New method of targeting vectors to treat astigmatism

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ABSTRACT

Purpose: To describe a method for optimizing the treatment of astigmatism using vector analysis of both refractive and corneal topographic values.

Setting: Cheltenham Eye Centre, Melbourne, Australia.

Methods: This study evaluated a method of vector analysis for planning surgery that uses both preoperative topographic and refractive values and determined how to select the relative treatment emphasis to be given to each. In addition, the significance of the phenomenon of ocular residual astigmatism (ORA) was explored. Its presence provides an inherent limitation on eliminating astigmatism from the eye's optical system.

Results: Various comparisons of preoperative and ORA values are plotted in a series of 100 excimer laser photoastigmatic refractive keratectomy patients. These ORA values are equivalent to the expected corneal astigmatism resulting from surgery where treatment is performed by refractive astigmatism values alone. A theoretical example is given in which the corneal astigmatism remaining from surgery is reduced by giving less emphasis to completely eliminating refractive astigmatism and consequently greater emphasis to completely eliminating topographic astigmatism.

Conclusion: Using vectors in astigmatism surgery enables the incorporation of topography and refractive values into the surgical plan. This would achieve a greater reduction in corneal astigmatism and potentially a better visual outcome than using refractive astigmatism values alone. *J Cataract Refract Surg 1997; 23:65–75*

The treatment of astigmatism is currently done using two different modes in which the goal of surgery is to achieve a zero result based on either corneal shape or ocular refraction. Treating astigmatism and analyzing astigmatism surgery would be considerably simpler if refractive and topographic astigmatism always coincided precisely. In reality, however, there are marked differences between the two. These inherent differences result in an inability to fully eliminate astigmatism from the refractive system of the eye[1] and complicate analysis of the results of surgery. This is particularly so when the magnitude or orientation of the applied treatment differs from not just one, but both topographic and refractive values. A further complication exists in the differences in the topography of the two hemidivisions of the cornea. This issue is not discussed in this article.

Excimer laser photoastigmatic refractive keratectomy (PARK) is usually performed based on preoperative refractive data alone. Because these data are different from topographical data, we have not in fact been targeting a spherical cornea. Astigmatism results of excimer laser PARK surgery published in the literature are, in most instances, analyzed by refraction alone.[2–5] The topographic target is not calculated; thus, the measured

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postoperative result for corneal astigmatism is of limited value.

The same is conversely true for astigmatic keratotomy, in which treatment is usually applied according to the preoperative corneal shape, ignoring the refractive component. A previously described analysis method[1] provides a yardstick with which to compare the results of all astigmatism surgery.

The analysis of results based on both parameters is essential in monitoring resulting changes occurring at the corneal surface. Corneal topography devices are valuable diagnostic and measurement tools whose quantitative information has, in the past, been disregarded in surgical planning and analysis. Surgical treatment for astigmatism performed on refractive parameters alone, disregarding corneal shape, may unfavorably distribute remaining astigmatism to the cornea, potentially reducing the quality of vision.

This paper describes a method of analyzing vectors for planning astigmatism surgery by discussing (1) the apportionment of the remaining astigmatism into its topographic and refractive components; (2) the methodology for choosing the target induced astigmatism (TIA) vector; (3) an example of planning surgery for maximum treatment using this method; (4) various methods of optimal and suboptimal treatment.

Materials and Methods

The ASSORT® refractive surgery planning and outcomes analysis computer program and an IBM-compatible 80486DX with 8 MB RAM were used to calculate all parameters. These values are displayed in the charts at the bottom of the figures.

A retrospective study of a personal series of 100 consecutive patients who had excimer laser PARK between May 1993 and March 1994 was undertaken. Each patient's manifest refraction was tested by the following routine method at a distance of 20 feet from an illuminated Snellen chart.

The spherical component of the refraction was tested starting with the patient's previous spectacle correction in the trial frames. Successive changes of 0.50 diopter (D) sphere were made, followed by 0.25 D spheres, positive and negative, until the subjective endpoint was reached. The cylindrical component was tested using the Jackson cross cylinder commencing with 0.50 followed by 0.25 D increments. The axis and then the magnitude were corrected until the subjective endpoint was reached. Fine tuning by Duochrome testing for the spherical component was performed. Corneal topography values were determined by the simulated keratometry value using the TMS Topographic Modeling System (Computed Anatomy Inc.). When this value differed from the refractive value, the cylindrical component was retested by manifest testing with this value as the starting point. The patient's preferred endpoint was used as the refractive value.

