Treatment of Irregular Astigmatism with the Excimer Laser

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Abstract

Introduction
While regular astigmatism has received steady attention in terms of diagnosis and treatment for over 200 years, the diagnosis and treatment of irregular astigmatism has often been shrouded in mystery. Often, the diminished vision associated with irregular astigmatism has been inappropriately attributed to cataracts, macular degeneration and amblyopia. Four basic types of irregular astigmatism are described: central elevation, central depression, eccentric elevation and eccentric depression.

Methods
The importance of the Munnerlyn formula is shown for the treatment of irregular astigmatism. In addition, a new diagnostic entity is described, the S/F (Steep/Flat) ratio, modeled on the I/S (Inferior/Superior) ratio described previously in keratoconus. Calculation of the S/F ratio is described using the cross sectional view of computed corneal topography as are specific treatments for the four types of irregular astigmatism described above. Surgical technique for repeat lamellar surgery is described in detail.

Results
Case studies are given for each of the forms of irregular astigmatism showing improved topographic appearance and treatment parameters. In each case, improvement of both uncorrected and best corrected vision is demonstrated.

Conclusions
Irregular astigmatism is an important complication of both incisional and lamellar refractive surgery. Identification and treatment protocols are described with case studies to correct four basic forms of irregular astigmatism. Both uncorrected and best corrected vision can be improved resulting in enhanced patient and surgeon satisfaction.

Introduction
The subject of irregular astigmatism and the accompanying decreased vision and complaints following lamellar corneal procedures has become of much greater importance as first ALK and, more recently, excimer laser PRK and LASIK, have increased in use. Little systematic evaluation of the occasional loss of best corrected vision or quality of vision has been available in the literature after refractive surgery and even less has been written on the treatment options for these patients. Many, if not most, papers on corneal and refractive procedures include the number of patients who experience a loss of best corrected visual acuity (table 1). Although this problem is demonstrably significant, little discussion is directed toward specific etiology or resolving the problem. This paper will explore both identification of irregular astigmatism, particularly after lamellar corneal procedures, and treatment options with the excimer laser.

Irregular astigmatism may be defined in a variety of ways depending on the modality used in the definition terminology. Certainly a subjective characteristic of irregular astigmatism is the induction of increased glare, induced regular astigmatism which often changes from visit to visit, and diminished best corrected vision. If manifest refraction is used in the definition of irregular astigmatism, the identifying factor can be an inability to achieve 20/20 vision with spectacles in an eye which can be improved with a hard or soft contact lens. If a keratometer is used as the standard, angulation, minification and jumping of the mires might be used. Despite the usefulness of these definitions, the most helpful, by far, is computed corneal topogra-
phy, particularly with respect to repair of the problem.

Examination of the computed corneal topography of irregular astigmatism reveals a common abnormality: variation of refractive power at or near the visual axis. 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. Computed corneal topography provides additional information which, for the first time, allows us to categorize and treat these abnormalities. Examination of the “optical” zones of a myopic and hyperopic LASIK patient (Figure 1a, 1b) with 20/20 uncorrected and best corrected vision shows the desirable characteristics of an “acceptable” correction. While all refractive procedures hold the potential for undesirable side effects, including decreased best corrected visual acuity, glare and distorted vision, acceptable corrections create a large central optical zone, with little variation of power over the central region of the cornea. The minimum size of the optical zone and the least acceptable variation of power over this region are a subject for debate but as a general rule, the optical zone should be at least 4-5 mm and the variation of refractive power over this region of the cornea should be less than 2-3 diopters.

An important concept introduced for use in keratoconus is the I/S ratio (inferior/superior ratio) which quantifies the variation of refractive power over the visual axis. While this definition is useful in keratoconus since steepening usually occurs inferiorly, we may generalize this concept with the F/S ratio (flat/steep ratio) which in an analogous fashion, quantifies the variation of power in any axis or indeed from a central small elevation to the periphery. As we will show later, this concept of the F/S ratio will guide appropriate treatment with the excimer laser. As has been observed by previous authors the size of the true “optical zone” varies from the parameter used in the surgery, for instance in radial keratotomy the size of the optical zone is usually 5-6mm despite a clear central zone of 3mm in a higher myopic correction. If the optical zone is small or variation of power is observed across the optical zone, the patient will have side effects if questioned closely enough and repair might well be considered.

