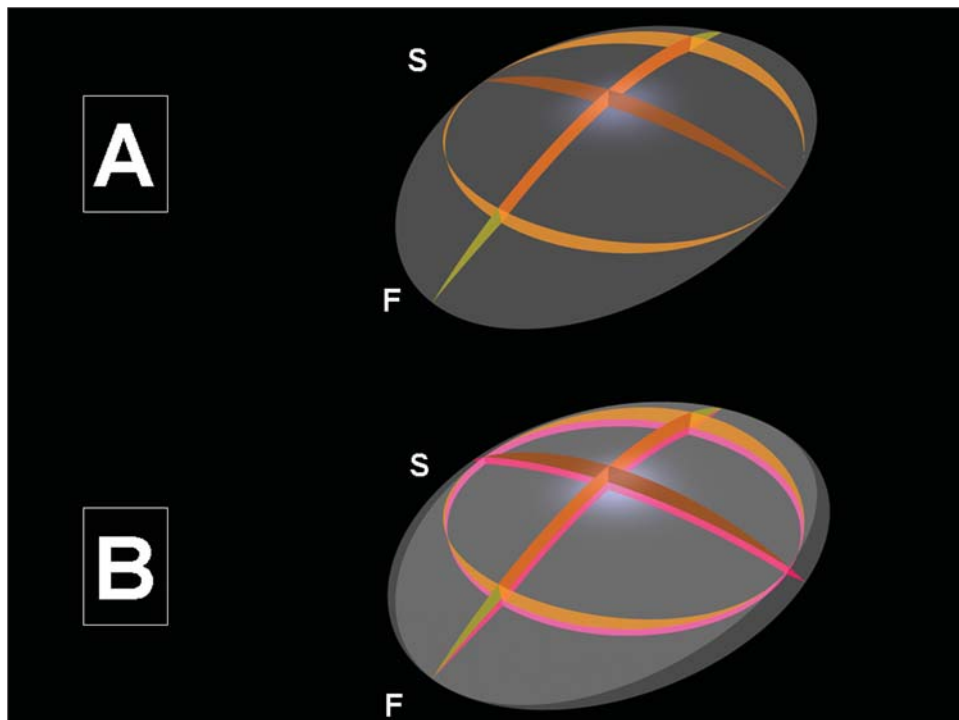
The authors have no proprietary interest in the materials presented herein.

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**Figure 1.** **A)** Schematic representation of the lenticule ablated for the correction of pure cylindrical myopia without a transition zone along the steep meridian (S) where there is no abrupt edge. The cross section corresponding to the direction of the principal meridians is outlined in dark orange within the optical zone, and the junction between the optical and transition zones is outlined in light orange. The thickness of the lenticule is maximized and constant along the direction of the initial flat meridian. The transition zone has the greatest width along the flat meridian (F); the cross section corresponding to the direction of the flat meridians is outlined in green within the transition zone. **B)** Schematic representation of the lenticule ablated for the correction of pure cylindrical myopia with a transition zone along both the steep (S) and flat (F) meridians. The addition of the transition zone along the steep meridian requires the additional ablation of a “plano” lenticule over the optical zone; this cross section is outlined in pink. This strategy results in an increase in the central depth of ablation.

edges of maximal depth are created along the initial flat meridians due to the cylindrical ablation. Blending these edges and moving the curvature changes further out into the periphery can be achieved by using aspheric algorithms or larger transition zones.<sup>6-10</sup>

Circular optical and transition zones can be used for the cylindrical and spherical components of the ablation; however, different geometric constraints apply to each component. Additionally, the use of large transition zones along certain meridians may result in increased ablation depth centrally. The three-dimensional schematic representation of the ablated lenticules of corneal tissue over the ablated zone allows better visualization of the differences between these strategies. Computer-assisted modeling with Boolean operation has been used previously to address the theoretical constraints of photoablative treatments for the correction of astigmatism.<sup>4,5</sup> Figure 1 depicts the theoretical shapes of the lenticules of corneal tissue etched from the corneal surface for minus cylinder ablation with and without an enlarged transition zone along the steeper meridian.

To reduce the risk of ectasia following LASIK, strategies reducing the depth of ablation are preferred. The NIDEK EC-5000 excimer laser (NIDEK Co Ltd, Gama-gori, Japan) allows surgeons to adjust the width of the optical and transition zones along the flat and steep meridians separately. Thus, circular or oval treatment zones can be programmed.

