Successful Correction of Irregular Astigmatism

Exploring ablation options with excimer and solid state lasers.

BY MARIA CLARA ARBELAEZ, MD; THOMAS MAGNAGO, DIPL-ING; AND BRUCE ALLAN, MD, FRCS

The Excimer Laser

Current technology can achieve a high level of success in moderate and high astigmatic correction.

By Maria Clara Arbelaez, MD; and Thomas Magnago, Dipl-Ing

Due to recent advances in refractive surgery, the complexities of correcting irregular astigmatism can now receive closer attention than ever before. Today, subjective evaluation of the patient’s refractive deficit may not produce an accurate depiction of his preexisting astigmatism. To minimize poor postoperative results, the golden rule of refracting a patient is to select the measurement with the lowest cylindrical value. In cases in which multiple measurements of the same cylindrical value can be used, we should choose the one with the axis closest to the 180º of with-the-rule astigmatism. In cases where these rules do not help, we should select the one that shows the lowest higher-order aberrations.

Although we have strategies to select the most accurate preoperative measurements, we must devise proper treatment strategies that translate these into the best astigmatism correction. We believe that excimer lasers are the best technology to reach this goal; they can compensate actively for all kinds of cyclotorsional errors and customize the treatment zone.

Newer ablation algorithms for correction of spherocylindrical values are typically aspheric, preserving existing higher-order aberrations. Wide optical zones are ideal for long-term stability. The advantage of transepithelial therapeutic treatment with a solid state laser is that no drying is required prior to commencing ablation. It is often impossible to obtain a useable wavefront map in the presence of significant astigmatism; the alternative is a topography-driven treatment.

COMPENSATING FOR CYCLOTORSION

With the patient in position under the excimer laser, the laser should compensate for static cyclotorsion, adjusting the ablation profile to match the upright cyclotorsional position of the eye. This subsequently creates the foundation for dynamic cyclotorsional compensation, in which eye movements are tracked intraoperatively. We have found that the static cyclotorsional change between the upright and the supine position is within ±2.5º of rotation in 39% of patients and within ±5º in 72% (Figure 1A). Regarding intraoperative dynamic cyclotorsion, 42% of patients are within 1º of rotation (Figure 1B).

The six-dimensional eye tracker of the Amaris (Schwind...
eye-tech-solutions, Kleinostheim, Germany) reacts to lateral eye movements, eye rolling, and variations in the z-axis that describe the height position. Arba-Mosquera et al showed that, at a cylindrical value of 3.00 D, a small rotation of 2° changes the refraction by 0.25 D; a 5° rotation immediately shifts the effect by 0.50 D.

Another key to successful astigmatism correction is the diameter of the optical zone. We typically choose an optical zone of 6.5 to 7 mm; however, in some cases it is safe to go even larger. Wide optical zones are ideal for long-term stability, whereas smaller optical zones can cause optical disturbances such as halos and glare.

Centration of the correction can be based on the pupil center or the corneal vertex; as long as the difference between the two is less than 250 µm, this choice will not significantly affect the treatment. We have found that a 5.00 D astigmatic correction with an offset of 200 µm will result in approximately 0.10 D of residual astigmatism, whereas an offset of 400 µm will result in almost 0.25 D of residual astigmatism. Mrochen et al and de Ortueta have shown similar results. Considering the mean values for photopic pupilary offset and cyclotorsion, we can conclude that centration is more important than cyclotorsion.

**FACTORS INFLUENCING THE CLINICAL OUTCOME**

The patient’s refraction, the cyclotorsional alignment, and the geometrical shape, optical zone, and centration of the treatment all influence the clinical outcome of cylindrical treatments. If any of these values is improperly used, the result should be thought of as residual astigmatism and not an undercorrection, except in the case of an imperfect refraction.

The surgeon must learn to deal with the combined effects and compounding influences that can result in unexpected outcomes in astigmatic treatments. Let us assume a simple combination: The treatment is carried out on the pupil center, located 300 µm from the corneal vertex; this is combined with a 5° torsional misalignment.
and use of an averaged K-reading rather than the appropriate K values for both axes. For a 5.00 D astigmatic treatment, this combination of errors will lead to almost 0.70 D of residual astigmatism.

CLINICAL APPLICATION
In a retrospective study of 50 eyes with preoperative astigmatism greater than 2.00 D, we analyzed astigmatic LASIK outcomes at 6 months.10 All aspheric treatments using a nonwavefront-guided ablation profile were planned with the Amaris’ ORK-CAM software module and performed as aberration-free treatments. LASIK flaps were created using the LDV femtosecond laser (Ziemer Group, Port, Switzerland).