Figure 2(a-d) roughly categorizes these problems as central and eccentric flattening and steepening. These problems are all easily treated as we will demonstrate in this paper through a series of case studies. One of the advantages of the laser lamellar procedures is the lack of coupling. The ability to act specifically on a given region of the cornea without a concomitant change in a region of the cornea 90 or 180 degrees away allows eccentric and central corrections unavailable with incisional techniques. As a downside of the lamellar techniques, the averaging effect provided by the coupling of incisional techniques makes irregular astigmatism much more common in lamellar surgery than incisional surgery. The purpose of this paper will be to describe in detail the treatment and nomograms for the four varieties of irregular astigmatism seen in figure 2(a-d).
Methods

The techniques required to correct irregular astigmatism build on the lamellar techniques used in keratomileusis and most recently laser refractive keratectomy which have been described elsewhere. 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 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.

A previous corneal flap can be easily lifted for the first three months and with more difficulty for up to six months with blunt dissection. The problem revolves about the degree of force required to lift the flap which can distort it, leading to problems resealing the flap and even irregular astigmatism from stretching. If the flap is to be lifted, the edge needs to be loosened. Figure 3(a-c) shows the use of an 18 gauge needle used at the slit lamp to first engage and then laterally displace the edge of the flap. The patient is then taken

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Figure 2a. A videokeratometric plot of a central elevation (central island) following LASIK.

Figure 2b. A videokeratometric plot of a central depression after a metallic foreign body removal.

Figure 2c. A videokeratometric plot of an eccentric elevation eye with keratoconus.

Figure 2d. A videokeratometric plot of an eccentric depression eye following a decentered ALK resection.
to the operating room and marked as if a full flap procedure is anticipated. I use a combination of a 3 and 9 mm optical zones, an 8 incision RK marker and an eccentric mark created with a t-cut marker. The entire cornea is then coated with methylene blue which highlights the marks and the previous edge lift of the flap.

If less than 3 months, the flap can be grasped with a Castroviejo forceps and simply lifted off (figure 3d-f). If any resistance is encountered or if a previous incisional procedure is present, it is wiser to introduce a cyclodyalisis spatula into the interface and with a sweeping motion, dislodge the adhesions of the flap before lifting. A previous RK after for example an ALK can present significant difficulties to lifting the flap with hard adhesions which either refuse to easily break or rip along the RK incision. Either consider recutting the flap with a microkeratome or use a blunt corneal knife to expose the correct interface.

If the flap is to be re-cut, a decision must be made as to proper plate selection. If a thinner plate is chosen, flap perforation may be seen and the thin section between the original cut and the new plane may come away in an irregular fashion. A deeper cut is a better option but may have implications on the nomogram used for the refractive correction, particularly with the scar of the previous resection above the cut. I have found that selecting the same 160 micron plate used on the original lamellar resection yields excellent results, frequently finding the previous plane and exposing the original refractive cut as though it were a fresh resection.

Figure 3a. Lifting of the lamellar flap. Use of an 18 guage needle to engage the lamellar flap edge at the slit lamp.

Figure 3b. Use of an 18 guage needle to lift the edge of the lamellar flap.

Figure 3c. Appearance of lamellar flap edge lift before placing the patient in the surgical suite. Note striae indicating the location of the lifted edge.

Figure 3d. Lifting the edge of the lamellar flap with forceps.

Figure 3e. Lifting the lamellar flap from the stromal bed with forceps.

Figure 3f. Final appearance of lifted lamellar flap before stromal laser ablation.
A previous radial keratotomy presents a particular challenge since the application of the suction ring can stretch poorly healed incisions, causing more correction in a manner similar to the effect we can see after cataract surgery. This problem can also be seen with astigmatic incisions. If topographic evidence of corneal instability is present (breaking of mires over incisions, the microdehiscence or keratopyramis) caution should be exercised in application of a lamellar incision, and as a practical matter, consideration should be given to corrective surgery such as circular or interrupted sutures to correct the instability. As an opposite action, the presence of the lamellar incision creates a large scale activation of corneal keratocytes. This can result in increased corneal wound healing which can resolve both radial and astigmatic overcorrections. This may present yet another means of resolving overcorrections by means of a simple lamellar incision although this method is unpredictable and may take a long period of time to achieve the anticipated result. In my experience, cases with a pre-existing incisional procedure are inherently more unpredictable and surgical planning should be conservative, discussion with the patient should include the distinct possibility of a secondary procedure.

