Treatment of Irregular Astigmatism with a Broad Beam Excimer Laser

Kurt A. Buzard, MD, FACS; Bradley R. Fundingsland, BS

ABSTRACT

BACKGROUND: Four basic types of irregular astigmatism are described: central elevation, central flat area, eccentric elevation, and eccentric flat area.

METHODS: The importance of the Munnerlyn formula is shown for the treatment of irregular astigmatism. A new diagnostic entity is described, the steep/flat ratio, modeled on the inferior/superior ratio described previously in keratoconus. Calculation of the steep/flat ratio is described using the cross sectional view of videokeratography, leading to specific treatments for the four types of irregular astigmatism. Surgical technique using the VISX Star excimer laser for repeated laser in situ keratomileusis (LASIK) is described.

RESULTS: Case studies are given for each of the forms of irregular astigmatism showing improved topographic appearance and indicating treatment parameters. In each case, improvement of both uncorrected and spectacle-corrected visual acuity is demonstrated.

CONCLUSIONS: Irregular astigmatism is an important complication of refractive surgery. Four basic forms of irregular astigmatism can be treated with a broad beam excimer laser. [J Refract Surg 1997;13:624-636]

The subject of irregular astigmatism1-6 and the accompanying decreased vision and complaints following lamellar corneal procedures1,7-10 has become more important as automated lamellar keratoplasty (ALK) and, more recently, excimer laser photorefractive keratectomy (PRK) and laser in situ keratomileusis (LASIK) have increased in use. Little systematic evaluation of the occasional loss of spectacle-corrected visual acuity or quality of vision after refractive surgery is available in the literature2,11-13 and even less has been written on the treatment options for these patients. Many papers on corneal and refractive procedures include the number of patients who experience a loss of spectacle-corrected visual acuity (Table 1). Although this problem is demonstrably significant, little discussion is directed toward specific etiology or resolution of the problem. This paper explores both identification of irregular astigmatism, particularly after lamellar corneal procedures, and treatment options with the excimer laser.

Irregular astigmatism is defined in a variety of ways.3,14,15 A subjective characteristic of irregular astigmatism is the induction of increased glare, induced regular astigmatism which often changes over time, and diminished spectacle-corrected visual acuity.16 If manifest refraction is used in the definition of irregular astigmatism, the identifying factor can be an inability to achieve 20/20 visual acuity with spectacles in an eye which can be improved with a hard or soft contact lens.17,16 If a keratometer is used as the standard, angulation, minification and jumping of the mires might be used.17,19 Despite the usefulness of these definitions, the most helpful, by far, is videokeratography, particularly with respect to treatment of the problem.

Examination of videokeratography of irregular astigmatism reveals a common abnormality: variation of refractive power at or near the visual axis.18,20-24 Even relatively small variations of power can result in debilitating distortion and loss of vision which may be difficult to describe with conventional Snellen testing. Videokeratography provides addi-
Table 1
Loss of Spectacle-corrected Visual Acuity after Refractive Surgery in Selected Studies

<table>
<thead>
<tr>
<th>Surgical Technique</th>
<th>Reference</th>
<th>No. Eyes</th>
<th>Percent of Eyes with Two or More Lines of Spectacle-corrected Visual Acuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epikeratoplasty</td>
<td>Goosey</td>
<td>32</td>
<td>6</td>
</tr>
<tr>
<td>Colin</td>
<td>29</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Radial keratotomy</td>
<td>Waring</td>
<td>793</td>
<td>3</td>
</tr>
<tr>
<td>Deitz</td>
<td>972</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Photorefractive keratectomy</td>
<td>FDA: VISX</td>
<td>521</td>
<td>1</td>
</tr>
<tr>
<td>Automated lamellar keratoplasty</td>
<td>Buzard</td>
<td>107</td>
<td>6</td>
</tr>
<tr>
<td>Lyle</td>
<td>128</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td>152</td>
<td>7</td>
<td></td>
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<tr>
<td>Automated lamellar keratoplasty</td>
<td>Ibrahim</td>
<td>88</td>
<td>14</td>
</tr>
<tr>
<td>Laser in situ keratomileus</td>
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<td>3</td>
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<td>Laser in situ keratomileus</td>
<td>Fiander</td>
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<tr>
<td>Laser in situ keratomileus</td>
<td>Bas</td>
<td>97</td>
<td>13</td>
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Table 2
Buzard Astigmatic LASIK Nomogram