This study compares the effectiveness of compound myopic astigmatism correction using LASIK with two

different optical and transition zones designs. One design used equal diameter circular optical and transition zones, and the second design used geometrically customized optical and transition zones that were formulated to reduce total tissue ablation by combining different diameters of circular optical and oval transition zones.

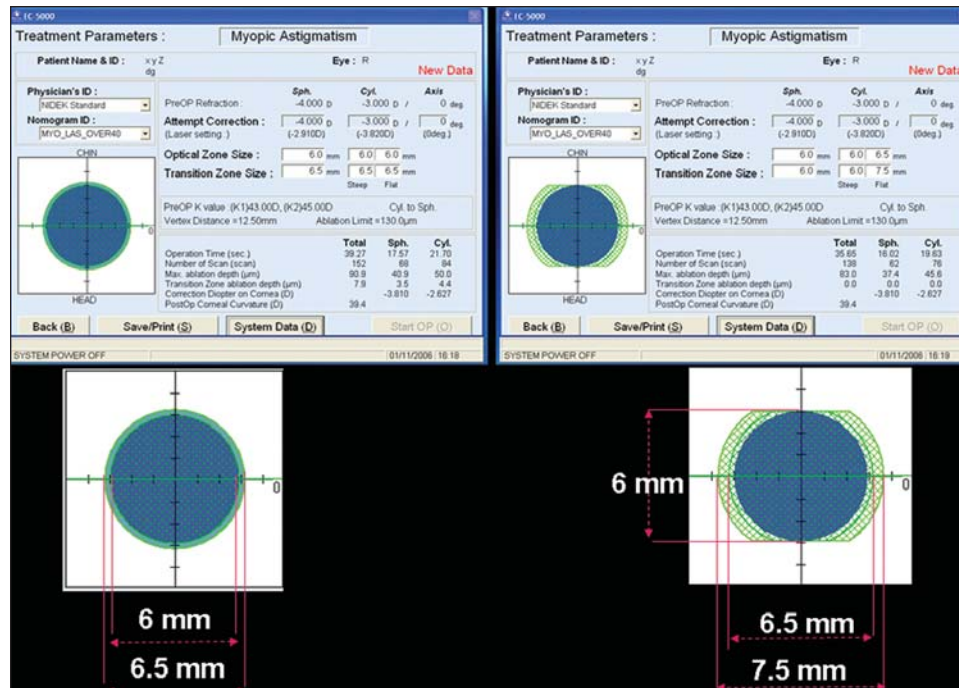
## PATIENTS AND METHODS

### LASER ABLATION DESIGN

This retrospective study analyzed the clinical outcomes of patients who underwent LASIK for compound myopic astigmatism  $\geq 1.00$  diopter (D) of cylinder. Patients were divided into the following two groups based on the laser ablation zone design, and all eyes underwent conventional ablation.

*Circular Treatment Group.* In this group, circular optical and transition treatment zones were used for both spherical and cylindrical ablation. The optical zone diameter was 6.00 mm, and the transition zone diameter was 6.50 mm. The width of the transition zone was held constant over the ablation zone and equal to 0.50 mm. The laser data entry parameters used for this group are shown in Figure 2.

*Customized Treatment Group.* In this group, geometrically customized optical and transition treatment zones were used for ablation. In this design, the geometric optimization aimed at preserving or increasing the dimensions of the optical zone and minimizing



**Figure 2.** Screen display for circular and customized treatments for the same compound myopic astigmatic correction:  $-4.00 -3.00 \times 0^\circ$ . The ablation depth for the customized (oval) treatment (right) is reduced compared with the ablation depth for the circular treatment (left) (90.9 vs 83.0  $\mu\text{m}$ , respectively).

the ablation depth. The optical zone was oval, using a 6.00-mm diameter that was enlarged to 6.50 mm (6.00 $\times$ 6.50 mm) along the flat meridian for the minus cylinder. The transition zone for the cylindrical ablation was oval, with a diameter of 6.00 mm along the steep axis and 7.50 mm along the flat meridian. In this configuration, the width of the transition zone was null along the steep meridian and extended progressively toward the flat meridian where it reached its maximal width of 1.50 mm. The laser data entry parameters used for this group are shown in Figure 2.