When preoperative parameters were analyzed, the refractive astigmatism (*R*) with its associated myopia was converted to the corneal plane. Table 1 provides a summary of mean preoperative parameters.

Table 1. Summary of mean preoperative parameters.

Parameter	Mean ± SEM	Range
Refractive astigmatism, *R* (D)	1.68 ± 0.10	0.39 to 5.15
Topographic astigmatism, *T* (D)	1.83 ± 0.10	0.20 to 5.50
Absolute difference *T* & *R* (D)	0.58 ± 0.05	0.00 to 2.30
Axis (degrees)	11.93 ± 1.20	0 to 78
Angular separation between *T* & *R* axis (degrees)	+0.57 ± 1.7	−78 to +52

SEM = standard error of the mean

Results

The magnitude of topographic astigmatism exceeded refractive astigmatism in 59 patients. In the re-

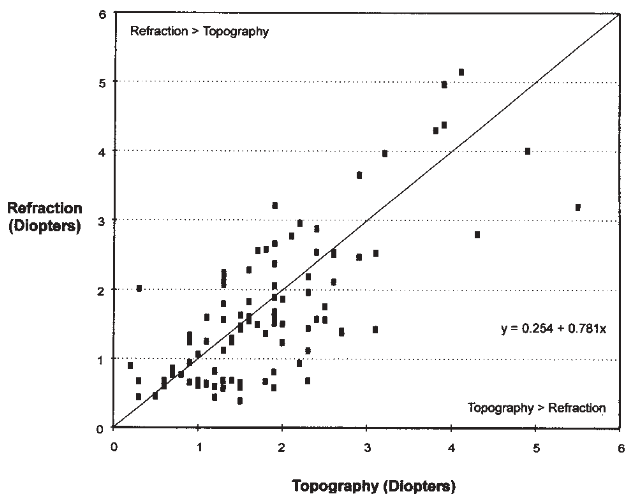


Figure 1. (Alpins) Preoperative refractive versus topographic astigmatism magnitudes ($r = .733$; $P < .0001$).

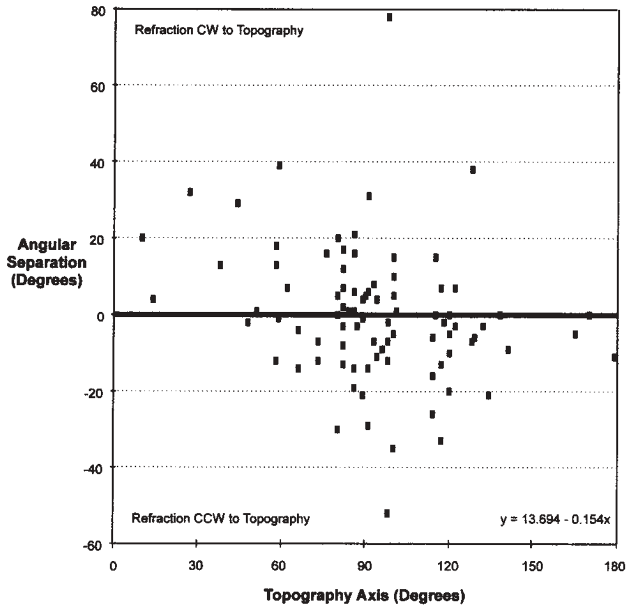


Figure 2. (Alpins) Preoperative angular separation in relation to the topographic axis (r = .257; P = .0097).

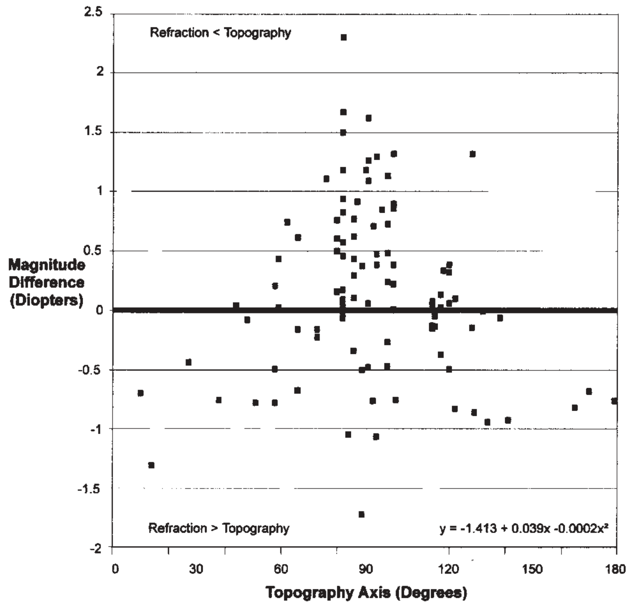


Figure 3. (Alpins) Preoperative magnitude difference between topography and refraction compared with the topographic axis (r = .437; P < .0001).

