Correction of High Astigmatism: Case Studies Using the Mixed-cylinder Approach

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ABSTRACT

PURPOSE: To explain the use of the mixed-cylinder approach in treating moderate to high astigmatism with the NIDEK EC-5000 excimer laser system.

METHODS: Retrospective case series report.

RESULTS: Three patients with bilateral moderate to high astigmatism were treated successfully using the mixed cylinder approach.

CONCLUSIONS: The use of the mixed-cylinder approach with the NIDEK EC-5000 excimer laser may be a safe and predictable option for treating moderate to high astigmatism. [J Refract Surg. 2006;22:S1073-S1078.]
ability, and regression. In addition, we highlight the apparent reduction of subjective complaints of halos and glare, which may be indicative of a larger functional optical zone.

**PATIENTS AND METHODS**

Three case studies are used to describe the technique. Specific individual calculations and results are reported along with topographic studies. The sample is a series from the authors’ experience and is considered representative of the typical outcomes and findings. All patients were treated at the Gimbel Eye Centre (Edmonton, Canada) by the authors (H.N.K. or G.B.K.) and followed for at least 6 months.

**PATIENT EXAMINATIONS AND SURGERY**

Baseline examination included uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), manual keratometry, manifest and cycloplegic refractions, slit-lamp and fundus examinations, Schirmer’s test, scotopic pupil assessment, corneal pachymetry, corneal topography (Orbscan; Bausch & Lomb), and an epithelial stress test. The epithelial stress test has been reported previously in refraction; therefore, it is added to the sphere.

A corneal flap at least 9.0 mm in diameter and 160 or 180 µm in thickness was created with the Hansatome microkeratome (Bausch & Lomb). A NIDEK EC-5000 excimer laser (NIDEK Co Ltd, Gamagori, Japan) with a 40-Hz repetition rate was used to carry out the corneal ablation. At the surgeon’s discretion, phototherapeutic keratectomy (PTK) was performed using a viscous masking agent (Laservis; TRB Chemedica, Vouvry, Switzerland) to smooth the surface after the corneal ablation. Postoperative examinations included UCVA, BSCVA, manifest refraction, corneal topography, and slit-lamp and fundus examinations. Patients were specifically asked about visual performance and subjective symptoms such as halos at the 1-, 3-, and 6-month postoperative examinations.

**NOMOGRAM CALCULATIONS**

In this technique, the spherical component of the refractive correction is determined by 1) the spherical equivalent, 2) the PTK effect (hyperopic shift) of the cylindrical treatment, and 3) nomogram adjustment for attempted versus achieved ablation. This last variable depends on patient age and a number of site- and surgeon-specific factors including altitude, humidity, temperature, surgical technique, and specific laser used. The Gimbel nomogram with minor modification was used in this case series.\(^\text{12}\) The astigmatic component is determined from the keratometric, manifest, or cycloplegic cylinder. In this study, manifest refraction was used to primarily determine axis and power to be treated. In some cases, an adjustment was made in the axis of treatment based on topography and keratometry.

The calculations to determine laser parameters were:

1. Calculate the spherical equivalent of refraction. This amount, after adjustment for PTK effect and attempted versus achieved ratio, is used in the final laser spherical parameter.
2. Determine the PTK effect of the total astigmatism. Total cylinder \(\times 35\%\) in our nomogram is the expected effect. This produces a hyperopic shift in refraction; therefore, it is added to the sphere.
3. Apply spherical treatment adjustment. Attempted/achieved ratio in our nomogram varies from 70% in patients aged >55 years to 80% in patients aged <30 years.
4. Divide the astigmatism by 2, and write hyperopic (plus) myopic (minus) components separately. Care must be taken to correctly identify each meridian.
5. Write laser treatment stages:
   a) Hyperopic cylinder with 5.5- to 9.0-mm zone.
   b) Myopic cylinder with 6.5- to 7.5-mm zone.

—Patients with >2.00 D of myopic cylinder are corrected with this component further divided by 2, and half the cylinder treated at a 6.0-mm optical zone and half at a 6.5-mm optical zone.
c) Nomogram-adjusted spherical refractive error.
6. For smoothing, four scans of PTK are placed at an 8.0-mm optical zone, using Laservis as a masking agent, prior to replacing the flap in LASIK, or placing a contact lens in PRK.

