Irregular astigmatism is a rare but significant complication of corneal surgery, including elective refractive procedures and penetrating keratoplasty (PKP). Patients often report decreased acuity, monocular diplopia, ghosting, halos, and a lack of subjective improvement with spectacles and hydrogel contact lenses. Objective findings include irregular topographic patterns, a poor endpoint with manifest refraction, and improved acuity with an overrefraction using a gas permeable contact lens. Currently, the management of these patients involves their wearing gas permeable contact lenses, the off-label use of procedures such as PRK and/or phototherapeutic keratectomy (PTK), and the Visx Custom-Contoured Ablation Pattern treatment (Custom-CAP; Advanced Medical Optics, Inc., Santa Ana, CA). Treatments guided by topography and wavefront software technology may be better suited for correcting irregular astigmatism. The following articles regarding the surgical correction of irregular astigmatism, particularly decentered ablation, were reviewed:


IRREGULAR ASTIGMATISM

Definition
In irregular astigmatism, the principal meridians are not 90° apart, and the result is decreased BSCVA. Although regular astigmatism is correctable using a cylindrical spectacle lens, irregular astigmatism occurs when the orientation of the principal meridians changes from one point to another across the pupillary zone. Although this description appears straightforward, the definitions used in the studies varied widely.

Surgical Causes
Studies investigating irregular astigmatism associated with PKP, refractive surgery, and corneal scarring did not use topographic maps to define the problem. Kremer et al.1 used a loss of BSCVA consistent with clinical findings such as scarring or corneal dystrophy, corneal degenerations, and band keratopathy. Mularoni et al.2 used reduced BSCVA as an indicator of irregular astigmatism in patients who previously underwent PKP.

Studies investigating the correction of irregularities following refractive surgery did use topographic maps, employing various methods. Rachid et al.3 used curvature maps to identify decentered ablations and central islands. They used the edges of the zone of greatest flattening to determine the geometric center, corresponding to the middle of the ablation zone. The distance from the middle of the ablation zone to the pupillary midpoint defined the distance of the decentration. Central islands were defined as one of three topographical abnormalities: (1) a circular area of central or pericentral steepening within the photorefractive ablation zone; (2) a central island power of at least 1.50D with a minimum diameter of 2.50mm; and (3) a steep central island surrounded by zones of lesser curvature that made up more than 50% of its boundary.

Lafond et al.4 measured the decentered ablation as the distance calculated on the topographic maps between the center of the ablation and the visual axis. They did not define the type of map. Lin and Manche5 used the definition required by the Visx Custom-CAP Humanitarian Use Device of at least a 6.00-mm difference in the elevation topography from the lowest to highest point over a 6.50-mm diameter or pupillary diameter as measured by the Humphrey Atlas topographer (Carl Zeiss Meditec Inc., Dublin, CA).

The remaining investigators6-8 described irregular astigmatism using difference maps of one form or another. Alessio et al.9 showed decentration using a cursor in the center of the optical zone of the differential elevation maps created by the Orbscan topographer (Bausch & Lomb, Rochester, NY). Subtracting the preoperative from the postoperative corneal topographic map and calculating the distance to the entrance of the pupil’s center localized the decentered ablation. Stojanovic and Suput10 measured the ablation’s decentration as the distance between the center of the entrance pupil and the center of the ablation zone as registered on a difference map between pre- and postoperative topography. They did not specify if the map was a curvature or elevation map, however. Mrochen et al.11 measured the decentration of the ablation by obtaining difference maps from pre- and postoperative tangential curvature maps. They determined the eccentricity of the ablation as the distance of the center of the flattened zone from the middle of the entrance pupil.

The variability in these definitions used to identify irregular astigmatism may be related to the technology used. Prior to the availability of computerized videokeratography, doctors relied on clinical methods of detecting astigmatism such as loss of spectacle correction. As topography developed, curvature maps were used, followed by elevation maps. Even with the best technology, eyes with severe irregularities such as corneal grafts continue to be challenging for topographical systems to map.

