Topography is valuable for preoperative ophthalmic examination of LASIK candidates. Three-dimensional imaging allows surgeons to look at corneal thickness, as well as the corneal anterior and posterior surface and it can also predict the shape of the cornea after LASIK surgery. Topographic analysis using three dimensional slit scan system allows us to predict which candidates would do well with LASIK and also confers the ability to screen for subtle configurations which may be a contraindication to LASIK.

**ORBSCAN**

The ORBSCAN (BAUSCH & LOMB) corneal topography system uses a scanning optical slit scan which makes it fundamentally different from the corneal topography that analyses the reflected images from the anterior corneal surface. The high-resolution video camera captures 40 light slits at 45 degrees angle projected through the cornea similarly as seen during slit lamp examination. The slits are projected on to the anterior segment of the eye: the anterior cornea, the posterior cornea, the anterior iris and anterior lens. The data collected from these four surfaces are used to create a topographic map. Each surface point from the diffusely reflected slit beams that over-lap in the central 5-mm zone is independently triangulated to x, y, and z coordinates, providing three-dimensional data.

This technique provides more information about the anterior segment of the eye, such as anterior and posterior corneal curvature, elevation maps of the anterior and posterior corneal surface and corneal thickness. It has an acquisition time of 4 seconds. This improves the diagnostic accuracy. It also has a passive eye-tracker from frame to frame and 43 frames are taken to ensure accuracy. It is easy to interpret and has good repeatability.
PRIMARY POSTERIOR CORNEAL ELEVATION

The diagnosis of frank keratoconus is a clinical one. Early diagnosis of forme fruste can be difficult on clinical examination alone. ORBSCAN has become a useful tool for evaluating the disease, and with its advent, abnormalities in posterior corneal surface topography have been identified in keratoconus. Posterior corneal surface data is problematic because it is not a direct measure and there is little published information on normal values for each age group. In the patient with increased posterior corneal elevation in the absence of other changes, it is unknown whether this finding represents a manifestation of early keratoconus. The decision to proceed with refractive surgery is therefore more difficult.

POSTERIOR CORNEAL TOPOGRAPHY

One should always use the ORBSCAN system to evaluate potential LASIK candidates preoperatively to rule out primary posterior corneal elevations. Eyes are screened using quad maps (Fig 6-8) with the normal band (NB) filter turned on. Four maps include (a) anterior corneal

![General quad map of an eye with primary posterior corneal elevation](image)

*Figure 6 - General quad map of an eye with primary posterior corneal elevation. Notice the red areas seen in the top right picture showing the primary posterior corneal elevation. In the figure upper left corner map is the anterior float, upper right corner map is posterior float, lower left corner is keratometric map while the lower right is the pachymetry map.*
Figure 7 - Quad map with normal band scale filter on in the same eye as in Figure 1. Only the abnormal areas are shown in red for ease in detection.

Figure 8 shows three-dimensional normal band scale map. In the top right note the red areas which shows the elevation on the posterior cornea. The anterior cornea is normal.

elevation: NB = ± 25 μ of best-fit sphere. (b) posterior corneal elevation: NB = ± 25 μ of best fit sphere. (c) Keratometric mean curvature: NB = 40 to 48 D (d) Corneal thickness (pachymetry): NB = 500 to 600 μ. Map features within normal band are colored green. This effectively filters out variations falling within the normal band. When abnormalities are seen on normal band quad map screening, a standard scale quad map should be
examined. For those cases with posterior corneal elevation, three-dimensional views of posterior corneal elevation can also be generated. In all eyes with posterior corneal elevation, the following parameters are generated (a) radii of anterior and posterior curvature of the cornea, (b) posterior best fit sphere, (c) difference between the corneal pachymetry value in 7mm zone and thinnest pachymetry value of the cornea.

In the light of the fact that keratoconus may have posterior corneal elevation as the earliest manifestation, preoperative analysis of posterior corneal curvature to detect a posterior corneal bulge is important to avoid post LASIK keratectasia. The rate of progression of posterior corneal elevation to frank keratoconus is unknown. It is also difficult to specify that exact amount of posterior corneal elevation beyond which it may be unsafe to carry out LASIK. Atypical elevation in the posterior corneal map more than 45 µm should alert us against a post LASIK surprise. ORBSCAN provides reliable, reproducible data of the posterior corneal surface and all LASIK candidates must be evaluated by this method preoperatively to detect an “early keratoconus”.