**STEP-BY-STEP NOMOGRAM CALCULATION**

*Calculations for Mixed Astigmatism Correction*

1. Identify desired refractive correction (power and axis) including spherical component.
2. Note spherical equivalent of the refractive error.
3. Calculate the hyperopic shift of total astigmatic correction (PTK effect of central tissue ablation); in this case, 35% of total cylinder.
4. Determine arithmetic sum of the spherical equivalent refraction and hyperopic shift from step 3.
5. Apply nomogram adjustment to spherical correction (varies).
6. Split cylinder into two and write as hyperopic (plus) and myopic (minus) components separately.
7. Note the laser treatment parameters.
   a) Hyperopic cylinder treated at a 5.5- to 9.0-mm zone.
b) Myopic cylinder treated at a 6.5- to 7.5-mm zone.
c) If myopic cylinder is $>2.00$ D, treat half of this amount at a smaller zone of 6.0- to 7.0-mm to conserve corneal tissue along with half at the zone in step 7(b).

d) Residual nomogram-adjusted sphere treatment.

8. A smoothing treatment can be applied with a few pulses in PTK mode at an 8.0-mm zone using Laservis as a masking agent.

Note: Adequate stromal bed tissue should remain after the ablation to ensure tectonic integrity of the cornea. In patients with large pupils, the myopic transition zone can be expanded to 8.0 mm.

RESULTS

CASE 1

A 34-year-old man presented with manifest refraction of $-5.50 \times -4.00 \times 10^\circ$ (20/20') in the right eye and $-4.75 \times -3.50 \times 165^\circ$ (20/20') in the left eye. Manual keratometry was 40.75/43.75 in the right eye and 40.75/43.50 in the left eye. Preoperative corneal topography is shown in Figures 1A and 1B.

LASIK was performed in both eyes using the nomogram outlined above without PTK smoothing.

Six months postoperatively UCVA was 20/15 in the right eye and 20/40 in the left eye. Manifest refraction was plano in the right eye and $\pm 0.50 \times -1.50 \times 60^\circ$ (20/25) in the left eye.

Postoperative corneal topography is shown in Figures 1C and 1D. A reduction of one line of BSCVA in the nondominant eye occurred, which was well tolerated. The patient was pleased with the outcome. Subjectively, the patient noted dry eye symptoms, which resolved by 6-month follow-up.

CASE 2

A 51-year-old man presented with manifest refraction of $-2.00 \times -4.50 \times 12^\circ$ (20/20') in the right eye and $-2.00 \times -5.50 \times 180^\circ$ (20/20') in the left eye. Manual
keratometry was 42.0/45.0 × 96° in the right eye and 42.25/45.37 × 79° in the left eye. Corneal topography is shown in Figures 2A and 2B.

LASIK was performed in both eyes using the nomogram outlined above with PTK smoothing.

The spherical component of the treatment nomogram was adjusted to −2.06 D in the right eye and −2.17 D in the left eye. Based on the planned astigmatic correction of 4.25 D in the right eye and 5.25 D in the left eye, the refractive treatment was divided into three components. In the right eye, plano +2.13 × 100° was treated with a 5.5-mm optical zone and a 9.0-mm transition zone; −2.06 −1.06 × 10° was treated with a 6.5-mm optical zone and a 7.5-mm transition zone; and plano −1.31 × 175° was treated with a 6.0-mm optical zone and a 7.0-mm transition zone.

At 7 months postoperatively, UCVA was 20/25 in the right eye and 20/15 in the left eye. Manifest refraction was +1.25 sphere (20/20) in the right eye and +0.50 −0.50 × 180° (20/15) in the left eye.

Postoperative topography is shown in Figures 2C and 2D. The patient underwent enhancement for residual hyperopia in the right eye.