maining 41, refractive astigmatism was greater. Examination of scatterplots of the preoperative refractive versus topographic astigmatism magnitudes (Figure 1) showed a close relationship between the values.

There was no clear relationship, however, when viewing the angular separation. The scatterplot in Figure 2 shows the angular separation in relation to the topographic axis. Positive values are shown where the refraction axis is clockwise to topography, and counterclockwise values are shown as negative values.

A scatterplot of the magnitude difference between topography and refraction compared with the topographic axis (Figure 3) shows that when the topographical axis was closer to the orientation of 90 degrees, the topographical magnitude exceeded the refractive. However, in the orientation closer to against the rule at 180 degrees, the refractive astigmatism had the greater value. This finding might suggest a greater optical tolerance of with-the-rule corneal astigmatism.

Data from this group showed a trend for refractive and topographic magnitudes to increase in parallel. However, examination of the differences between each in their preoperative magnitude values or axis orientations showed no definite relationship.

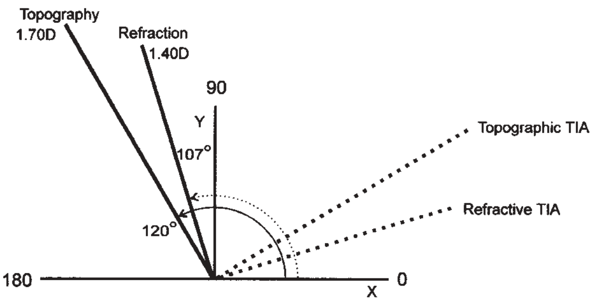
Preoperative Topography and Refractive Parameters

Figure 4A shows the astigmatism and surgical vector diagram of a cornea with differing values for the magnitude and orientation of refractive (corneal plane) and topographic astigmatism. For refraction and shape comparisons, the orientation of the refractive astigmatism is shown at the power meridian of the negative cylinder. Alternatively, this could be represented by the cylinder axis of the positive cylinder. All examples containing refractive astigmatism values were calculated using both plus and minus cylinder notations. Each steepening force required to correct these two astigmatism values was equal in magnitude and orientated perpendicular to each respective astigmatism.

The chart at the bottom of Figure 4A shows that the astigmatism T-value measured topographically was 1.70 D at axis 120 degrees and the TIA was 1.70 D at axis 30 degrees to produce a target result of zero (based on topography alone). The astigmatism R-value measured by refraction was 1.40 D at axis 107 degrees (for plus cylinder refraction) and the TIA was 1.40 D at axis 17 degrees to produce a target value of zero (based on refraction alone).

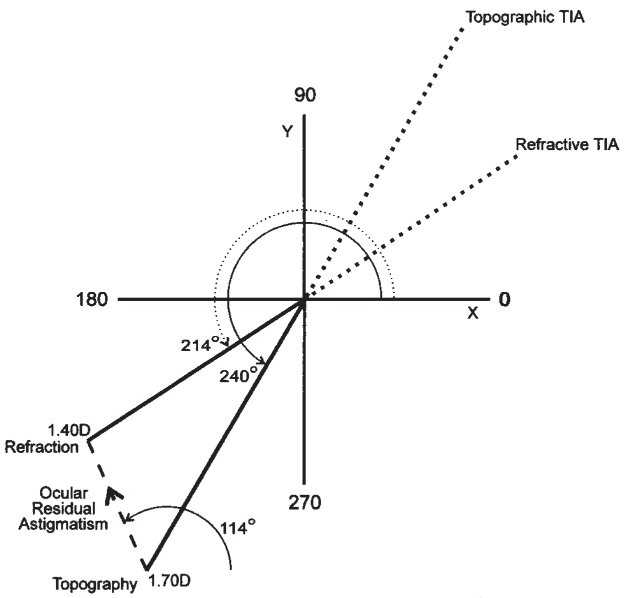
Each of the two astigmatism values and vectors can be displayed on a double-angle vector diagram (Figure 4B) and each TIA is now opposite, with orientation at 180 degrees to the respective astigmatism, showing the force and its orientation required to spherify the cornea or refraction.