CRITERIA TO DIAGNOSE PRIMARY POSTERIOR CORNEAL ELEVATION

1. Ratio of the Radii of anterior and posterior curvature of the cornea should be more than 1.2.
2. Posterior best fit sphere should be more than 52 D.
3. Difference between the thickest and thinnest corneal pachymetry value in the 7 mm zone should be more than 100 microns.
4. The thinnest point on the cornea should correspond with the highest point of elevation of the posterior corneal surface.
5. Elevation of the posterior corneal surface should be more than 45 microns above the posterior best fit sphere.
EPITHELIAL INGROWTH

Epithelial ingrowth after LASIK is a known complication occurring in upto 0.2 to 0.4% of cases. The incidence may be higher upto 15% of cases where adherence to meticulous surgical technique is not followed. It may remain as an innocuous, non-progressive condition or may progress to become a potentially sight threatening condition.

<table>
<thead>
<tr>
<th>EPITHELIAL INGROWTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epithelial cell ingrowth may be secondary to one of two mechanisms in a post LASIK patient. The cells may be introduced into the interface either during the microkeratome pass or other steps such as irrigation of the bed or repositioning of the flap. The other possible mechanism for epithelial ingrowth is due to loss of contact inhibition of the epithelial cell layer. Epithelial cells on the surface of the cornea have contact inhibition. Therefore, as long as a cell is surrounded on all sides with other epithelial cells, it does not have any stimulus to migrate. On the other hand, once this contact is gone, the epithelial layer starts to migrate to fill in this defect due to loss of contact inhibition. In LASIK, the discontinuity in the epithelium at the margin of the flap acts as a stimulus for epithelial ingrowth. This is overcome in the large majority of patients by the firm adhesion of the flap to the stromal bed. In cases with poor adhesion, the epithelial cells actively proliferate and begin to move centrally into the interface to cover the perceived defect.</td>
</tr>
</tbody>
</table>

SYMPTOMS

Epithelial ingrowth may be mild, which is usually asymptomatic and seen on routine evaluation. In moderate cases, the patient may have foreign body sensation, photophobia, congestion, pain, irritation, ghosting, glare and haloes as well as loss of best corrected visual acuity. The dry eye symptoms may be worse in these patients as compared to others due to the irregular ocular surface leading to a decreased tear break up time. In very severe cases, the patient may present with loss of vision, intense pain, and other symptoms due to stromal melting. It can cause haze and discomfort, especially if the lifted edge is sensed when blinking.
SIGNS

The epithelial ingrowth may be seen as white or gray nests of cells (fig 9) or as fingerlike extensions extending inwards from the flap edges. Epithelial ingrowth may also be seen as a thin sheet within the interface or sometimes as a combination. Indirect slit lamp illumination is sometimes required to see the sheet like proliferation. It can also be seen on retroillumination. Epithelial ingrowth is usually located at the periphery but may occasionally begin from the center of the flap, especially in cases secondary to buttonhole or central epithelial defects. In nasally hinged flaps, it is seen most commonly at the temporal margin whereas in superiorly hinged flaps, it is seen commonly at the inferior margin and at the border of the hinge. Fluorescein solution when instilled into the flap stains the involved area. It may also delineate the area of ingrowth. An increase in staining at the area of impending flap melt may also be seen. One can also detect the potential for ingrowth by instilling fluorescein. This demonstrates areas of the cut in the cornea which have yet to be epithelialized.

![Figure 9: Epithelial ingrowth after Lasik (right). Patient with an epithelial ingrowth after a nasal hinge flap (left)](image)

Epithelial ingrowth can cause a decrease in vision either by growing into the visual axis or secondary to irregular astigmatism via interface elevations. Progressive epithelial ingrowth may induce astigmatism by causing flattening of the meridian at which the ingrowth is located and steepening of the meridian 90° away. Very severe cases may present with flap or stromal necrosis.
<table>
<thead>
<tr>
<th>BENIGN FORM</th>
<th>AGGRESSIVE FORM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seen within 2mm of the flap edge</td>
<td>appears in the shape of cell nests – pearl-like small islands, sheaths, colonies, strands or cysts</td>
</tr>
<tr>
<td>May occur as diffuse or localized Progressive or non progressive Disappear</td>
<td>Progressive</td>
</tr>
</tbody>
</table>

**COMPLICATIONS**

Epithelial ingrowth may induce regular and irregular astigmatism with resulting decreased vision. It may also result in melting of the flap or the stromal bed. Epithelial fistulas may be formed near the flap margin. Clinically significant ingrowth may interfere with diffusion of nutrients between aqueous and flap tissue. Collagenase and protease enzymes that are released by necrotic epithelial cells may result in stromal and flap melting. Presence of stromal inflammation may be an early sign of necrosis.