MANAGING ASTIGMATISM

Methods
The articles reviewed here describe techniques for managing astigmatism, including surface ablation, combined hyperopic and myopic ablations, wavefront-guided treatment, and topography-guided treatment.

PTK for Corneal Irregularities
Kremer et al.1 investigated the use of PTK in patients with corneal irregularities that resulted in a loss of BCVA. The investigators performed a Biomask (Maverick Technologies, Inc., Clearwater, FL) surgical procedure in which a mask protected lower areas of epithelium during ablation with a broad-beam excimer laser. According to the results, BSCVA in patients with corneal scarring was best in patients with Salzmann’s degeneration and prior refractive surgery. BSCVA in patients with corneal scarring was the most difficult to improve. There was an average loss of three lines of vision in 15% of patients (three eyes of 20 patients). Twenty percent (four eyes of 20 patients) failed to achieve an improvement in visual acuity using the Biomask. The average hyperopic shift was 3.44D for all patients.

PTK for Decentered Ablations and Central Islands
Rachid et al.3 used PTK to correct decentered ablations and central islands. In eight patients, the investigators performed a three-step technique that included PTK with a transepithelial ablation set at 200 pulses (50µm) on a 6.00- to 6.50-mm area, followed by PRK for residual refractive error. They then repeated a PTK ablation but with three to 15 pulses to eliminate or confirm the absence of residual epithelium in the treatment area. According to the study, the decentration improved in seven patients, but BSCVA was not reported postoperatively. The investigators also described the results of
PTK, PRK, or a combination of both in six eyes that had central islands. Although UCVA was significantly improved, postoperative BSCVA was not given.

Decentered Excimer Laser Ablations

Lafond et al treated 16 eyes of 14 previously myopic patients with decentered excimer ablations through combined treatments. In one surgical session, the ophthalmologist decentered a hyperopic ablation in the same direction as the initial treatment. A second myopic ablation of nearly equal dioptic power 180º away from the original treatment was immediately performed. The investigators used the Technolas excimer laser (Bausch & Lomb). Greater displacement (2mm) was used in patients with an initial decentration of more than 2mm. For eyes with a decentration smaller than 2.0mm, 1.0-mm or 1.5-mm displacement was used. A combination of ±1.00D or ±1.25D was used in most eyes. One patient reported mild improvement. Four reported moderate improvement, and 10 found their symptoms markedly improved. However, five of 16 eyes required retreatment. Due to a second decentered ablation in the opposite direction, one eye lost one line of BSCVA. However, the BCSVA loss was corrected after a third procedure.

Wavefront-Guided Correction

Mrochen et al planned to use wavefront-guided treatments to correct decentered ablations in three patients. Tscherning aberrometry was used for wavefront measurements both pre- and postoperatively. An Allegretto laser (WaveLight AG, Erlangen, Germany) was used for the treatment of two cases (patients 1 and 2). In patient 1, BSCVA improved to better than 20/20, and coma (a higher-order aberration associated with decentered ablations) improved significantly. In patient 2, the BSCVA improved from 20/30 to 20/20. The coma value did not improve, and topography still showed a decentered ablation zone. The patient continued to report halos and multiple images following the retreatment. The third patient’s wavefront error was unavailable because the aberrometer was unable to measure it due to significant higher-order aberrations. The investigators suggested that eyes with aberrations that were too large for imaging using wavefront technology require lamellar or penetrating keratoplasty for correction.

