Numerous factors make the treatment of corneal astigmatism with laser corneal surgery more challenging than treatment of spherical error alone. Astigmatism can be irregular and complex, and it can be compounded by myopic or hyperopic error. Each scenario requires choice of an appropriate treatment approach. Choosing the wrong treatment can lead to regression of effect, excessive tissue ablation, and other complications. Selection of the best ablation approach can help to minimize some of the difficulty inherent in treating astigmatism, avoid postoperative complications, and ensure happy patients.

Regular astigmatism is characterized by the presence of two principal, orthogonal meridians on the cornea: the steepest and the flattest meridians. Even with simple orthogonal astigmatism, however, refractive surgeons must be aware that astigmatism always includes a component of higher-order aberrations (HOAs).1 HOAs on the corneal surface, which are naturally irregular and asymmetric, influence the cylinder power and axis measured preoperatively and must be corrected before the true astigmatism can be identified. The correction of HOAs may reveal the true cylinder power and axis, eliminating the coma- and trefoil-related portions of astigmatism (Figure 1). This approach spares precious tissue during the refractive procedure.

**TREATMENT CHALLENGES**

A number of factors must be considered when planning astigmatic treatment. These include taking into account the patient’s anatomic characteristics, such as pupil displacement, and choosing the proper treatment parameters, such as optical zone size and placement.

Pupil and line-of-sight displacement can make it difficult to correct astigmatism.2 For example, superonasal displacement of the pupil can lead to inferotemporal steepening, inducing regression and HOAs such as coma (Figure 2). Astigmatic patients are more sensitive to pupil diameter shift, and therefore optical zones must be wider in astigmatic treatments than in pure spherical ablations.

Astigmatism treatment must be distributed over the entire cornea. To perform adequate astigmatic correction, the diameter of the optical zone must be set accordingly. Figure 3 illustrates how a small ablation optic zone diameter leaves peripheral astigmatism on the astigmatic meridian. With time, the healing process will fill the angle between the treated and untreated cornea.3

Figure 1. After higher-order errors are treated, the true cylinder power emerges.
reducing the optical zone size and inducing regression on both meridians. A new myopic astigmatism will develop on the steepest meridian, and a positive spherical equivalent will develop due to hyper-correction on the orthogonal neutral meridian, which will become flatter.

A delicate point in the creation of a new surface with excimer laser ablation is the transition zone. A marked variation of curvature in the peripheral cornea can lead to a healing response as the tissue attempts to reduce the induced curvature variation. This process may lead to regression and restriction in the size of the effective optical zone.

PLANNING ASTIGMATISM TREATMENT

The cross-cylinder technique is a satisfactory method to reduce several of the complications related to astigmatic correction. The technique requires limited tissue ablation—half in the center and half in the periphery. It results in a smoother transition at both meridians and preserves the mean corneal radius of curvature, leaving the cornea prolate and symmetrical with a final shape closer to that of the normal prolate cornea. The cross-cylinder technique also increases the diameter of the optical zone and reduces tetrafoil aberrations, which are frequently related to astigmatic correction performed on a single meridian.4 In this technique, cylinder power is divided into two symmetric parts,5 positive and negative, which helps to preserve the mean corneal radius of curvature and corneal eccentricity. The diameters of the ablation and transition zones must be symmetrical for the positive and negative cylinder corrections.

The multizone cross-cylinder6 method creates a progressive transition with a low dioptic gradient between the treated and untreated cornea. Advantages of this approach include the following: maintaining a physiologically prolate and symmetrical corneal shape; inducing less regression; producing better postoperative visual acuity; and sparing tissue by splitting part of the cylinder ablation into the periphery.7

The cross-cylinder technique is recommended for both high and low compound myopic astigmatism. Its advantages for this indication include the following: reducing and distributing the amount of tissue removed across the total corneal surface, thereby better preserving biomechanical corneal strength; producing a constant final corneal curvature gradient through a reduction of corneal curvature gradient from the center to the periphery; and positioning the final curvature gradient in the extreme periphery, beyond 9 mm, where the cornea is thicker and flatter, induces further reduction of spherical aberration and results in excellent quality of vision even when the pupils are dilated.

Figure 2. Superonasal displacement of the pupil can lead to inferotemporal steepening, inducing regression and HOA.

Figure 3. A small optical zone diameter can leave peripheral astigmatism on the astigmatic meridian.

TYPE OF ASTIGMATISM

Mixed astigmatism. Several ablation patterns have been described to treat mixed astigmatism:8,9 Correction on the steep meridian (myopic cylindrical ablation plus hyperopic spherical ablation) runs the risk of over-correction of the oblique meridians, leading to hyperopic shift, regression, and visual acuity reduction. Correction on the flat meridian (hyperopic cylindrical ablation plus myopic spherical ablation) removes less corneal tissue; however, astigmatic ablation on one meridian alone leads to marked corneal peripheral asymmetry and induces an oblate cornea with an increase in aberrations (spherical aberration, tetrafoil, astigmatism) even with slight pupil dilation.

Other ablation patterns include cross-cylinder ablation (as discussed above); bitoric ablation, which splits correction asymmetrically into two meridians;10 and custom ablation with torsion error detection.11

Compound hyperopic astigmatism. In hyperopic astigmatism, the conventional approach to ablation
aims to increase steepness on the flatter meridian and minimize treatment of the steepest meridian. The end result is an irregular four-leaf astigmatism with under-correction along the oblique meridians and a myopic shift. If regression occurs after this type of treatment, the cornea will develop mixed astigmatism. Custom ablation with torsion error detection is our preferred treatment for this defect.

THE ORIGIN OF REGRESSION

If the selected approach to ablation results in an optical zone that is too small, or if inadequate surgical planning is carried out, postoperative regression can occur. It is important to be able to understand and treat the origin of regression.

To understand which meridian causes the regression, the surgeon must identify the meridian that cramps the optical zone. Examine the topography for two moon-shaped segments, look at the corneal region involved, and consider HOAs as the source of regression. If the two moon-shaped segments are red, the treated meridian is small. If the two moon-shaped segments are blue, the untreated meridian is small.

If the flat meridian is the source of regression, half of the power should be treated as plus cylinder and half as minus cylinder, thereby increasing the size of the untreated optical zone. If the steep meridian is causing regression, the size of the untreated optical zone should be increased without creating any deeper ablation.

A gradient map can help to predict the location of postoperative astigmatism. To identify the source of regression, look for the area where the corneal curvature gradient is greater.

CONCLUSION

Choosing the best ablation pattern and surgical technique has an important role for the accurate correction of astigmatism. In the past few years, different ablation patterns have been developed to obtain a corneal shape that removes stable over time.

The aims of a custom treatment are to achieve an aspheric cornea and to obtain a topography map in which the preoperative astigmatism is no longer detectable. If these two conditions are fulfilled, the surface created should no longer be sensitive to decentration and pupil diameter. The corneal curvature gradient is fundamental to reach these goals. If a low curvature gradient remains, the ablation pattern will likely be stable and the patient will be satisfied; however, a high curvature gradient (red ring) will produce a significant change, leading to regression and restriction in the size of the effective optical zone.

We suggest using a custom ablation that respects the postoperative corneal curvature gradient, identifying true corneal astigmatism after HOAs are eliminated, and accurately compensating for possible cyclotorison.

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TAKE-HOME MESSAGE

• Astigmatism always includes a component of HOAs.
• When planning astigmatic treatment, take the patient’s anatomic characteristics into account.
• Astigmatism treatment must be distributed over the entire cornea.
• If the selected approach to ablation results in an optical zone that is too small, or if inadequate surgical planning is carried out, postoperative regression can occur.