Residual astigmatism[6] is a combined measure of angular separation and magnitude difference between the refractive and corneal astigmatism. Residual astigmatism will be called ocular residual astigmatism (ORA) in this article to distinguish it from the astigmatism remaining after surgery, which is commonly referred to as residual astigmatism and which will be referred to in this article as surgical residual astigmatism (SRA).



	Topography	Plus Cylinder Refraction	Minus Cylinder Refraction
Preop	1.70 Ax 120	+1.40 Ax 107	-1.40 Ax 17
TIA	1.70 Ax 30	1.40 Ax 17	
Target	0.00 Ax	0.00 Ax	0.00 Ax

Figure 4A. (Alpins) Astigmatism and surgical vector diagram.



Ocular Residual	0.76 D Ax 57

Figure 4B. (Alpins) Ocular residual astigmatism; double angle vector diagram.

The ORA K_{TR} is the vectoral difference between the total net astigmatism of the optical system of the eye as measured by refraction at the corneal plane K_R and the corneal astigmatism as measured by topography values K_T. The ORA is a calculated vector value with a magnitude and an orientation that can be expressed by the formula

$$K_{TR} = K_R - K_T$$

Its value in the example is 0.76 D A × 57 degrees. The magnitudes of each ORA are charted in Figure 5 against their respective axes.

Evaluating ORA Values

Scatterplots of the ORA magnitudes versus the preoperative refractive and topographic magnitude differences (Figure 6) indicate a relationship between them. Further, a relationship also appears when the ORA magnitude and the preoperative angular separation between refractive and topographic axes are charted (Figure 7).

The mean ORA in the sample group as determined by vector analysis was 0.81 D with a standard error of the mean (SEM) of ±0.05 D (range 0.01 to 2.32 D). The ORA exceeded 1.00 D in 34 patients; in 7 of these, it

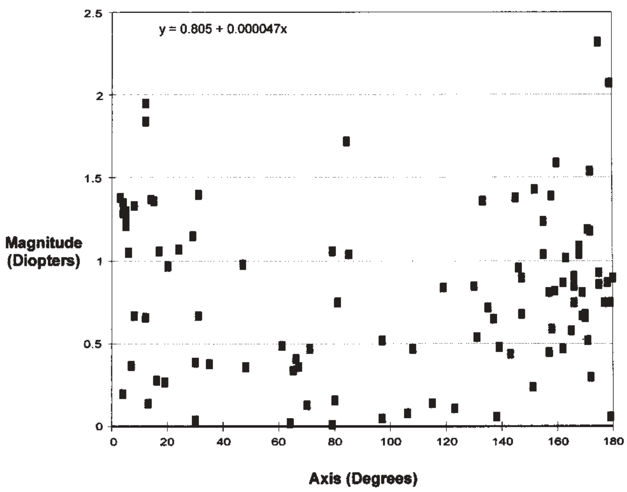


Figure 5. (Alpins) Magnitudes of each ORA against their respective axes (r = .006; P = .95).

exceeded the preoperative magnitude of topographic astigmatism.

The trends evident in Figures 6 and 7 show a direct relationship between the ORA values and the differences between preoperative topography and refractive values for both magnitudes and angular separation. These differences seem to have no relationship to preoperative astigmatism orientation (Figures 2 and 3).