<table>
<thead>
<tr>
<th>Correction (D)</th>
<th>6 mm Zone</th>
<th>3 mm Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 x 6 mm slit (µm)</td>
<td>4 x 6 mm slit (µm)</td>
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<tr>
<td>0.50</td>
<td>2</td>
<td>2</td>
</tr>
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<td>4</td>
<td>4</td>
</tr>
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<tr>
<td>3.00</td>
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</tr>
</tbody>
</table>

All corrections were performed with the VISX Star (Santa Clara, Calif) excimer laser and we include nomograms developed by regression analysis of our patients using the LASIK technique and the VISX Star excimer laser. Significant variation may occur between different brands of lasers and among lasers of the same manufacturer. Therefore, these nomograms should be considered only a general guide and not a specific recommendation for surgery.

Excimer lasers outside the United States are programmable at any ablation zone for myopic, hyperopic, and astigmatic corrections. In the United States, only myopic corrections below -6.00 D are directly programmable on the VISX Star laser. To work around this problem, we utilized the PRK cards provided by the manufacturer for standard myopic corrections and the PTK cards with nomograms to correct hyperopia and astigmatism. The three nomograms are for astigmatism at 3.0 and 6.0 mm ablation zones, hyperopia, and myopia primarily for the correction of central elevations at a 2.0 mm ablation zone (Tables 2, 3, 4).

Surgical Planning
The treatment of the cornea with non-standard ablation zones requires referral to the Munnerlyn formula, in which the resection depth is equal to the dioptic correction, divided by 3, and multiplied by the ablation zone (mm) squared.

For a 3 mm ablation zone, a 3 D correction will require a 9 µm resection. One nice thing about a corneal flap is that it blends edges of the ablation and nonstandard resections. As an additional planning paradigm, we defined a steep/flat ratio, analogous to the inferior/superior ratio used in keratoconus. This steep/flat ratio is a definition of the power difference across the 5.0 mm diameter zone. Usually, this number can be easily obtained from the
Treatment of Irregular Astigmatism with the Excimer Laser/Buzard and Fundingsland

Figure 1: Case #1 - Central Elevation, A) Map of a central island that developed 1 day after a LASIK procedure. B) Map of an increasing central island 10 days after the procedure with a loss of central vision. C) Map of a further developing central island 3 weeks after the initial procedure with near total loss of central vision. D) Map 1 day after treating the eye with a small, central laser ablation.

Table 3
Buzard Myopia Nomogram

<table>
<thead>
<tr>
<th>Intended Correction (D)</th>
<th>Depth of Ablation (pm)</th>
</tr>
</thead>
<tbody>
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<td>3</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
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<td>3</td>
<td>9</td>
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</table>

Table 4
Buzard Hyperopia Nomogram

<table>
<thead>
<tr>
<th>Intended Correction (D)</th>
<th>Depth of Ablation (pm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>4</td>
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<td>1.00</td>
<td>8</td>
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<tr>
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<td>20</td>
</tr>
<tr>
<td>3.00</td>
<td>24</td>
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</tbody>
</table>

RESULTS

Central Elevation

For most central elevations, we used either a 3 mm ablation zone with a 0.50 mm transition or a straight 2.5 mm ablation zone, depending on the size of the island being corrected. The attempted
Treatment of Irregular Astigmatism with the Excimer Laser/Buzard and Fundingsland

correction depends on the steep/flat ratio, since the goal is an even refractive power across the ablation zone. In general, the correction chosen is 1.5 times the elevation seen on the cross sectional view of the topography. Refraction is often an unreliable measure of a central elevation since the spectacle-corrected visual acuity is decreased and the patient may be easily overcorrected. Additionally, the patient may simply have an undercorrection as a component of the problem which should be corrected with a full ablation zone in addition to the central elevation problem. In either case, the correction should rely primarily on the topography.

Case #1. A 46 year-old female had high myopia and amblyopia in the left eye. LASIK was performed in the left eye. One day after the procedure, a central island started to develop (Fig 6A) Ten days after the procedure, the manifest spherical equivalent refraction was -6.75 +1.75 x 87° with a loss of visual acuity (Fig 6B). Three weeks after LASIK, a prominent central island developed to 3.50 D with a loss of visual acuity (Fig 6C). Treatment of the central island consisted of lifting the lamellar flap and treating the bed with a 15 µm deep central ablation with a 3.0 mm ablation zone and a 0.7 mm transition zone. One day after this treatment, the central island was eliminated, leaving a manifest spherical equivalent refraction of -1.75 +2.00 x 118° at last follow-up (Fig 6D).