The excimer laser can be applied at two basic locations in the cornea, on the surface and within the cornea. Several problems exist with respect to surface application of the excimer laser. First, application on the surface makes subsequent surface laser resection more difficult due to increased epithelial adherence. In more complex repair situations, the likelihood of secondary procedures increases. Secondarily, the use of the laser involves the risk of haze which increases significantly with previous corneal procedures (figure 4). While the precise incidence of haze with procedures other than RK is not available, it is clear that the possibility of increased haze is present. Additionally, secondary procedures on the surface may increase the possibility of superficial corneal haze. In fact, in our own practice, we now rarely perform surface ablations due to significant postoperative patient discomfort despite a variety of therapeutic maneuvers, the slow visual recovery and the incidence of decreased best corrected visual acuity.

Surgical Planning

The treatment of the cornea with non-standard optical zones requires referral to the Munnerlyn formula in which the resection depth is equal to the dioptric correction, divided by three multiplied by the optical zone (mm) squared.

For a 3 mm optical zone, this implies a 3 diopter correction will require a 9 micron resection. One nice thing about a flap is that it blends edges and nonstandard resections. As an additional necessary planning paradigm, we can define a S/F ratio (Steep/Flat ratio), analogous to the I/S ratio used in keratoconus. Usually, this number can be easily obtained from the cross sectional corneal topography plot. By extending the concept of the I/S ratio to encompass power gradations across any meridian we can begin to understand the mechanics of the disability associated with irregular astigmatism. The usefulness of this power ratio becomes obvious for central islands and will be shown to be just as useful for eccentric elevations and depressions. Moreover, the S/F ratio can give an estimate of the disability associated with the central elevation.

For most central elevations, we either use a 3 mm optical zone with a 0.50 mm transition or a straight
2.5 mm optical zone depending on the size of the island being corrected. The attempted correction depends on the S/F ratio, since the goal is an even refractive power across the optical zone. In general, the correction is chosen as 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 best corrected vision is decreased and the patient may be easily overminused. Additionally, the patient may simply have an undercorrection as a component of the problem which should be corrected with a full optical zone in addition to the central elevation problem. In either case, the correction should rely primarily on the topography. Two additional complications may be introduced into the correction of central elevations, astigmatism and hyperopia. The elevation may take the form of a central astigmatic error and this too can be identified on corneal topography and repaired with an appropriate 3mm astigmatic correction as will be demonstrated in the case reports and in the accompanying nomograms. If a patient presents with a hyperopic or spherical refraction and a central elevation, a hyperopic correction must be performed as well as the central correction as described below.

For hyperopic corrections, the strategy is to increase optical zone and/or deepen the peripheral curvature. If the contact lens is made too small, a central elevation will occur resulting in decreased best 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 have found a 3.5 mm contact lens to be satisfactory with a 6mm ablation zone. An AcuVu soft contact lens is trephined on a teflon block with a 3.5 mm trephine. The resulting contact lens fragment is handled only with toothless forceps. It is placed and centered on the previous resection (figure 5a). The contact allows the patient to see the laser fixation light quite well and the laser resection is usually easily accomplished with the precaution that the edges of the contact lens fragment should be dried with a week sponge. Once the laser ablation is completed, the contact lens is picked up and discarded. This leaves an elevated area with a relatively sharp edge (figure 5b). This area is smoothed with a round grieshaber blade. This procedure is particularly useful for overcorrected lamellar procedures, for extending the size of the optical zone in the context of overcorrection or plano refractions and even as a blocking procedure for eccentric problems and a hyperopic correction as will be demonstrated in a case study.

Eccentric elevations, as in keratoconus, present an interesting problem since keratoconus is often a progressive refractive disorder. In many cases however, 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 carefully with respect to treatment options and include the possibility of potential future corneal transplantation. Obviously, the central “nipple” style cones respond better than the eccentric “oval” cones but both can have acceptable results with lamellar refractive surgery. With the eccentric elevations, the topography is

Figure 5a. Hyperopic correction through the placement of an 3.5mm contact lens occluding the central cornea from laser ablation.

Figure 5b. Appearance of the stroma after removal of the 3.5mm contact lens. Notice the peripheral ablation.
again examined on the cross sectional view for the f/s ratio and the eccentric region is removed to provide a constant refractive surface to complete the correction. Usually a 3mm oz is used with a 0.5mm transition utilizing the Munnerlyn formula as a general guide for correction. Usually an additional astigmatic correction will be required to complete the correction which may be estimated by examining the superior cornea relative to the section 90 degrees away. For the “nipple” cones, the correction is usually applied without regard to the central elevation and repaired secondarily if a central elevation develops. The situation will change if the central elevation is particularly small (less than 3mm) and or presents an elevation of more than 3 diopters. In this case the central elevation is handled as previously described.