**TREATMENT**

The limited, benign form of epithelial ingrowth, less or equal than 2 mm in diameter, does not require treatment. Treatment is required only when epithelial ingrowth interferes with or threatens to interfere with visual acuity by encroaching onto the visual axis or by causing other complications such as irregular astigmatism or threatening to cause stromal necrosis or flap melt. Treatment is also indicated in case of symptomatic ingrowth. Numerous techniques have been described for the management of epithelial ingrowth. Techniques for removal include scraping of epithelial ingrowth and excimer laser phototherapeutic keratectomy (PTK). The flap is reflected and the ingrowth is removed by peeling off as a sheet using fine

*Figure 10: Forceps can be used to grasp the epithelial ingrowth. One should be careful so that a flap tear does not occur.*
forceps (fig 10) or by scraping from both the stromal bed as well as the undersurface of the flap. The bed is then irrigated well before replacing the flap. Excimer laser PTK may also be used to remove the epithelial cells. Adjuncts such as cryotherapy, cocaine, Nd:YAG laser, mitomycin C, and sutures may lead to a decreased incidence of recurrence. Some authors have reported success with ethanol and laser therapy for recurrences. The major bugbear in the management of epithelial ingrowth is the high incidence of recurrences even after treatment. Recurrence of epithelial ingrowth after treatment has been reported to be as high as 44%.

Recurrence of ingrowth can be caused due to improper adhesion of the flap to the bed which leaves behind a potential space for the cells to grow into. It has been suggested to place interrupted sutures with just enough tension to oppose the flap to the bed without inducing striae at the site of ingrowth after epithelial removal. The sutures can be removed after 1 month.

PREVENTION

Extra care in patients with known risk factors, minimal and careful use of local anesthetics, avoiding excessive flap manipulations, careful relifts, using new blades and careful attention to meticulous technique all play a very important role in decreasing the incidence of epithelial ingrowth. It is important to avoid large transition zones on small beds and shield the hinge area as necessary.

DECENTERED ABLATION

To adequately define decentration of the ablation zone, a review of the differences between curvature and elevation maps is necessary. Dioptric curvature maps indicate surface shape using the axial radius of curvature, or the distance along the normal from the surface to the optic axis. Once a radius is determined, it is converted to a dioptric value using a paraxial keratometry formula. This value indicates the surface refractive power when incident rays are normal to the cornea; therefore, it is valid for the corneal apex only. When this formula is applied to all corneal points, radius-based dioptric maps misrepresent corneal power. Instead, radius-based dioptric maps should be thought of as dioptric curvature maps.

In contrast, elevation maps using an appropriate reference surface can describe subtle variations in surface geometry and are valuable when true topography is required. Elevation maps are incredibly useful in both diagnosis and treatment of decentration, and in monitoring surface changes.
An example of the difference between axial and elevation maps can be seen in Figure 11 for a keratoconic cornea. Keratoconus presents a corneal condition resulting in progressive decentration of the corneal apex. On the axial map, keratoconus appears as an area of inferior steepening. On the elevation map, the cornea is elevated superior to the area of thinning.

**Figure 11:** Curvature (left) and elevation (right) maps for a keratoconic cornea are noticeably different. On the axial map, keratoconus appears as an area of inferior steepening. On the surface height map, the elevation appears superior to the area of thinning.

**Figure 12:** Axial (left) and elevation (right) maps for a patient with a decentered ablation. The elevation map shows an inferior decentration of the treatment zone in this patient S/P myopic LASIK.
Figure 12 demonstrates curvature and elevation maps for a patient with a decentered ablation. The elevation map shows a decentration of the optical zone. Note the inferior decentration of the treatment in this patient who previously underwent a myopic LASIK treatment. The key observation on curvature maps is the dioptric difference between the superior and inferior keratometric readings. The key observation on elevation maps is the misalignment of the center of ablation from the optical center.

A patient with a decentered ablation generally presents with the following clinical signs and symptoms:

1) a decentration of the ablation zone on corneal topography,
2) increased higher order aberrations as measured using wavefront aberrometry, predominantly coma,
3) the appearance of a tail on point spread function,
4) reduced best-corrected visual acuity that improves only with gas permeable lenses,
5) a cylinder measurement on autorefraction and wavefront that differs from manifest refraction, and
6) a history of reduced vision immediately following surgery that fails to improve with time. TOPOGRAPHY

To evaluate decentration on corneal topography, both axial curvature and elevation maps are useful. The axial algorithm provides the refractive result of ablation, i.e. the optical zone. A large corneal curvature gradient between treated and untreated cornea, such as that resulting from a highly myopic correction, creates a smaller optical zone, increasing the refractive effect of the decentration. The elevation algorithm delineates the location and size of the ablation zone. Decentration of the ablation zone can be measured by comparing the distance between the center of the flattened zone and the center of the entrance pupil on preoperative and postoperative elevation maps using a difference map (Figure 13).
Wavefront Aberrations

Wavefront aberrometry shows increased higher order aberrations in patients S/P LASIK, specifically those with decentered ablations. Subclinical decentrations less than 1 mm significantly increase wavefront aberrations, deteriorating the optical quality of the retinal image. On average, all Zernike coefficients increased post-operatively, with coma being the predominant high order aberration. Decentrations as small as 0.2 mm increased wavefront aberrations. However, decentrations less than 0.5 mm have been considered clinically insignificant. Wavefront aberrometers typically display aberrations using several methods, including Point Spread Function (PSF) and Snellen letter appearance from the patient’s perspective.
Management

Relieving patients of symptoms associated with decentration may be complex. The most frequently used method involves gas permeable lenses, which reshape the anterior cornea optically, restoring visual quality. These fittings often require reverse geometry lenses or aspheric lenses to be successful. This is time-consuming, and most patients do not want to venture down the road that motivated them to pursue refractive surgery initially.