Case #2. A 37 year-old white male was referred with a history of two ALK procedures performed by another surgeon, and an undercorrected LASIK. Evaluation revealed moderate myopia (-4.00 +2.50 x 122°, 20/30 visual acuity) and topography that revealed central astigmatism (Fig 7A). The steep/flat ratio was approximately 3.00 D (Fig 7B). Treatment consisted of a 3 mm ablation zone with the following parameters: 5 µm with a full circle, 4 µm with a 2 x 3 mm slit axis at 25°, and 4 µm with a 1 x 3 mm slit axis at 25°. Note the reduction of the central island and the 3 mm astigmatic correction seen on the difference plot (Fig 7A). The uncorrected visual acuity was 20/25 the next day with manifest spherical equivalent refraction of -1.00 +0.75 x 112°, 20/20 visual acuity, and keratometry of 36.75 x 37.25 D at 114°.

Case #3. A 45 year-old white female had a history of high myopia (-9.00 +0.25 x 150° in the right eye) and underwent ALK in this eye at 1 year prior to repair of diminished spectacle-corrected visual acuity. Examination revealed an astigmatic central island of 2.50 D, resulting in glare and decreased spectacle-corrected visual acuity. An astigmatic central island correction was performed with a dramatic improvement. The treatment consisted of 3 µm at a 3 mm ablation zone, 4 µm at a 1 mm wide x 3 mm long slit, and 4 µm at a 2 mm wide x 3 mm long slit, both at an axis of 180°. Manifest spherical equivalent refraction improved from -2.25 +3.50 x 89° to
**Figure 3**: Case #3 - Central Elevation. A) Subtraction plot of treatment of a central elevation with a small central ablation. B) Profile map of the central elevation or central island.

**Figure 4**: Case #4 - Small Resections for Hyperopia. Subtraction plot of the treatment of a hyperopic eye with a large ablation over a centrally placed small, occluding contact lens. The map in the upper left is the preoperative plot, the map in the upper right is the 2 month postoperative plot, and the map at the bottom is the difference plot induced by the surgery.
Small Resections for Hyperopia

For hyperopic corrections, the strategy is to increase the optical zone and/or flatten the peripheral curvature. We accomplished this peripheral flattening by performing a laser ablation over a small contact lens that functioned as a central occluding device. If the contact lens is made too small, a central elevation will occur, resulting in decreased spectacle-corrected visual acuity. Alternatively, if the lens is made too large, little additional tissue will be removed from the periphery, resulting in little correction. As a reasonable compromise, we found a 3.5 mm contact lens to be satisfactory with a 6 mm ablation zone. An AcuVue soft contact lens (Johnson & Johnson, Jacksonville, Fla) was trephined on a teflon block with a 3.5 mm trephine. The resulting contact lens fragment was handled only with toothless forceps and was placed and centered on the previous resection. The contact allowed the patient to see the laser fixation light quite well and the laser resection was usually easily accomplished with the precaution that the edges of the contact lens fragment should be dried with a micro sponge. Once the laser ablation was completed, the contact lens was picked up and discarded. This left an elevated area with a relatively sharp edge. This area was smoothed with a round blade. This procedure is particularly useful for overcorrected lamellar procedures and for extending the size of the optical zone in the context of overcorrection or plan0 refractions.

Case #4. A 30 year-old white female had a history of myopia with significant anisometropia (-5.25 D sphere right eye and -1.75 D sphere left eye). She underwent ALK in her right eye with an overcorrection and a small optical zone. After 1 month the spherical equivalent refraction was +1.00 +0.75 x 165°, 20/25 visual acuity with a steep/flat ratio of 3.00 D. The correction in this case must both enlarge the optical zone and correct hyperopia. To solve this problem, we must spare the central optical zone and by means of an enlargement of the optical zone, improve corrected visual acuity and reduce the correction. This contact lens was centered over the previous resection and a 6 mm ablation zone with a 15 µm resection was performed. The postoperative topography is shown along with a difference plot.
Treatment of Irregular Astigmatism with the Excimer Laser/Buzard and Fundingsland

(Fig 9). The uncorrected visual acuity 1 day after surgery was 20/25. Two months after surgery, visual acuity was 20/20 with a plano refraction.