The final and perhaps most interesting / useful treatment is described for the eccentric depression. While less intuitive than the previous treatments, eccentric depression 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 f/s ratio as determined on cross sectional topography dictates treatment. As an interesting aside, these patients usually present with a regular astigmatism with an axis 90 degrees from the axis of decentration in an amount approximately equal to the S/F ratio. In the usual treatment, the abnormal S/F ratio is balanced with an equal correction 180 degrees away from the eccentric depression usually with a 3mm optical zone and 0.5mm transition zone with the actual correction guided as before by the Munnerlyn formula. If the eccentric depression is irregular, it may require 2 or more separate corrections as shown in one of the case studies. Additionally, a hyperopic or plano spherical equivalent may require a hyperopic correction which may be applied in an eccentric manner as shown in one of the case studies and may require more than one treatment session. This treatment in particular can be extremely gratifying to the surgeon and patient, resulting in improved best corrected visual acuity and decreased symptoms of glare and distortion.

Nomograms

All corrections described in this paper were performed with the Visx Star excimer laser. As documentation of the methods used for treatment, we include our nomograms which have been developed by regression analysis of our patients using the LASIK technique and the Visx Star excimer laser. It should be noted that significant variation may occur between different brands of lasers and in fact among lasers of the same manufacturer. Therefore, these nomograms should be considered only a general guide and not a specific recommendation for surgery.

Outside of the United States, myopic, hyperopic and astigmatic corrections are programmable at any optical zone. In the United States, only myopic corrections below 6.00 diopters are directly programmable on the Visx Star laser. To work around this problem, we utilize the PRK cards provided by the manufacturer for standard myopic corrections and the PTK cards with the following nomograms to correct hyperopia and astigmatism.

The three nomograms presented here are for astigmatism at a 3.0 and 6.0 mm optical zone, hyperopia and myopia primarily for the correction of central elevations at a 2.5mm optical zone (Tables 2,3,4).
Case Studies

Central Elevations

Case Study #1

The patient is a 46 year-old female high myopia and amblyopia in the left eye. LASIK was performed in the left eye. One day after the procedure a central island starts to develop (Figure 6a). 10 days after the procedure, the manifest refraction was -6.75+1.75 x 87 with a loss of central vision (Figure 6b). 3 weeks after the LASIK a prominent central island has developed to 3.5 diopters with a total loss of central vision (Figure 6c). Treatment of the central island consisted of lifting the lamellar flap and treating the bed with a 15 micron central ablation with a 3.0mm optical zone and a 0.7mm transition zone. One day after this treatment, the central island was eliminated leaving a manifest refraction of -1.75+2.00x 118 at last follow-up (Figure 6d).

Figure 6a. Videokeratometric map of a central island developing one day after a LASIK procedure.

Figure 6b. Videokeratometric map of an increasing central island 10 days after the procedure with a loss of central vision.

Figure 6c. Videokeratometric map of a further developing central island 3 weeks after the initial procedure with near total loss of central vision.

Figure 6d. Videokeratometric map 1 day after treating the eye with a small, central laser ablation.
Case Study #2

The patient is a 37 year-old white male s/p ALK OS in 3/95 with a repeat ALK 6/95 seen in referral for a poor result. On admission his refraction was -3.25+1.75x105 giving 20/30 vision. One year later the patient underwent LASIK for the correction of the central elevation. Pre-op evaluation revealed slightly more myopia (-4.00+2.50x122 giving 20/30 vision) and the topography (Figure 7a). F/S ratio was approximately 3 diopters (Figure 7b). Note the central astigmatism, complicating the case.

The treatment consisted of a 3mm optical zone with the following parameters, 5 microns with a full circle, 4 microns with a 2x3 mm slit axis 25 degrees and 4 microns with a 1x3 mm slit axis 25 degrees. Note the reduction of the central island and the 3 mm astigmatic correction seen on the difference plot (Figure 7a). The uncorrected vision was 20/25 the next day with refraction -1.00+0.75x 112 giving 20/20 vision and keratometry of 36.75 x 37.25 at 114.

Figure 7a. Videokeratometric subtraction plot of treatment of a central elevation with a small central ablation. In the subtraction plot, 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.