CASE 3

A 44-year-old man presented with manifest refraction of −4.75 −4.50 × 2° in the right eye and −4.75 −6.00 × 164° in the left eye. Manual keratometry was 42/45 × 95° in the right eye and 42/45.5 × 80° in the left eye. Preoperative corneal topography is shown in Figures 3A and 3B.

LASIK was performed in both eyes using the nomogram outlined above with PTK smoothing.
The spherical component of the treatment nomogram was adjusted to $-4.09 \text{ D}$ in the right eye and $-4.24 \text{ D}$ in the left eye. Based on planned astigmatic correction of $4.25 \text{ D}$ and $5.75 \text{ D}$ in the right and left eyes, respectively, treatment was divided into three components. In the right eye, plano $+2.25 \times 91^\circ$ was treated with a 5.5-mm optical zone and a 9.0-mm transition zone; $-4.09 \times -1.13 \times 1^\circ$ was treated with a 6.5-mm optical zone and a 7.5-mm transition zone; and plano $-1.13 \times 1^\circ$ was treated with a 6.0-mm optical zone and a 7.0-mm transition zone. In the left eye, plano $+2.88 \times 76^\circ$ was treated with a 5.5-mm optical zone and a 9.0-mm transition zone; $-4.24 \times -1.44 \times 166^\circ$ was treated with a 6.5-mm optical zone and a 7.5-mm transition zone; and plano $-1.44 \times 166^\circ$ was treated with a 6.0-mm optical zone and a 7.0-mm transition zone.

At 8 months postoperatively, UCVA was 20/25 in the right eye and 20/30 in the left eye. Manifest refraction was plano $-0.50 \times 175^\circ$ (20/20) in the right eye and $-1.00 \times -0.25 \times 25^\circ$ (20/20) in the left eye.

Postoperative corneal topography is shown in Figures 3C and 3D. The patient was pleased with the monovision result, and no further treatment was performed.

**DISCUSSION**

Previous studies have shown a reduced level of efficacy compared with spherical treatments in patients with high degrees of astigmatism.\textsuperscript{6,14,15} This reduced level of efficiency is based on the loss of a physiologic surface profile that results from ablation in a single meridian. In PRK, this can lead to increased haze and regression of clinical effect. In LASIK, there is a delay in refractive stability, followed by mild regression. In both cases, there is a tendency toward undercorrection.

To produce a better ablation profile, the astigmatic correction can be applied to both meridians. The effect...
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is to ablate a cylindrical profile in the steeper meridian to flatten it. A midperipheral ablation in the flat meridian causes the flat meridian to steepen. Optically, this combination leads to a nearly spherical cornea.

Using a combined hyperopic and myopic cylinder correction, high astigmatic refractive errors can be corrected predictably with stable results. The goal of reducing optical aberrations from a small optical zone is addressed using this method of treatment. In addition, the rapid visual rehabilitation of these patients, along with refractive stability, suggests a better corneal surface profile. Over time this has become our standard approach for all patients with >1.50 D of astigmatism. Studies to evaluate spherical, coma, trefoil, and other higher order aberrations are required to determine whether the eye has an optimal pattern. Benefit in terms of improved low contrast acuity and subjective outcomes remains to be determined.

In addition to the corneal flattening resulting from the treatment of the original spherical refractive error (spherical equivalent), some overall flattening of the cornea occurs due to central ablation of tissue or PTK effect. This is analogous to coupling that is seen in astigmatic keratotomy. However, this coupling is not a 1:1 ratio and does not operate in the same direction as seen in astigmatic keratotomy. In our nomogram, a rate of 35% is used as a hyperopic shift from total cylindrical correction. This shift is then added to the spherical correction to reduce myopia (or increase hyperopia). Phototherapeutic keratectomy smoothing was added as final step because of its reported benefits. Vinciguerra et al have shown in two separate studies that PTK smoothing leads to better surface quality and reduced haze. Four scans of PTK, in conjunction with a masking agent, do not produce any observable refractive effect in our experience.

We have demonstrated the steps in performing the calculation of mixed astigmatism correction for high degrees of astigmatism and reviewed case studies. Further calculation of mixed astigmatism correction for high degrees of astigmatism appears to improve the refractive options available to surgeons and their patients.

REFERENCES