Case #5. A 44 year-old white female with a history of myopia (-5.50 +0.50 x 5° right eye and -5.50 +0.50 x 165° left eye) had undergone radial keratotomy and experienced an under-correction. Two years later, LASIK for myopia was performed. Two months after LASIK, the spherical equivalent refraction was +1.25 +0.50 x 8° and 20/30 uncorrected visual acuity in her left eye. Utilizing a 3.5 mm soft contact lens as a blocking agent in the central portion of the cornea, the laser was used to create a circular groove with an outer diameter of 6 mm and an inner diameter dictated by the contact lens using the therapeutic anode of the excimer laser. With an 18 µm depth, the patient initially obtained approximately a -2.75 D myopic correction that resulted in satisfactory monovision without induced astigmatism, glare, or diminished spectacle-corrected visual acuity. Over the next month, the correction regressed by approximately 1.00 D, resulting in an uncorrected visual acuity of 20/20 with a spherical equivalent refraction of -0.50 +0.75 x 3°, which remained stable over 3 months with a wide optical zone (Fig 11). When questioned, she found her vision after the hyperopic correction to be about the same as her preoperative vision with the aid of a contact lens.

Eccentric Flat Area

While less intuitive than the previous treatments, an eccentric flat area accounts for a large number of the cases of irregular astigmatism, particularly after ALK with the typical nasal depression caused by the microkeratome. In addition, this technique is also useful for any refractive procedure with decentration, including incisional procedures. Again, the steep/flat ratio, as determined on cross sectional topography, dictates treatment. In the usual treatment, the abnormal steep/flat ratio is balanced with an equal correction 180° away from the eccentric flat area, usually with a 3 mm ablation zone and 0.5 mm transition zone, with the actual correction guided by
the Munnerlyn formula. If the eccentric flat area is irregular, it may require two or more separate corrections. Additionally, a hyperopic or plano spherical equivalent may require a hyperopic correction which may be applied in an eccentric manner and may require more than one treatment session.

**Case #7.** A 32 year-old female with a history of high myopia of -8.00 -2.00 x 82° with 20/20 visual acuity underwent ALK 2 years prior to LASIK with a decentered flat area in the upper left quadrant. On follow-up her uncorrected visual acuity was 20/100 with decreased spectacle-corrected visual acuity and a flat/steep ratio of 2.50 D (Figs 12A,B). To improve vision in her left eye, two LASIK procedures were performed. The first treatment was a 15 µm spot with a 3.0 mm ablation zone and a 0.5 mm transition zone placed superotemporally, resulting in the topography shown in Figure 12C. The second treatment consisted of a 10 µm spot with a 3.0 mm ablation zone placed laterally. Postoperative improvement was observed with an uncorrected visual acuity of 20/20 and improvement in quality of vision, manifest refraction of +0.25 D sphere (Fig 12D). Again, note the induction of steep meridian regular astigmatism 90° away from the meridian of decentration.

**Case #8.** A 32 year-old white male physician had a 32-incision radial keratotomy approximately 8 years prior to evaluation. The patient noted decreased corrected visual acuity with glare and distorted vision. Evaluation of the corneal topography revealed both regular and irregular astigmatism with a well-centered incision pattern, but increased flattening inferiorly-perhaps due to asymmetric wound healing in the inferior portion of the cornea. Of particular interest was the presence in the manifest spherical equivalent refraction of 4.00 D of astigmatism at 166°, despite the absence of a true astigmatic “bow tie” on the topography (Fig 13). The appearance of astigmatism, steep meridian 90° from the meridian of decentration with decreased spectacle-corrected visual acuity is typical in eyes with eccentric flattening. Discussion centered on the importance of recentration of the optical zone by means of an eccentrically placed LASIK ablation. Using a 9 µm ablation with a 3.0 mm ablation zone and a 0.5 mm transition zone placed superiorly, the patient experienced an improvement in spectacle-corrected visual acuity, decreased glare, an overall improvement in the quality of vision, and an uncorrected visual acuity of 20/25 and manifest spherical equivalent refraction of -1.00 +1.25 x 149°.

**Case #9.** 46 year-old white male with a history of myopia corrected with ALK in the left eye had a preoperative spherical equivalent refraction of -13.75 +2.75 x 90°. After surgery, the spherical equivalent refraction was plano +1.50 x 100° but spectacle-corrected visual acuity was 20/150 because of significant irregular astigmatism. Examination of Figure 14 shows a significant steep/flat ratio of approximately 5.00 D and a 3 mm optical zone, causing the diminished visual acuity. The case was additionally complicated by a slight amount of hyperopia. In the first of two stages, a hyperopic correction was performed with a 3.5 mm contact lens decentered nasally to protect the area of excessive flattening and a 10 µm ablation with a 6 mm optical zone, resulting in an improved spectacle-corrected visual acuity of 20/30 with -3.25 +3.25 x 90° and uncorrected visual acuity of 20/50 (Fig 14A). The patient was now nearsighted and the steep/flat ratio was reduced to 3.00 D at a 3 mm optical zone. A second procedure was then performed with a 3 mm ablation zone and a 0.5 mm transition zone centered temporally with a 9 µm resection. Postoperatively, the patient achieved...
Treatment of Irregular Astigmatism with the Excimer Laser/Buzard and Fundingsland