Figure 7b. Videokeratometric profile map of the central elevation / central island.
Case Study #3

The patient is a 45 year-old white female with a history of high myopia -9.00+0.25x150 in the right eye who underwent an ALK in this eye at one year prior to repair of diminished best corrected visual acuity. As examination revealed an astigmatic central island of 2.5 diopters resulting in glare, decreased best corrected visual acuity, and in the patient’s own words, her vision “is terrible”. An astigmatic central island correction was performed with a dramatic improvement. The treatment consisted of 3 microns at a 3mm optical zone, 4 microns at a 1mm wide by 3mm long slit and 4 microns at a 2mm wide by 3mm long slit both at an axis of 180 degrees. Manifest refraction improved from -2.25+3.50x89 to -0.75+0.25x37. Uncorrected vision improved from 20/100 to 20/30 and best corrected vision improved from 20/40 to 20/20 (Figure 8a,b). While the numbers used to describe the visual disability of this patient do not seem to represent a dramatic difference, the patient went from the danger of losing her job due to poor vision to being overjoyed with her uncorrected vision.

Figure 8a. Videokeratometric subtraction plot of treatment of a central elevation with a small central ablation.

Figure 8b. Videokeratometric profile map of the central elevation / central island.
Small Resections (Hyperopia)

Case Study #4

The patient is a 30 year-old white female with a history of myopia with significant anisometropia (-5.25 sph OD and -1.75 sph OS). She underwent ALK OD with an overcorrection and a small optical zone. After one month the refraction was +1.00+0.75x165 giving 20/25- vision with a F/S ratio of 3 diopters. The correction in this case must both enlarge the optical zone and correct hyperopia. To solve this difficult problem, we must spare the central optical zone and by means of an enlargement of the optical zone, improve best corrected vision and reduce the correction. A 3.5 mm soft contact lens was prepared using a soft contact and a 3.5 mm corneal trephine. This contact lens was centered over the previous resection and a 6 mm OZ with 15 micron resection was performed. The postoperative topography is shown along with a difference plot (Figure 9). The uncorrected vision one day postoperatively was 20/25. Two months postoperatively, the vision was 20/20 with a plano refraction.

Figure 9. Videokeratometric subtraction plot of the treatment of a hyperopic eye with a large ablation over a centrally placed small, occluding contact lens.
Case Study #5

The patient is a 44 year-old white female with a history of myopia (-5.50+0.50x05 OD and -5.50+0.50x165 OS) who underwent RK 2 years prior to evaluation. Over time the initial correction regressed, requiring intervention. The preop refraction was -1.50 sph OD giving 20/20 vision. The patient underwent LASIK with an overcorrection. At 2 months after the LASIK, the refraction was +1.25+0.75x14 giving 20/20 vision. Examination of the topography shows a very distinct central flattening with a 4 diopter f/s ratio, and a hyperopic correction was planned with LASIK. A central 3.5 mm soft contact lens was placed centrally and a 10 micron resection was performed with a 6mm optical zone. Two months postoperatively the uncorrected vision was 20/20 with a refraction of -0.25+0.50x42 giving 20/20 vision (Figure 10).

Figure 10. Videokeratometric subtraction plot of the treatment of a hyperopic eye with a large ablation over a centrally placed small, occluding contact lens.
Case Study #6

The patient is a 51 year-old white female with hyperopia at a manifest refraction of +1.25+0.50x08 and 20/30 uncorrected vision in the left eye. The patient had recently worn a soft contact lens in the right eye and wished to convert the contact lens wear with refractive surgery into a permanent condition. Utilizing a 3.5mm 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 6mm and an inner diameter dictated by the contact lens using the therapeutic anode of the excimer laser. With an 18 micron depth, the patient initially obtained approximately a 2.75 diopter myopic correction resulting in satisfactory monovision without induced astigmatism, glare or diminished best corrected vision. Over the next month, the correction regressed approximately one diopter resulting in uncorrected visual acuity of 20/20 with a refraction of -0.50+0.75x03 which has remained stable over a three month period with a wide optical zone as shown in the final topography (Figure 11). When questioned she found the vision after the hyperopic correction to be about the same as the vision induced by the contact lens.

Figure 11. Videokeratometric postoperative map of an eye treated for hyperopia. Note the wide optical zone.
Case Study #7

The patient was a 32 year-old female with a history of high myopia of -8.00+2.00x82 giving 20/20 vision who underwent ALK 2 years prior to the LASIK with a decentered optical zone in the top left quadrant. On follow-up her uncorrected acuity was 20/100 with decreased best corrected visual acuity with a flat steep ratio of 2.5 diopters (Figure 12 a,b). To improve vision in the left eye, two LASIK procedures were performed. The first treatment was a 15 micron spot with a 3.0mm optical zone and a 0.5mm transition zone placed superior temporally resulting in the topography shown in figure 12c. The second treatment consisted of a 10 micron spot with a 3.0mm optical zone placed laterally. Dramatic improvement was observed with an uncorrected vision of 20/20 and improvement in quality of vision to a manifest refraction of +0.25 sphere (figure 12d). Again, note the induction of steep axis regular astigmatism 90 degrees away from the axis of decenteration.