**PATIENT EVALUATION**

Patients treated in this study had a manifest refractive sphere ranging from  $-1.50$  to  $-9.00$  D with negative cylinder magnitude ranging from 1.00 to 4.50 D. All eyes underwent preoperative and postoperative ophthalmic examinations that included corneal topography (Orbscan; Bausch & Lomb, Salt Lake City, Utah), uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA) (decimal notation), manifest refraction, cycloplegic refraction, slit-lamp microscopy, dilated funduscopy, and ultrasound corneal pachymetry. For the purpose of laser refractive correction and analysis, the magnitude and axis of the astigmatism were based on the manifest refraction. The axis of astigmatism was refined using a  $\pm 0.25$  D Jackson cross-cylinder attached to the phorometer. Eyes with topographic abnormalities such as forme fruste keratoconus, keratoconus, pellucid marginal degeneration, contact lens warpage, marked corneal irregularity, and preoperative central corneal

thickness  $< 510 \mu\text{m}$  were excluded from this study. Patients were evaluated preoperatively and 1 day, 1 week, and 1 and 3 months postoperatively.

**SURGICAL TECHNIQUE**

Patients were treated consecutively using LASIK for compound myopic astigmatism performed by two surgeons (D.G., T.H.X.). In all cases, the cornea was marked at the 3 o'clock and 9 o'clock positions with a Gentian violet marker with the patient seated at the slit lamp prior to surgery to allow determination of the axis of astigmatism and to mark a reference point to detect any cyclotorsion intraoperatively.

The eye undergoing surgery was prepared in a sterile fashion. Topical anesthetic was instilled on the cornea, and a lid speculum was inserted for maximum globe exposure. The Hansatome microkeratome (Bausch & Lomb, Rochester, NY) was used to create a superior hinge. The corneal flap was reflected back, and laser ablation was delivered to the stroma using the NIDEK EC-5000 excimer laser with the 1.26 software version. Optimized nomograms were used for all treatments in the following manner: 20% of the spherical equivalent refraction of the intended correction was subtracted from the sphere in both groups; in the customized treatment group, an additional 33% of the intended cylindrical correction was subtracted from the sphere. All eyes were targeted for emmetropia after treatment. The NIDEK EC-5000 laser ablation algorithm uses an expanding diaphragm and rotating scanning slit

TABLE 1  
**Mean Preoperative Refractive Parameters for 90 Eyes That Underwent LASIK for Compound Myopic Astigmatism**

	Mean±SD (Range) (D)		P Value
	Circular Treatment Group	Customized Treatment Group	
Sphere	-4.39±1.98 (-1.50 to -9.00)	-4.41±1.89 (-1.50 to -8.00)	.97
Cylinder	-1.94±0.87 (-1.00 to -4.00)	-1.91±0.90 (-1.00 to -4.50)	.86
Spherical equivalent refraction	-5.36±2.13 (-2.00 to -9.88)	-5.36±2.02 (-2.00 to -9.00)	.99
J0*	0.25±0.84 (-1.75 to +1.75)	0.32±0.76 (-1.10 to +1.75)	.69
J45†	0.03±0.60 (-1.25 to +1.60)	0±0.65 (-1.48 to 1.74)	.79
Blur strength index‡	5.46±2.14 (2.06 to 9.97)	5.46±2.02 (2.06 to 9.06)	.99

\*J0 denotes a Jackson crossed cylinder at axis 0°.  
 †J45 denotes a Jackson crossed cylinder at axis 45°.  
 ‡Overall refractive error of the spherocylindrical lens.

delivery system to ablate corneal tissue. During ablation, patients fixated on a red fixation light that was coaxial with the surgeon’s line of sight and the excimer laser beam.

Following ablation, the flap was repositioned and the interface was irrigated using balanced salt solution. Patients received topical fluoroquinolone antibiotic and corticosteroid drops to administer 4 times daily for 5 days. Patients were instructed to use artificial tears as needed.