Topography-Guided Correction

The remaining investigators dealt with the topography-guided surgical correction of irregular astigmatism. Stojanovic and Suput studied optimal customized ablation plans from elevation maps measured with the Orbscan in patients with irregular astigmatism. Their goal was to identify the best method to preserve corneal tissue and achieve a smooth spheric cornea with the desired refractive correction. An aspheric surface of 6.5mm in diameter served as the target surface. The center of the target surface was fitted perpendicularly to the visual (fixation reflex) axis and to the morphological axis. The morphological axis is defined as the axis of corneal symmetry approximating the best match between the axis of ideal shape and that of the current form of the cornea. No attempt to correct the refractive error was made. The parameters of the target surface included an aspheric surface with a basic curvature matching the flattest meridian, an asphericity index of -0.26, a 6.5-mm optical zone, and a 7.5-mm transition zone. Investigators relied on the Corneal Interactive Programmed Topographic Ablation software (CIPTA; Ligi, SpA, Taranto, Italy) to determine the ablation depth for each surgical plan based on the axis used. Surgical plans based on the two treatment strategies for 50 eyes with decentered ablations were compared to 50 virgin eyes with astigmatism. The surgical plans using the visual and morphological axes were significantly different in the
decentered group, and only minor differences between the two strategies were found in the virgin eyes.

The variation was attributed to the visual disturbances secondary to induced asymmetric corneal irregularities after refractive surgery. In short, a decentered ablation causes the visual axis to move from its original physiologic position to a new location. Wavefront aberrometry, autorefractometry, placido-based topography, and unilateral manifest refraction are all affected by the movement of the visual axis. Thus, a retreatment based on these measures is not 100% efficacious due to the axial shift and the need to ablate more tissue.

Two studies used CIPTA to address astigmatism. Mularoni et al\(^2\) used a two-stepped LASIK approach that was guided by topography in patients with previous PKP. Fifteen eyes were treated for a reduction in astigmatism by creating a flap using a Hansatome microkeratome (Bausch & Lomb). Rather than proceeding immediately with excimer ablation, the surgeons monitored patients until their refractions were stable. In this study, creating the flap changed the cylindrical correction by more than 1.00D (average). Stability occurred in a mean of 45 days. Once the eyes were stable, the surgeon lifted the flap and performed an excimer treatment using the Laserscan LSX (Lasersight Technologies, Inc., Winter Park, FL) according to the plans provided by CIPTA. They chose the apex of the cornea as the ablation’s center. The postoperative asphericity index was zero. No eye lost Snellen acuity. The mean BSCVA improved from 20/32 to 20/25. The mean cylindrical reduction was 5.00D with a 75% decrease in astigmatism.

Alessio et al\(^6\) performed one-step procedures using CIPTA and the Laserscan LSX excimer laser system on decentered ablations in 32 eyes. The ablation was centered over the pupils’ centroid. The ablation profiles were planned to obtain a postoperative corneal shape with an asphericity index of 0. The average decentration was reduced from 1.19 to 0.15mm. The mean BSCVA improved from 20/28 to 20/22. Eighteen (56.25%) eyes gained Snellen lines, and no eye lost Snellen acuity.

The final topography-guided study used Custom-CAP. Lin and Manche\(^3\) used the device with the Visx Star S4 excimer laser (Advanced Medical Optics, Inc., Santa Ana, CA) to correct decentered ablations in eight eyes. BSCVA improved by three lines in one eye, two lines in two eyes, and one line in three eyes. The BSCVA was unchanged in two patients with 20/20 or better. No eye lost BSCVA. Two eyes required a retreatment for decentration, one eye required a LASIK enhancement for residual regular astigmatism, and one required the removal of epithelial ingrowth.

**BOTTOM LINE**

Although all studies reviewed showed some improvement in the level of astigmatism, some methods required additional surgery and/or caused some loss of BSCVA. Given the high expectations (even when dealing with complications) of today’s refractive surgery patients, it is imperative to minimize risk with the greatest efficacy in a single corrective surgery. Only CIPTA and Custom-CAP procedures maintained BSCVA in all patients. Custom-CAP and PRK techniques required retreatments. PRK/PTK typically induced a hyperopic shift. Wavefront-guided corrections were limited by an inability to measure the irregularity commonly found in aberrant corneas. Further investigation using CIPTA will determine if this technique, which spares tissue in aberrant eyes while optimizing the shape of the cornea, will prove to be as beneficial as presented in these studies.

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