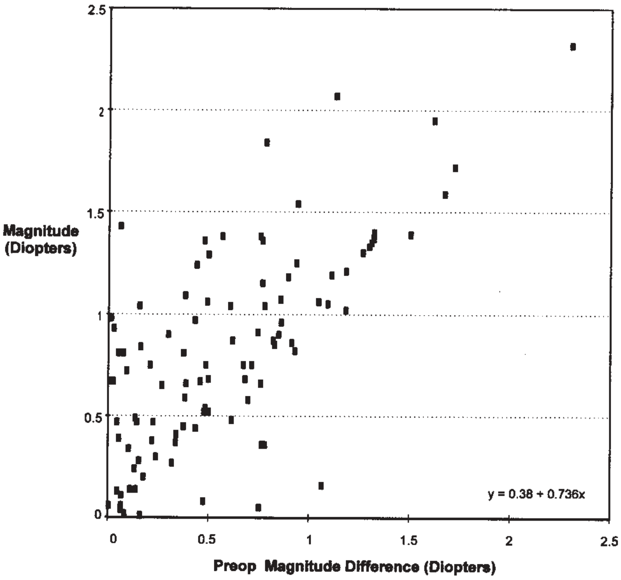


Figure 6. (Alpins) Ocular residual magnitudes versus preoperative refractive and topographic magnitude differences ($r = .693$; $P < .0001$).

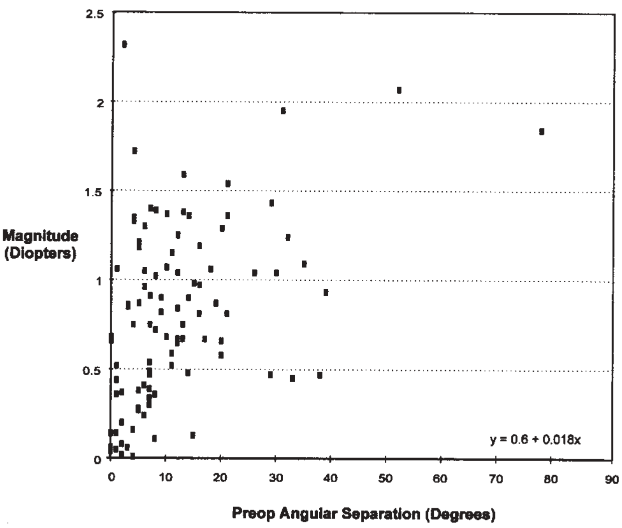


Figure 7. (Alpins) The ORA magnitude and preoperative angular separation between refractive and topographic axes ($r = .430$; $P < .0001$).

This would suggest that the ORA is a valuable parameter to gauge differences in these two preoperative modes for measuring astigmatism. These ORA values would also indicate that the problem of differences in preoperative refractive and topographic values of astigmatism is a significant one that should be addressed when performing refractive surgery to treat astigmatism.

Target Refraction Using Topography

Target refraction (*R*) is the amount of refractive astigmatism remaining after treatment to eliminate topographical astigmatism. The refractive effect of choosing a TIA that would spherify the cornea can be ascertained by applying the topographical TIA to the preoperative refraction to determine the target refraction (Figure 8A). This target has the same magnitude and orientation as the ORA (Figure 4B), and the line that connects the extremities of the refractive and topographic TIAs is also equivalent to the ORA.

Target Topography Using Refraction

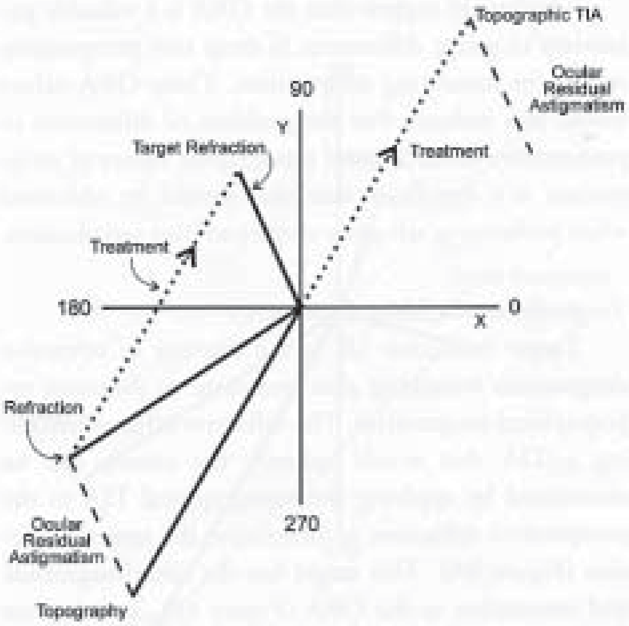
Target topography (*T*) is the corneal topographical astigmatism remaining after treatment to eliminate refractive astigmatism. Similarly, the topographical target astigmatism can be determined by applying the refractive TIA to achieve a spherical refraction to the preoperative topography. This target is equivalent in magnitude, and its axis is aligned to neutralize the ORA. The arrows in Figures 4B, 8A, and 8B indicate the direction of the vectors.