Figure 9: Case #9 - Eccentric Flat Area. A) Subtraction map of an eccentric flattening after ALK treated with a 10 µm large ablation with a 3.5 mm occluding contact lens placed nasally. The map in the upper left is the preoperative plot, the map in the upper right is the postoperative plot, and the map at the bottom is the difference plot induced by the surgery. B) Subtraction map of this eye treated a second time with a nasally placed ablation. The map in the upper left is the preoperative plot, the map in the upper right is the postoperative plot, and the map at the bottom is the difference plot induced by the surgery.

20/25 uncorrected visual acuity, 20/20 spectacle-corrected visual acuity, and a refraction of +0.25 D sphere (Fig 14B).

Case #10. A 41 year-old white male had undergone LASIK for correction of -6.00 +3.25 x 80° approximately 4 months prior to consideration for repair of irregular astigmatism. Despite the appearance of good centration in the period immediately following the LASIK procedure, subsequent healing resulted in an irregular topographic pattern (Fig 15). The patient complained of poor vision: uncorrected visual acuity was 20/100 with a loss of spectacle-corrected visual acuity to 20/40 and a spherical equivalent refraction of -1.75 +2.50 x 91°, with the steep astigmatic meridian 90° away from the apparent meridian of decen-

Eccentric Elevation

Eccentric elevations, as in keratoconus, present an interesting problem because keratoconus is often a progressive refractive disorder. In many cases, the keratoconus is a forme fruste variety with relatively little progression, particularly if the patient is above age 40. In these cases, we counsel the patient care-
fully with respect to treatment options and include the possibility of potential future corneal transplantation. With eccentric elevations, the topography is again examined on the cross sectional view for the steep/flat ratio and the eccentric region is removed to provide a constant refractive surface to complete the correction. Usually a 3 mm ablation zone is used with a 0.5 mm transition utilizing the Munnerlyn formula as a general guide for correction. Usually an additional astigmatic correction is required to complete the correction which may be estimated by examining the superior cornea relative to the section 90° away. For nipple cones, the correction is usually applied without regard to the central elevation and repaired secondarily if a central elevation develops. The situation changes if the central elevation is particularly small (less than 3 mm) and/or presents an elevation of more than 3.00 D.

Case #11. A 43 year-old male with a long history of gas permeable contact lens wear was found on topographic examination to have keratoconus. Baseline keratometry values in the left eye were approximately 46.50 D with a spherical equivalent refraction of -6.75 +3.50 x 75° and 20/30 spectacle-corrected visual acuity. A discussion with the patient included the implications of keratoconus as it relates to corneal refractive surgery and despite the patient’s statement-supported by medical records-that no change had occurred in glasses or contact lenses over the past 5 years, the results of corneal refractive surgery were likely to be unpredictable and unstable in his particular situation. Despite this discussion, the patient elected to proceed with LASIK in both eyes. A decision was made to program the initial refraction for the ablation parameters without regard to the inferior steepening, since the average keratometry was not excessively high. Postoperatively, the patient developed 20/70 uncorrected visual acuity with glare and visual distortion. Examination of topography (Fig 16A) revealed continued inferior steepening and residual astigmatism which led to a second procedure with an additional eccentric treatment over the apex of the cone with a 3 mm ablation zone at a 10 µm depth to resolve the original astigmatism. Postoperatively, the patient experienced an uncorrected visual acuity of 20/20, a spherical equivalent refraction of -1.00 -1.50 x 56° and some residual astigmatism which decreased over a follow-up period of approximately 5 months (Fig 16B).

Case #12. A 48 year-old white female had a history of severe keratoconus. She had a spherical equivalent refraction of -6.75 +2.50 x 33° with a spectacle-corrected visual acuity of 20/20 and she expressed an interest in achieving better uncorrected visual acuity. Corneal topography showed a central nipple cone with moderate keratometric steepening of 48.12/45.37 D (Fig 12). She underwent an astigmatic correction with a 2 mm wide by 6 mm long slit far 10 µm and a 4 mm by 6 mm slit for an additional 10 µm. The spherical correction for myopia was -4.10 D. Postoperative uncorrected visual acuity was 20/25.