Figure 12a. Photokeratometric photograph of an eye with a decentered ALK resection.

Figure 12b. Videokeratometric map of an eye with a decentered ALK resection.

Figure 12c. Videokeratometric map of the eye after a fifteen micron ablation was placed superior temporally.

Figure 12d. Videokeratometric map of the eye after an additional ten micron ablation was placed laterally.
Case Study #8

The patient is a 32 year-old white male physician status post 32 incisions radial keratotomy approximately 8 years prior to evaluation. The patient noted decreased best corrected visual acuity with glare and distorted vision. Evaluation of the corneal topography revealed both regular and irregular astigmatism with well-centered incision pattern, but increased flattening effect inferiorly perhaps due to asymmetric wound healing in the inferior portion of the cornea. Of particular interest was the presence in the manifest refraction of four diopters of astigmatism at 166 despite the absence of a true astigmatic “bowtie” on the topography (Figure 13). The appearance of astigmatism, steep axis 90 degrees from the axis of decentration with decreased best corrected visual acuity is typical of these cases of eccentric flattening. Discussion centered on the importance of recentration of the optical zone by means of an eccentrically placed LASIK. Using a 9 micron ablation with a 3.0mm optical zone and a 0.5mm transition zone placed superiorly, the patient experienced an improvement in best corrected vision, decreased glare, an overall improvement in the quality of vision and an uncorrected vision of 20/25 and a manifest refraction of -1.00+1.25x149.

Figure 13. Videokeratometric subtraction map of an eccentric flattening treated with a nine micron ablation placed superiorly.
Case Study #9

The patient is a 46 year-old white male with a history of myopia corrected with ALK in the left eye with a preoperative refraction of -13.75+2.75x90. Postoperatively, the result was good by refraction (plano+1.50x100) but best corrected vision was 20/50 as a result of significant irregular astigmatism. Examination of figure 14a shows a significant S/F ratio of approximately 5 diopters at a 3 mm OZ leading to the diminished vision. The case is additionally complicated by a slight degree of hyperopia. This case was performed in two stages. First, a hyperopic correction was performed with a 3.5 mm contact lens decentered nasally to protect the area of excessive flattening and a 10 micron ablation with a 6mm OZ. Postoperatively, the best corrected vision improved to 20/30 with -3.25+3.25x90 and uncorrected vision of 20/50 (Figure 14a). The essential difference is that the patient was now nearsighted and the F/S ratio has been reduced to 3 diopters at a 3 mm OZ. A secondary procedure was then performed with a 3mm oz and a 0.5 mm transition centered temporally with a 9 micron resection. Postoperatively the patient did extremely well, with a 20/25 uncorrected vision, 20/20 best corrected vision and a refraction of +0.25 sphere with the topography shown in figure 14b.

Figure 14a. Videokeratometric subtraction map of an eccentric flattening after ALK treated with a 10 micron large ablation with a 3.5mm occluding contact lens placed nasally.

Figure 14b. Videokeratometric subtraction map of this eye treated a second time with a nasally placed ablation.
Case Study #10

The patient is a 41 year-old white male who underwent a LASIK correction for a correction of -6.00+3.25x80 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 (Figure 15). Again, the patient reported poor vision, uncorrected 20/100 vision with a loss of best corrected visual acuity to 20/40, a refraction of -1.75+2.50x91 and the characteristic steep astigmatic axis 90 degrees away from the apparent axis of decenteration. With the application of a 9 micron, 3mm spot temporally, the patient experienced a dramatic improvement in both uncorrected and best corrected vision to 20/20 and a refraction of -0.25 sphere (Figure 15). Subsequent follow-up has shown this correction to be stable over a period of three months.

Figure 15. Videokeratometric subtraction map of an eccentric depression treated with a temporally placed ablation.
Eccentric Elevations:

Case Study 11

The patient is a 43 year-old male with a long history of gas permeable lens wear who was found on topographic testing of the eye to have keratoconus. Keratometry values preoperatively in the left eye were approximately 46.5 with a refraction of -6.75+3.50x75 giving 20/30 best corrected vision. A careful discussion with the patient examined the presence and implications of keratoconus as that diagnosis relates to corneal refractive surgery and despite the patient’s statement supported by past 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 surgery in both eyes. A decision was made to simply 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 was developed 20/70 uncorrected visual acuity with glare and visual distortion. Examination of topography (figure 16a) revealed continued inferior steepening and residual astigmatism which led to a secondary treatment with an additional eccentric treatment over the apex of the cone with a 3 mm optical zone at a 10 micron depth to resolve the original astigmatism. Postoperatively, the patient did reasonably well with uncorrected vision of 20/30, a refraction of -1.00+1.50x56 and some residual astigmatism which seems to be decreasing over a follow-up period of approximately 5 months (Figure 16b).

