Several of the qualities of a normal cornea influence its refractive behavior: namely, asphericity, shape (steeper in the center and flatter in the periphery), and positive spherical aberration (which is compensated by negative spherical aberration in the crystalline lens). Furthermore, like any curved biologic surface, the cornea’s curvature varies between contiguous points, with every point on the surface having its own defined curvature. The difference between the curvatures of two points determines the curvature gradient in that direction.

The shape of a normal cornea minimizes aberrations and corneal reflexes and provides the best image resolution, even at the edge of the cornea. After the cornea changes shape in response to the ablations produced during refractive surgery, however, the patient’s visual quality can decrease even if an optimized visual acuity is achieved. Frequently after refractive surgery, patients report a reduction of visual quality, even if their UCVA is 20/20. Normally, this worsening in visual quality is a byproduct of an increase in spherical aberration, coma, or chromatic aberration.

Spherical aberration reduces contrast sensitivity and resolution. In particular, resolution decreases from the center of the cornea to the periphery, and it is different for every wavelength. Chromatic aberration is a type of distortion in which the lens fails to focus all colors on the same convergence point. This is different from coma, a skewed or asymmetric version of spherical aberration, which can induce double vision and halos.

PUPIL SIZE AND OPTICAL ABERRATIONS
Pupil size influences optical aberrations. Large pupils have greater wavefront error, leading to spherical aberration that induces halos around images. Generally, aberrations increase as the second power of the pupil radius ($r^2$); this is because most wavefront aberrations are second-order aberrations, which have a square-radius dependency. Conversely, spherical aberration increases as the third power of the pupil diameter. Thus, a small change in pupil size can significantly affect refraction. Because coma increases as $r^2$, astigmatism and chromatic aberrations are not influenced by pupil size.

Due to the increase of spherical wavefront error, an aberrated eye has not only a reduction in overall contrast sensitivity and resolution.
but also in image quality from the center to periphery, similar to the effect of visual field change in glaucoma (Figure 1).

Another problem associated with aberrated eyes is difficulty in recognizing and identifying what is out of focus. In photography, this phenomenon is called bokeh, a term that comes from the Japanese words boke (暈け or ボケ), which means blur or haze, and boke-aji (ボケ味), which refers to the way the lens renders out-of-focus points of light. Some lenses have subjectively more pleasing out-of-focus areas; the image is sharp when perfectly focused, and, in the areas that are out of focus, image quality deteriorates progressively. The degradation of image quality is worse when higher-order aberrations (HOAs) are present.

TRADITIONAL AND MODERN TREATMENTS

With earlier refractive surgery treatments, it was common for ablation profiles to treat only the central cornea; to create different profiles in the center and the periphery; and to result in regression, decentration (even with the use of eye trackers), slow visual recovery, and halos (Figure 2).

Coma can be increased after refractive surgery due to two factors: (1) If the ablation of lower-order aberrations (LOAs) is not centered on the visual axis, increasing coma, and (2) if the ablation of HOAs (assuming these are measured) is not centered on the pupil center. One must remember that the visual axis is not always coincident with the corneal vertex or the pupil axis. Traditionally, centration of ablations was based on the pupillary center (as referenced from the rim of the pupil) or on the coaxial light reflex at the corneal vertex.

Modern excimer laser treatments are capable of tracking and ablating LOAs on the visual axis and HOAs on the pupillary center and aim to avoid several complications associated with older treatments by creating aspheric corneas, correcting preoperative sphere and cylinder so that it is no longer detectable by topography and wavefront maps, and centering the ablation so that it covers the pupillary aperture and respects the corneal vertex as the optical axis of the ablation in order to avoid decentration.

TWO NEW TOOLS

Curvature gradient map. To accomplish these objectives, an ablation profile must cover the entire cornea, feature a smooth transition from the optical zone to the limbus, avoid abrupt changes in the curvature gradient in order to prevent regression, and respect the original corneal shape. When an ablation profile meets these criteria, the postoperative outcome can last for many years, and the risk of regression can be dramatically reduced, even in high corrections. A new topography map, the curvature gradient (CG) map, can be used to evaluate the rate of change in curvature over the corneal surface and predict the postoperative healing process (Figure 3).

Centration technique. Another new tool that has the potential to enhance postoperative outcomes is a centration technique devised by Schwind eye-tech-solutions. In this technique, HOAs are corrected in reference to the pupil center (line of sight) and manifest refraction values are referred to the corneal vertex. This asymmetric offset increases the quality of the profile without ablating more tissue (Figure 4).

Preliminary results of an ongoing clinical study with this centration technique showed significant decreases of spherical aberration, coma, and total HOAs from pre- to postoperative measurements, demonstrating that the ablation profile increased the quality of vision in addition to improv-
It is our hope that combining this profile with customized ablation will help to create a corneal profile that is similar to that of a normal eye (Figure 5).

When the CG map shows a low curvature gradient, one can assume the eye has a low risk of regression and has achieved immediate stability; extremely low HOAs; and good image quality across the entire cornea, not only in the center. Hence, these eyes are almost insensitive to changes in pupil size.

**CONCLUSION**

In addition to good UCVA after refractive surgery, new ablation profiles should give patients high-quality vision, regardless of pupil size. To obtain this goal in eyes with HOAs, we suggest the use of customized ablation, a corneal curvature gradient that avoids regression, and an appropriate offset profile.

**TAKE-HOME MESSAGE**

- New ablation profiles should be able to give patients high-quality vision regardless of pupil size.
- An offset ablation technique, in which HOAs are corrected in reference to the pupil center and manifest refraction values are corrected in reference to the corneal vertex, can increase quality of vision in addition to improving visual acuity.
- The corneal curvature gradient map is a new topography map that is able to predict the healing process after surgery. When the curvature gradient is high, the surface curvature modification remains in progress months after surgery.

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