**DISCUSSION**

Spherical ametropia and regular astigmatism are relatively well defined, based on the technology required to create spectacle lenses; irregular astigmatism represents an area of imperfect definition and even poorer treatment options. Irregular astig-
Irregular astigmatism is considered undesirable but the specific disability and tests to objectively measure disability related to irregular astigmatism remain to be described.

Diminished spectacle-corrected visual acuity is certainly an imperfect measure of irregular astigmatism, partly because vision may be diminished by so many other factors than the cornea and because loss of spectacle-corrected visual acuity does not adequately describe the disability induced by this disorder. Inadequate as the measure is, decreased spectacle-corrected visual acuity is a significant issue in a range of ophthalmic, particularly corneal procedures (Table 1).

The excimer laser allows corneal resections in both diameter and depth, and central and eccentric locations. This ability-coupled with modern corneal curvature and topographic maps-allows for relatively sophisticated smoothing of an irregular corneal surface.

The techniques required to correct irregular astigmatism build on the lamellar refractive surgery techniques used in keratomileusis[^36][^37] and most recently laser refractive keratectomy.[^36][^38] Issues involved in the correction of postoperative irregular astigmatism will be a decision to place the correction on the surface or beneath a flap, whether to lift a pre-existing flap or to re-cut the flap, and...
Treatment of Irregular Astigmatism with the Excimer Laser/Buzard and Fundingsland

what the contribution of potentially unstable previous operations might be on the refractive result. In general, all refractive procedures should be performed on stable refractive errors and this applies equally to irregular refractive errors.

Should the refractive problem show evidence of progressive change, consideration should be given to waiting until the condition stabilizes or to extensive discussion with the patient concerning the advisability of performing lamellar refractive surgery.

It is our intention to provide a coordinated system of classifying irregular astigmatism based on topographical maps and realistic treatment options available with the excimer laser. We think that many instances of irregular astigmatism can be broken into one or more of the four categories and subsequently treated in a systematic fashion. Yet, in many cases, the precise spherical or regular astigmatic component remaining after resolution of an irregular surface may be difficult, or impossible, to predict and many of these corrections will require more than a single treatment to reach a satisfactory conclusion.

Although central islands may resolve over time, it is our experience that they may change, but rarely go away completely and in fact may worsen, as in Case #1. Frequently, the central elevation will have astigmatic characteristics and as Case #2 demonstrates, astigmatic corrections may be successfully applied at any optical zone, with the approximate nomogram for a 3 mm optical zone, 3 mm per diopter split between a 1 x 3 mm and 2 x 3 mm slit correction.

With hyperopic corrections, a circular trough surrounding an acceptable size central optical zone effectively creates a central elevation. Enlargement of the optical zone is not common with well centered refractive procedures, but when required (Case #4) the procedure functions well. Even mild to moderate decentration provides the opportunity to change positioning of the optical zone without overcorrecting the patient.

The most interesting technique described is the treatment of flat areas. Eccentric flat areas are common in lamellar techniques and even a relatively small abnormality seems to cause decreased corrected visual acuity and patient complaints. This relatively simple procedure affords significant improvements for previously insoluble surgical results.

Finally, the correction of eccentric elevations—particularly in keratoconus—is a new and relatively unexplored area of treatment. As we have shown in the case examples, treating the refraction only results in poor uncorrected visual acuity and residual myopia and astigmatism. Even with mild or form fruste keratoconus, patients can undergo multiple treatments with improvement in uncorrected visual acuity, but often with continued loss of spectacle-corrected visual acuity. For eccentric elevations unrelated to keratoconus, the results are better since an eccentric elevation may also be thought of as an eccentric flat area 180° away.

Irregular astigmatism is a significant and sometimes overlooked problem that results in a variety of symptoms including decreased spectacle-corrected visual acuity, induced regular astigmatism, glare, and visual distortion. In refractive surgery, irregular astigmatism accounts for a small but significant number of patients. We have described a classification system and a series of techniques based on this
classification to resolve irregular astigmatism in a large percentage of patients. Not all patients with irregular astigmatism are candidates for this system of correction, since the irregular astigmatism must represent a stable and unchanging condition. These techniques may be helpful in some unstable refractive conditions, such as unstable corneal wounds, but it is advisable to utilize wound strengthening procedures to create a stable cornea prior to application of these techniques.

REFERENCES