Figure 16a. Videokeratometric subtraction map of an eccentric elevation treated with a spherical and toric refractive ablation.

Figure 16b. Videokeratometric subtraction map of this eye further treated with an inferonasally placed ablation.
Case Study #12

The patient is a 48 year-old white female with a history of severe keratoconus. The patient had a refraction of -6.75+2.50x33 with a best corrected vision of 20/20. The patient expressed an interest in achieving better uncorrected visual acuity which had a significant myopia. The corneal topography showed a central nipple cone with moderate keratometric steepening of 48.12/45.37 (Figure 17). She underwent an astigmatic correction with a 2mm wide by a 6mm long slit for 10 microns and a 4mm by 6mm slit for an additional 10 microns. The spherical correction for myopia was -4.1 diopters. The outcome was good with an uncorrected visual acuity of 20/25.

Figure 17. Videokeratometric subtraction map of an eccentric elevation treated with a spherical and a toric ablation.
SUMMARY

While the definitions of spherical aemmetropias and regular astigmatism are relatively well-defined and centered on the technology required to create spectacle lenses, irregular astigmatism represents an area of imperfect definition and even poorer treatment options. While irregular astigmatism is universally considered to be undesirable, the specific disability and tests to objectively measure disability related to irregular astigmatism remain to be described. Diminished best 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 in our opinions, the simple loss of best corrected visual acuity does not adequately describe the disability induced by this disorder. Inadequate as the measure is, decreased best corrected visual acuity is a significant issue in a range of ophthalmic, particularly corneal, procedures as shown in table 1. In many ways, the irregular astigmatism has been the limiting factor to popular acceptance of lamellar procedures before the advent of the excimer laser. Freeze keratomileusis procedures often suffered from diminished best corrected visual acuity for six months or more and even the non-freeze ALK procedure had a significant number of patients with a two line loss of best corrected visual acuity. The advent of the excimer laser allows for the first time corneal resections in both diameter and depth in both central and eccentric locations. This ability coupled with modern computed corneal curvature and elevation maps allows for relatively sophisticated smoothing of an irregular corneal surface. While one might imagine even more sophisticated combinations of topography directly linked to scanning ultraviolet lasers, the current technology allows us to classify and correct a large number of patients who were otherwise not amenable to treatment.

The inclusion in this paper of a relatively large number of disparate topics is not accidental. It is our intention to provide a coordinated system of classification of irregular astigmatism based upon topographical maps and realistic treatment options available today with the excimer laser. It is our belief that many, if not most, instances of irregular astigmatism can be broken into one or more of the categories and subsequently treated in a systematic fashion. The inclusion of techniques and nomograms for myopia, hyperopia and astigmatism based on the VISX Star excimer laser are intentional and necessary based on the necessity, on occasion, to correct an undesirable elevation while avoiding a hyperopic overcorrection. (Chalice) The case study is a good example of this problem and the use of a blocking contact lens in the nasal aspect of the cornea, while redistributing the optical zone, more temporally, induced a small degree of myopia, which could then be utilized to finish the correction. In many cases, the precise spherical or regular astigmatic component left 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.

A few comments are appropriate regarding the case studies for each type of irregular astigmatism are appropriate. Although it is often said that central islands may resolve over time, it is our experience that white they may change, they rarely go away completely and in fact may worsen as in the first case study. Frequently, the central elevation will have astigmatic characteristics and as the next case study demonstrates, astigmatic corrections may be successfully applied at any optical zone, with the approximate nomogram for a 3mm optical zone, 3mm per diopter split between a 1x3mm and 2x3mm slit correction.

One potential problem with ultraviolet laser corrections is the fact that tissue may only be removed and for hyperopic corrections, the addition of tissue, or apparent central addition is needed. The trick is to remove a circular trough surrounding an acceptable size central optical zone which effectively creates a central elevation. In PRK the technique is less successful due to epithelial filling of the trough but in LASIK the technique functions nicely as illustrated in the case examples. Enlargement of optical zone is not common with well centered refractive procedures, however when needed the procedure functions well as shown in the case example, but with even mild to moderate decentration and a plano or slightly hyperopic correction the blocking technique described here with a small soft contact lens functions extremely well and
provides the opportunity to change positioning of the optical zone without overcorrecting the patient.