**STATISTICAL ANALYSIS**

Manifest refractive error at the spectacle plane was expressed using power vectors as described by Thibos and Horner.<sup>11</sup> This method expresses the spherocylindrical refractive error in three fundamental dioptric components (M, J0, J45) using the following formulas:

$$M = S + C/2 \tag{1}$$

$$J0 = (-C/2) \cos (2\alpha) \tag{2}$$

$$J45 = (-C/2) \sin (2\alpha) \tag{3}$$

where S, C, and α are the sphere, cylinder, and axis, respectively, used in conventional refractive notation (S C × α).

The overall blurring strength, B, of the refractive error is given by:

$$B = (M^2 + J0^2 + J45^2)^{1/2} \tag{4}$$

Statistical analysis was performed using Student t test. A P value <.05 was considered statistically significant. Three-month postoperative data are presented.

**RESULTS**

The circular treatment group comprised 45 eyes of 24 patients (13 men and 11 women), and the customized treatment group comprised 45 eyes of 24 patients (14 men and 10 women). Average patient age was 30±6.5 years (range: 21 to 49 years) in the circular treatment group and 32±7.5 years (range: 21 to 51 years) in the customized treatment group. There was no statistically significant difference in age or gender between the two groups. The mean preoperative refractive parameters are shown in Table 1, and the mean postoperative refractive parameters are shown in Table 2. There were no statistically significant differences in preoperative spherical or astigmatic vectorial components between the two groups (Table 1).

The mean postoperative logMAR UCVA was 0.048±0.048 (range: -0.08 to 0.03) in the circular treatment group and 0.12±0.009 (range: -0.08 to 0.22) in the customized treatment group. Patients in the customized treatment group had significantly better UCVA than patients in the circular treatment group (P<.05). Figure 3 plots the postoperative change in BSCVA for both groups. In the circular treatment group, 3 eyes lost 1 line of BSCVA. In the customized treatment group, no eyes lost lines of BSCVA. The gain in lines of BSCVA was significantly greater in the customized treatment group than in the circular treatment group (P<10<sup>-6</sup>).

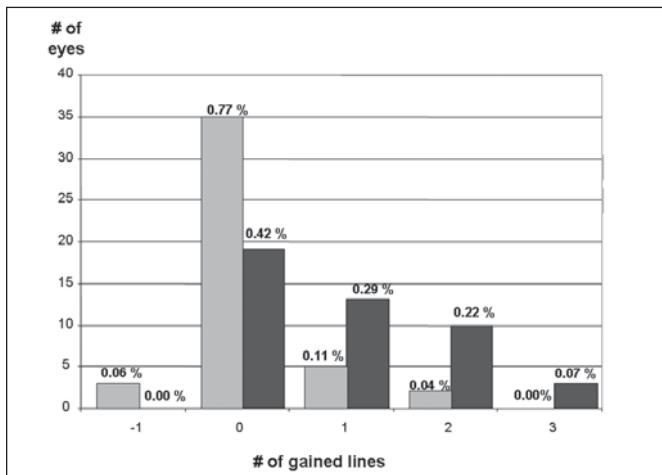
The change in astigmatism due to surgery is shown in Figures 4 and 5. The magnitude of the two dimensional vector (J0, J45) was significantly lower in the customized treatment group compared to the circular treatment group (P=.015). No statistically significant difference was observed in the reduction of the spherical component between the two groups.

The mean depth of ablation was 76±13 μm (range: 30 to 110 μm) in the circular treatment group and

TABLE 2  
**Mean Postoperative Refractive Parameters for 90 Eyes That Underwent LASIK for Compound Myopic Astigmatism**

	Mean±SD (Range) (D)		P Value
	Circular Treatment Group	Customized Treatment Group	
Sphere	0.34±0.70 (−1.00 to +1.50)	0.23±0.32 (−0.75 to +1.00)	.34
Cylinder	−0.49±0.39 (−1.25 to 0)	0.22±0.43 (−1.00 to +0.50)	.00072
Spherical equivalent refraction	−0.49±0.39 (−1.50 to +1.13)	0.22±0.43 (−1.00 to +1.00)	.91
J0*	0.08±0.22 (−0.37 to +0.63)	0.01±0.14 (−0.37 to +0.28)	.037
J45†	0.03±0.20 (−0.50 to +0.46)	0.01±0.14 (−0.44 to +0.25)	.26
Blur strength index‡	0.68±0.44 (0 to +1.58)	0.39±0.27 (0 to +1.03)	.0001

\*J0 denotes a Jackson crossed cylinder at axis 0°.  
 †J45 denotes a Jackson crossed cylinder at axis 45°.  
 ‡Overall refractive error of the spherocylindrical lens.