Surgical options for treatment of decentered ablations are limited. For mild degrees of decentration following PRK, a small (3 to 4 mm) diameter ablation at the edge of the original optical zone can serve to enlarge the optical zone in the pupillary axis. Another technique involves a series of three small-diameter ablations at the edge of the decentered ablation followed by phototherapeutic keratectomy (PTK) smoothing. A risk of this, however, is a hyperopic shift due to the removal of tissue centrally. These two methods are difficult S/P LASIK because the enhancement will be constrained by the size of the original bed. Ablating over the edges of the bed poses a risk for epithelial ingrowth.

Custom-Corneal Ablation Pattern (Custom–CAP) (VISX, CA) received United States Humanitarian Use Device approval for the treatment of decentrations in 2002. Elevation data is obtained using the Humphrey Atlas (Zeis Meditech), and a software program allows simulation of surgeon directed ablations of chosen location, shape, size, and depth, to improve corneal topographic appearance. Although effective, Custom-CAP does not address the refractive error. While most surgeons consider an improvement in best correction and reduction of symptoms a surgical success, many patients are frustrated by the lack of improvement or, in some cases, worsening of uncorrected vision. The use of a placido-based system for elevation data may limit its success.

Wavefront-driven custom treatment may be used to correct decentrations, assuming the technology currently available is able to detect the irregularities reliably. Hartman-Schack aberrometers may fail when attempting to measure eyes with considerable irregularity, due to limitations of the lenslet array. While decentrations may increase higher order aberrations, attempting to correct the aberrations may not fully correct the topographical errors. These systems assume a normal prolate cornea in treatment planning, and the refractive error corrections may be less accurate. Thus, these treatments may be less effective than topographically-directed
Retreatment using conventional enhancement techniques rarely fully corrects the problem, and typically increases the effective decentration. This occurs because the neural axes (visual axis and line of sight) and the optical axis (geometrical) are not aligned in cases of decentration. Image placement on the fovea requires the eye to rotate, making full correction of the optical problem unlikely when all measurement and planning occurs on the visual axis. Conventional technology is not able to decouple these axes, and treats solely on the visual axis information.

The advancement of Scheimpflug imaging to create three dimensional models of corneal shape may be the missing link to accurate topographically-driven treatments. These systems measure the corneal shape directly and with greater accuracy than placido or slit scanning methods. Combining precise topographical measurements with sophisticated software programs, such as the Corneal Integrated Planning and Treatment Algorithm (CIPTA) (Ligi, Taranto, Italy) software, may enable treatment of irregular astigmatism. CIPTA incorporates dynamic pupillometry, topography, a scanning laser, and sophisticated software for surgical planning to correct for irregularities and improve corneal asphericity. It determines the location of the morphological axis, and treats based on this rather than the visual axis. It can incorporate the manifest refraction in planning in addition to regularizing the cornea to restore visual quality.

NEWER INVESTIGATIONS

FOURIER DOMAIN OCT FOR POST LASIK STROMAL INFLAMMATION ASSESSMENT

Optical coherence tomography is a newer diagnostic imaging technique with wide range of clinical applications. Recently anterior segment OCT has been used for the clinical evaluation and progression analysis for corneal stromal infections. Anterior segment OCT that has been used routinely for corneal evaluation uses high speed infrared light of wavelength 1310 nm is a time domain (TD) OCT. Fourier domain OCT (RTvue, Optovue, Fremont, CA) can be used for evaluation of the anterior stromal opacities. Images were taken on day of presentation of clinical symptoms in post LASIK inflammation. Serial follow up images are taken with OCT(Fig 14).
Figure 14: Comparison of Frequency domain OCT of cornea in post lasik inflammation quantification at day 1 (D1) and 2 weeks (D14).

<table>
<thead>
<tr>
<th><strong>FD OCT VS TDOCT</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>FD OCT has higher axial (5 vs 18 microns) and transverse (15 vs 60 microns) resolution than TD OCT. The acquisition time is lesser than TD OCT. Number of scans taken by FD OCT is 26,000 A-scan/second and TD OCT is 512 scans / 0.25 second and a three dimensional image is possible in FD OCT.</td>
</tr>
</tbody>
</table>