The most dramatic and interesting of the techniques described in this paper is the treatment of eccentric depression. Eccentric depressions are common in lamellar techniques and even a relatively small abnormality seems to cause a significant visual problem as evidenced by decreased best corrected vision and patient complaints. This relatively simple procedure affords significant improvements for previously insoluble surgical results. The interesting clinical observation that regular astigmatism is observed on manifest refraction 90 degrees from the axis of decenteration despite the absence of a “bowtie” pattern on computed corneal topography both helps in the diagnosis and to understand the theory of the treatment. In a sense, an eccentric depression is one half of a cylindrical laser astigmatic resection. The addition of the other half resolves both the regular and irregular components of residual astigmatism.

Finally, the correction of eccentric elevations, particularly in keratoconus, is an exciting but relatively unexplored area of treatment. As we have shown in the case examples, simply treating the refraction results in poor uncorrected vision and residual myopia and astigmatism. Even in a mild or form-fruste keratoconus these patients can experience multiple treatments with uncorrected visual improvement but often with continued loss of best corrected vision. While this avenue of treatment is certainly worth continued investigation and the patients seem happy, the continued loss of best corrected vision is troubling. For eccentric elevations unrelated to keratoconus, the results are better since in fact an eccentric elevation may be thought of in another way as an eccentric depression 180 degrees away. The results in frank keratoconus should be a cause for some consideration, since with any eccentric elevation of the cornea, such as a new patient presenting for refractive surgery, simply treating with the manifest refraction (ignoring the eccentric elevation) will result in unpredictable refractive results. A better approach, if a patient with an eccentric elevation elects to proceed with laser surgery, is to confront the problem directly, treating the eccentric elevation as part of the surgical plan.

In summary, irregular astigmatism is a significant problem, sometimes overlooked, in all areas of ophthalmology, resulting in a variety of symptoms including decreased best corrected visual acuity, induced regular astigmatism, glare and visual distortion. In refractive surgery, irregular astigmatism accounts for a small but significant number of patients. This paper has described in detail a classification system and a series of techniques based on this classification to resolve the irregular astigmatism in a large percentage of patients. Not all problems of irregular astigmatism are candidates for this system of correction, since the irregular astigmatism must represent a stable and unchanging condition. While these techniques may be helpful in some unstable refractive conditions such as unstable corneal wounds, it is advisable to utilize wound strengthening procedures to create a stable cornea prior to proper application of these techniques.
<table>
<thead>
<tr>
<th>SURGICAL TECHNIQUE</th>
<th>REFERENCE</th>
<th>EYES</th>
<th>LOSS OF 2 LINES BCVA</th>
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<tbody>
<tr>
<td>EPIK</td>
<td>Goosey</td>
<td>32</td>
<td>6%</td>
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<tr>
<td>EPIK</td>
<td>Colin</td>
<td>29</td>
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</tr>
<tr>
<td>RK</td>
<td>Waring</td>
<td>793</td>
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</tr>
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</tr>
<tr>
<td>LASIK</td>
<td>Bas</td>
<td>97</td>
<td>13%</td>
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</table>

Table 1. Comparison of loss of best corrected vision in large studies of several different refractive procedures.

### BUZARD ASTIGMATISM NOMOGRAM

<table>
<thead>
<tr>
<th>Correction (Diopters)</th>
<th>6mm zone correction</th>
<th>3mm zone correction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flat Slit 2mm wide</td>
<td>Flat Slit 4mm wide</td>
</tr>
<tr>
<td></td>
<td>6mm long (Microns)</td>
<td>6mm long (Microns)</td>
</tr>
<tr>
<td>0.5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1.5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>2.5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>12</td>
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</table>

Table 2. Nomogram for treating astigmatism with the excimer laser.
### BUZARD MYOPIA NOMOGRAM

Ablation optical zone: 3.0mm  
Ablation transition zone: 0.5mm

<table>
<thead>
<tr>
<th>Diopters of intended correction</th>
<th>Depth of Ablation (microns)</th>
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<tr>
<td>1</td>
<td>3</td>
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<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
</tr>
</tbody>
</table>

*Table 3. Nomogram for treating myopic with the excimer laser.*

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### BUZARD HYPEROPIA NOMOGRAM

Ablation optical zone: 6.0mm  
With use of a 3.5mm diameter trephined contact lent

<table>
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*Table 4. Nomogram for treating hyperopia with the excimer laser.*
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