Minimum Target Astigmatism

Ocular residual astigmatism is equivalent in magnitude to the refractive and topographic targets (Figures 8A and 8B). The maximum correction of astigmatism is achieved when the remaining astigmatism is at its minimum (the minium target astigmatism) and is equal to the ORA. This remaining astigmatism will be refractive, topographic, or a combination. The combined magnitude of astigmatism remaining (the total target astigmatism) is the sum of the magnitudes of astigmatism as determined by topography, plus the astigmatism as determined by refraction.

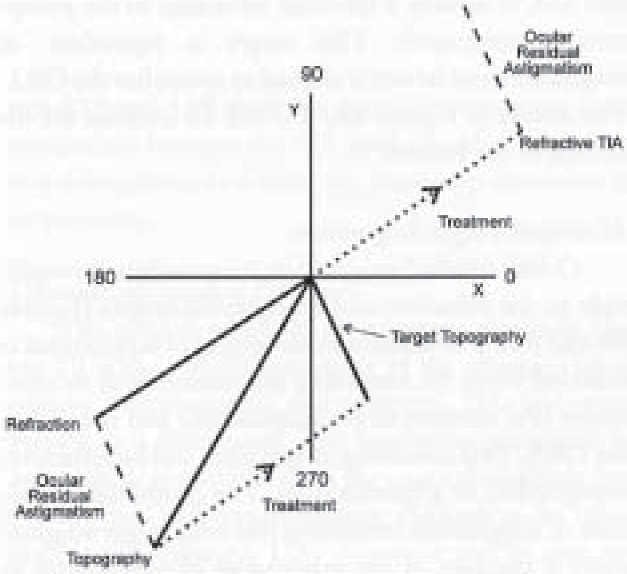
Determining a TIA

An intermediate TIA (Figure 9) can be chosen between the boundaries of the topographic TIA and the



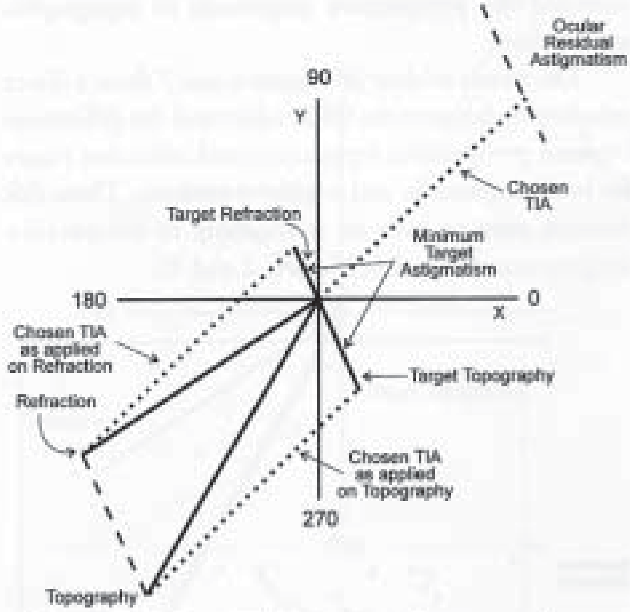
	Topography	Plus Cylinder Refraction	Minus Cylinder Refraction
Preop	1.70 Ax 120	+1.40 Ax 107	-1.40 Ax 17
TIA		1.70 Ax 30	
Target	0.00 Ax	+0.76 Ax 57	-0.76 Ax 147
Emphasis	100%	0%	

Figure 8A. (Alpins) Double-angle vector diagram of treatment by topography for spherical cornea.



	Topography	Plus Cylinder Refraction	Minus Cylinder Refraction
Preop	1.70 Ax 120	+1.40 Ax 107	-1.40 Ax 17
TIA		1.40 Ax 17	
Target	0.76 Ax 147	0.00 Ax	0.00 Ax
Emphasis	0%	100%	

Figure 8B. (Alpins) Double-angle vector diagram of treatment by refraction for spherical refraction.



	Topography	Plus Cylinder Refraction	Minus Cylinder Refraction
Preop	1.70 Ax 120	+1.40 Ax 107	-1.40 Ax 17
TIA		1.47 Ax 22	
Target	0.50 Ax 147	+0.26 Ax 57	-0.26 Ax 147
Emphasis	34%	66%	

Figure 9. (Alpins) