An astigmatically neutral postoperative result is a major goal of modern small-incision phacoemulsification and refractive lens surgery. Techniques and technologies including carefully planned incision locations, intraoperative limbal relaxing incisions (LRIs),1-8 and toric lenses for higher levels of preoperative astigmatism have allowed surgeons to achieve this goal.9-11 LRIs are widely performed for low dioptric corrections.12 They preserve the optical qualities of the cornea, do not cause significant patient discomfort, and are sufficiently effective for correcting lower levels of astigmatism. The limbal location of these incisions results in a consistent 1:1 coupling ratio13 that causes little change in spherical equivalent and eliminates the need to change implant power. Gills1 and Osher14 were early advocates of these incisions.

Successfully placed LRIs reduce cylinder without an overcorrection or axis shift. Determining the exact location of the cylinder, however, is often challenging. Keratometry, refraction, and corneal topography may not correlate. Of these, corneal topography has been the most helpful and is most often used to guide the surgical plan and to evaluate the postoperative result. In addition to diagnostic methodology, incision construction technique has also varied among surgeons.15 Peripheral corneal pachymetry, incision depth, and optical zone size (distance from the visual axis or corneal apex to the incisions) appear to play important roles in effectiveness. Variability in results is likely multifactorial, but a consistent technique is the minimum requirement for beginning to understand the variation in response.

**BENEFITS OF AUTOMATION**

Recently, femtosecond laser keratotomy has been introduced as a more precise way to achieve incisional correction of astigmatism, including high degrees of astigmatism in postkeratoplasty eyes.16-18 Abbey et al demonstrated correction of about 2.50 to 3.00 D of naturally occurring refractive astigmatism with femtosecond laser astigmatic keratotomy.19 Common sense suggests that automating the incisional technology and thus eliminating the variability in performance that is an attribute of manual incision construction will lead to greater reproducibility in results.

The potential for femtosecond LRIs to place the photodisruptive cutting effect at the right orientation and to make cuts of the correct length and depth to create the desired refractive effect should lead to greater consistency of outcomes. The laser’s ability to make sub-Bowman’s incisions may have benefits in limiting the effect of healing, which can be responsible for regression of the effect. Sub-Bowman’s incisions may also improve patient comfort postoperatively. Overall, laser-mediated LRIs should make outcomes more predictable and reliable for all surgeons.

**UNDERSTANDING THE INCISION EFFECT**

To develop LRIs with femtosecond technology, it is necessary to model the cornea so that changes induced by the incisions can be predicted and the most effective treatment algorithm selected. The model should be able
to predict the published outcomes of current surgical methods so that laser treatments can be compared. Changes in topography should be predictable and confirmed on animal and human cadaver eye models. Finally, clinical testing should confirm the outcomes predicted from the model.

Nichamin and coworkers developed a corneal model to study the effects of LRIs (Figure 1). The model includes five layers with different material properties: Bowman’s membrane (one layer), stroma (three layers), and Descemet’s membrane (one layer). These reflect the mechanical properties of the cornea at different depths. An incision profile created for use with the corneal model was well defined in terms of arc length, depth and profile, and optic zone diameter. To assess the stress distribution of the incisions, a nominal IOP must be selected. Outcomes will vary depending on the IOP selected (Figure 2).

In using this model to study the effects of LRIs, we assessed the effects of age, stiffness, and various incision lengths and optic zones. Figure 3 shows the results in simulated 25- and 75-year-old corneas. The change in refractive cylinder increases with the arc length of the incision and is greater in the younger cornea than the older one.

**TAKE-HOME MESSAGE**

- Automating incisional technology and eliminating variability in performance may lead to greater reproducibility.
- LRIs created with the femtosecond laser may mitigate the effects of healing on regression.
- Finite element analysis modeling and ex-vivo studies suggest that femtosecond LRIs produce results equivalent to those of manual LRIs.

**CORNEAL RESPONSE**

The use of the femtosecond laser to create LRIs introduces the possibility to create intrastromal incisions, which may mitigate the effects of healing on regression. In our corneal model, as expected, the change in refractive power is reduced compared with surface incisions, but the results can be enhanced by using multiple incisional arcs and differing incision heights (ie, how much of
the intrastromal tissue is ablated). Ex-vivo work has demonstrated the feasibility of these procedures on animal eyes, in which corneal power can be verified using instruments such as the Keratron Scout (Optikon 2000 Industrie, Rome). Finite element analysis modeling has confirmed the corneal response to LRIs. Younger corneas showed a greater response to incisional surgery but also regressed more postoperatively.

The model and early ex-vivo studies suggest that femtosecond LRIs produce results equivalent to those of manual LRIs. The effect of sub-Bowman’s incisions have been demonstrated in animals.

**INTRAOPERATIVE Aberrometry**

Modeling and automation may reduce variation in technique, but they do not take into account variation in response. A recent advance in astigmatism management may prove complementary to the femtosecond laser in this regard. ORange (WaveTec Vision, Aliso Viejo, California) is an intraoperative aberrometer based on Talbot Moiré interferometry that provides wavefront-guided refraction during cataract and refractive lens exchange surgery (Figure 4). The device analyzes sphere, cylinder, and axis and enables surgeons to make decisions regarding the need to reduce residual and/or induced astigmatism while performing the procedure. Intraoperative aberrometry is used to measure the effectiveness of incision construction and allow decisions to be made as to whether a secondary incision may be necessary. The drive toward greater accuracy and predictability in the outcomes of our incisional surgery for astigmatism represents a tremendous benefit for our patients because they will be able to achieve their desired results with a single procedure. Ultimately, our abilities to titrate and enhance precise LRIs may prove superior to outcomes achieved with toric IOLs for most degrees of astigmatic correction.

**Conclusion**

The drive toward greater accuracy and predictability in the outcomes of our incisional surgery for astigmatism represents a tremendous benefit for our patients because they will be able to achieve their desired results with a single procedure. Ultimately, our abilities to titrate and enhance precise LRIs may prove superior to outcomes achieved with toric IOLs for most degrees of astigmatic correction. □

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**Figure 4. The intraoperative aberrometer: device is attached to microscope, and the display screen is behind the surgeon.**