Preoperatively, the mean manifest defocus refraction was -3.08 ± 2.32 D (standard deviation [SD]; range: -7.13 to -1.00 D); the mean manifest astigmatism magnitude was 3.54 ± 0.85 D (range: 2.00 to 4.75 D); the mean manifest cardinal astigmatism was 1.26 ± 3.29 D (range: -3.49 to 4.60 D); the mean manifest oblique astigmatism was -0.04 ± 1.46 D (range: -2.15 to 2.05 D; Figure 2); and the vectorial mean of the manifest astigmatism was -1.26 D at 179º.

At 6 months postoperative, the mean residual defocus was -0.12 ± 0.25 D (range: -0.75 to 0.75 D); the mean residual astigmatism magnitude was 0.50 ± 0.26 D (range: 0.00 to 1.25 D); the mean residual cardinal astigmatism was 0.10 ± 0.43 D (range: -0.86 to 1.12 D); the mean residual oblique astigmatism was -0.02 ± 0.35 D (range: -0.76 to 0.66 D); and the vectorial mean of the residual astigmatism was -0.10 D at 179º. Thirty-eight eyes (76%) were within ±0.50 D of the attempted astigmatic correction (Figure 3), and 46 eyes (94%) were within ±1.00 D.

Postoperatively, 36% of patients gained 1 or more lines of distance BCVA, and 4% lost 1 line. No eye lost 2 or more lines of distance BCVA (Figure 4). Additionally, the magnitude of the potential coupling factor was less than 5%, far below other reported values.11,12

We have had the opportunity to work with different excimer laser brands and generations; the characteristics of this technology enable exceptional correction of moderate to high astigmatism. It is an appropriate mode for treating patients with irregular astigmatism.

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The Solid State Laser

This laser provides topography-driven treatments and unique diagnostics software.

By Bruce Allan, MD, FRCS

Treatment of irregular astigmatism is a particular challenge in corneal and refractive surgery. Many current excimer laser systems do not offer a topography-driven treatment option, and it is often impossible to produce a Hartmann-Shack aberrometry map of these irregular corneas. Both limitations are addressed by the Pulsar Z1 platform with Tracey diagnostics (CustomVis, Balcatta, Australia; Tracey Technologies, Corp., Houston). This system’s potential is underlined by positive results for treatment of irregular astigmatism in a small case series.1 We are currently extending this work at Moorfields Eye Hospital in London; our series of transepithelial surface treatments is driven by a combination of aberrometry and topography data for patients with irregular astigmatism after failed refractive surgery, penetrating keratoplasty, crosslinking for keratoconus, infection-related scarring, and dystrophic corneal surface change.

TRANSEPIHELIAL TREATMENT

Transepithelial surface laser treatment seeks to utilize the natural mask provided by epithelial remodelling after corneal injury. Over time, the epithelium partially fills troughs and thins peaks of stromal surface irregularity, thus smoothing the surface. Given that aberrometry and topography images are taken from the epithelial surface, it makes sense to apply a transepithelial ablation when using information derived from these scans to drive remedial treatments.2

A 213-nm solid state laser ablation is suitable for transepithelial treatment because, unlike excimer laser irradiation at 193 nm, which is strongly absorbed by water, it can be applied in a wet field. Far ultraviolet (UV) irradiation at 213 nm is closer to the peak absorption for collagen than 193 nm and is 20 times less strongly absorbed by water.3 The net effect is that the treatment surface is covered with a film of fluid as the ablation proceeds—a disturbing sight for surgeons conditioned to drying the surface as soon as fluid appears during excimer refractive laser treatment. Some organic molecular fragments are retained within this fluid layer. The extent to which this ablation pattern masks the incoming pulse is unknown. However, good results with 213-nm refractive treatments and the absence of surface profile anomalies after treatment4 indicate that any masking is uniform, and that there are no problems with 213-nm wet field ablation.