**Figure 3.** Loss and gain of lines of best spectacle-corrected visual acuity for the circular (gray bars) and customized (black bars) treatment groups.

59±26 μm (range: 34 to 138 μm) in the customized treatment group. The mean ablation depth was significantly lower in the customized treatment group compared to the circular treatment group (P=.028).

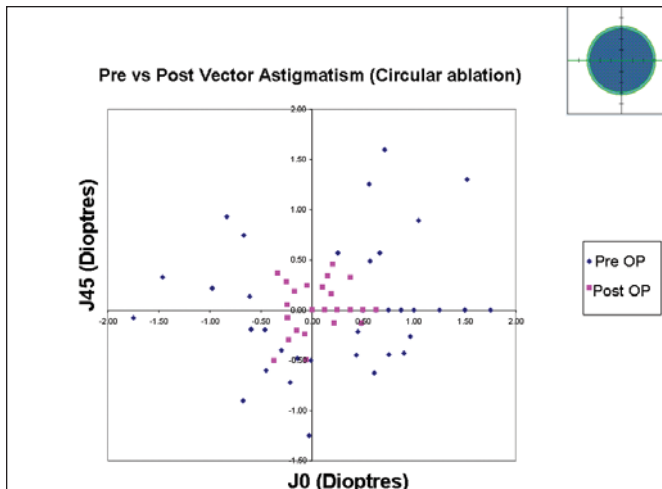
**DISCUSSION**

This study compared the outcome of LASIK using geometrically customized treatment zones versus circular treatment zones for the correction of compound myopic astigmatism. There was a statistically significant reduction in preoperative cylinder using geometrically customized treatment zones compared to circular treatment zones. The greater reduction of astigmatism that was observed in eyes in the customized treatment group may be due to the oval shape of the perimeter of the total ablation zone. This geometric customization may favor a physiological wound healing response

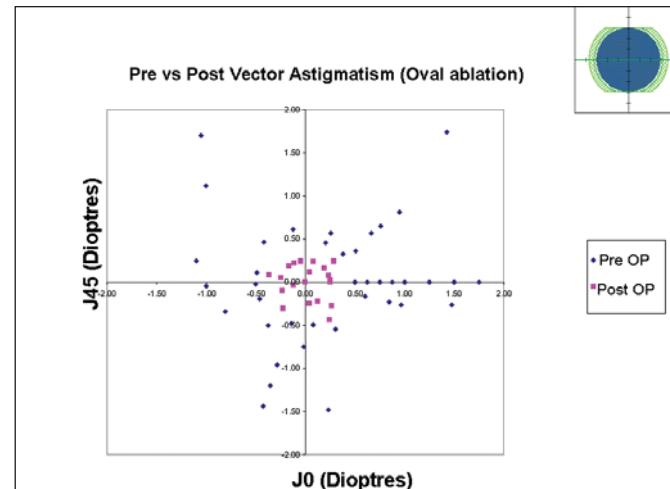
that tolerates the toric ablation due to a greater geometric congruence of the edges of the ablation. Wound edge architecture has been shown to affect the healing response,<sup>12</sup> and mathematical relationships for corneal smoothing after laser ablation have been developed.<sup>13</sup> The creation of smooth surfaces between the junction of the optical and transition zone, and the transition zone and nascent cornea presumably will reduce the wound healing response and the chance of stromal scarring.<sup>2</sup> Insufficient blending along the flat axis may result in abrupt edges that can lead to a robust wound healing response, which may promote a hyperopic shift.<sup>2,13</sup>

One drawback of our study is the lack of 6-month postoperative data, which may show greater differences due to cylinder regression over an extended follow-up period. However, US Food and Drug Administration approval data using a different version of software than in our study confirms stability is reached within the 3- to 6-month postoperative window, with <−0.05 D change taking place during this period.<sup>14</sup>