STANDARD PTK

Transepithelial treatment requires an estimation of the epithelial thickness and assumes that the epithelial ablation rate matches that of the stroma. Based on ultrasound biomicroscopic data suggesting a mean central corneal epithelial thickness of 53.4 ±4.6 µm,5 we use standard 60-µm phototherapeutic keratectomy (PTK) as a starting point for treatment. PTK does not fully remove the epithelium in all cases. Uneven epithelial thickness (in normal corneas, the epithelium is thicker inferiorly than superiorly) is likely to be reproduced after healing, with deeper ablations possibly leading to a hyperopic shift. Using the epithelium as a natural mask in ablations for irregular astigmatism is likely to be beneficial, but further studies of the epithelial versus stromal ablation rates, and improved methods for measuring epithelial thickness, may enhance results.

GENERATING THE TREATMENT PATTERN IN IRREGULAR ASTIGMATISM

Conventional refractive ablations either assume a regu-
lar optical surface or rely on aberrometry to provide information to correct irregularities leading to defocus. Hartmann-Shack aberrometry measures deviations from the expected ideal position of a point light source bounced off the retina and sampled across an array of loci over the entrance pupil. It is used by several leading laser platforms. The denser the array, the greater chance that light emerging at one point will be detected by the

Figure 2. (A, B) There is no active surface disease in this patient undergoing transepithelial ablation.
Tracey aberrometry is not limited by aliasing. The origin of each spot is always certain, and even highly irregular corneas can be scanned.

neighboring element in the sampling array (ie, aliasing) if deviations from the expected position are large. Therefore, it is often impossible to obtain a usable wavefront map in the presence of significant irregular astigmatism. The alternative is a topography-driven treatment in which the direct measurement of corneal shape is the basis for treatment. Placido-disc or Schleimpflug imaging modalities are used to map the corneal shape, with treatment algorithms varying among the topographic systems. Basic steps used by the CustomVis platform are as follows. First, the surface is mapped using Placido-disc topography, followed by definition of the optical zone with reference to the mesopic pupil diameter. Refraction and aberrometry values are then used to fit a regular toric aspheric lens shape (required to optimize postoperative focus; Figure 1) to the irregular surface shape across the optical zone. The back surface of the lens—the new ideal optical surface for the eye—is sunk to the level of the deepest trough in the corneal shape map. Next, the ablation is programmed with the aim of removing the volume of tissue between the existing surface and the ideal new surface.

It is often difficult to obtain a reliable manifest refraction endpoint in the presence of significant irregular astigmatism. Tracey aberrometry is used in the CustomVis system to estimate the refractive adjustment and generate an appropriate lens shape to produce the new optical surface.

Tracey aberrometry is not limited by aliasing. Rather than sampling reference light at an array of points simultaneously, this technology projects light in a raster pattern of sequential spots through the pupil. The origin of each spot is always certain, and even highly irregular corneas can be scanned.

DELIVERY

Having generated the ablation pattern, the task is then to deliver it accurately. Most current laser systems use beam-steering galvanometers with a response time limited to 2 milliseconds plus later hysteresis (continued wobble). However accurate the tracking input, in the presence of any movement, lasers with a pulse rate close to or exceeding 500 Hz will spray pulses around rather than on the target position. The Pulsar Z1 platform utilizes dual analog and video tracking with less than 1 millisecond total response time. Instead of galvanometers, it uses a piezoelectric crystal system further back in the beam path to supply faster beam steering. At 300 Hz (the current ablation rate), each spot should be accurately placed. The system tracks on the limbus rather than the pupil, eliminating errors due to pupil centroid shift.

The surgeon can correct errors in acquisition of the limbus image manually during treatment programming using the ZCad software (CustomVis). Manual adjustment of cyclotorsion is also available to ensure that tracking features, typically a blood vessel or a pigmented mark, are superimposed on the scan and treatment images.

CLINICAL EXPERIENCE

We commenced a case series of transepithelial treatments for irregular astigmatism using the CustomVis Pulsar Z1 platform in October 2009. We have treated 15 patients to date, five of whom we have followed for 3 months (Figure 2). We plan to present preliminary results at the European Society of Cataract and Refractive Surgeons (ESCRS) meeting in Paris later this year.

Early experience has been positive, with quick healing after transepithelial ablation (ie, epithelial closure within 4 days) and gains in BCVA, particularly in cases with irregular astigmatism following complicated previous refractive surgery. Patients in this group are typically unhappy and frustrated preoperatively, and it is useful to be able to offer them realistic hope of successful remedial treatment.

With advances in imaging and treatment delivery, we will be able to offer better solutions for the treatment of corneal irregularity. Accurate tracking, the ability to deliver transepithelial treatments out to a 9.5-mm diameter zone in a wet field, and flexibility in treatment programming offer exciting potential for development in this challenging area.

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