Our outcomes test the theory put forth by MacRae<sup>2</sup> on the use of elliptical transition zones. Indeed, we found outcomes were better with elliptical treatment zones compared to circular treatment zones; moreover, there was less tissue removal. However, longer-term results will determine whether there is less regression with the elliptical zone architecture than with the circular optical zone. Shah et al<sup>15</sup> postulated a circular ablation is more likely to stimulate epithelial healing in the flat meridian, causing regression of astigmatism.<sup>15</sup> Our results agree with their finding that elliptical treatment zones were more effective for the treatment of astigmatism using photorefractive astigmatic keratectomy.<sup>15</sup> In our study, UCVA was significantly better in eyes with geometrically customized treatment



**Figure 4.** Comparison between the preoperative (diamonds) and postoperative (squares) values of the cardinal components of the astigmatic vector in the circular treatment group. This graph plots the astigmatic component of the power vector as represented by the two-dimensional vector (J0, J45), which is the projection of the power vector into the astigmatism plane formed by the coordinate (J0, J45).



**Figure 5.** Comparison between the preoperative (diamonds) and postoperative (squares) values of the cardinal components of the astigmatic vector in the customized treatment group. This graph plots the astigmatic component of the power vector as represented by the two-dimensional vector (J0, J45), which is the projection of the power vector into the astigmatism plane formed by the coordinate (J0, J45).

zones compared to eyes with circular treatment zones. The better UCVA in eyes in the customized treatment group was likely the result of the lower residual astigmatism in these eyes compared to eyes in the circular treatment group.<sup>16,17</sup>

Laser in situ keratomileusis for the correction of compound myopic astigmatism remains challenging. For example, meridian misalignment can result in an undercorrection of the cylindrical component.<sup>18</sup> In this study, we attempted to minimize possible torsional errors by creating perilimbal marks along the horizontal meridian. This allowed us to realign the patient's eye under the laser microscope prior to as well as during ablation if necessary. Despite optimal alignment, the results of myopic astigmatism correction can vary because of the geometric constraints imposed by the toric ablation on the stromal bed.

Wavefront-guided treatments take into account higher order aberrations for the establishment of the ablation profile. Similarly, geometric customization of the optical and transition zones may require specific adjustments for the wavefront-guided correction of myopic compound astigmatism. In this study, the NIDEK EC-5000 excimer laser was used. However, the newer generation of this platform, the EC CXIII has evolved since this study to incorporate fully aspheric algorithms and large aspheric transition zone algorithms<sup>6</sup> as well as iris registration, which may reduce the differences observed in this study. However, there is probably a greater number of NIDEK EC-5000 models in use than the EC CX III. Hence, the results presented in this study are clinically pertinent. Tissue conserva-

tion using geometric customization likely represents a feasible alternative for the larger, aspheric ablation zones that tend to remove larger volumes of tissue compared to conventional ablation.

From our outcomes and those of others, we believe the sequential approach is not the only treatment for compound myopic astigmatism. In the elliptical modality, astigmatic and myopic correction is achieved by varying the diameter in an elliptical fashion, with the narrowest diameter achieving the greatest flattening effect.<sup>11</sup> The relative size of the major and minor axes of the elliptical ablation depends on the ratio of the cylindrical to spherical magnitude. A comparative clinical study has shown the elliptical method leads to a significant improvement in cylinder correction in eyes treated for myopic compound astigmatism.<sup>19,20</sup>

The elliptical method offers several theoretical advantages, such as a reduction in the maximal depth of ablation and the induction of a natural transition zone with no steep edges. However, this strategy could risk functional optical zone reduction because of the rapid changes in the curvature between the treated and untreated zones at the periphery of the steep axis. Potentially, a marked reduction of the diameter of the optical zone along the initially steeper meridian may occur in cases of high negative cylinder. The reduction of the functional optical zone may induce deleterious wavefront aberrations, which in turn may induce scotopic symptoms. The effect of aberrations within the scotopic pupil zone was beyond the scope of this study because an aberrometer was not available.

In this study, we have enlarged the optical and tran-

sition zone along the flat meridian to prevent excessive regression and scarring. A transition zone was not added along the steep meridian of eyes in the customized treatment group. The design used for the customized treatment group allowed a reduction in the ablation depth and avoided the creation of an abrupt step that would require a blend along the steep meridian. We currently use enlarged optical and transition zones routinely along the flat meridian when treating compound myopic astigmatism with photorefractive keratectomy, laser epithelial keratomileusis, and LASIK with the NIDEK EC-5000 excimer laser.

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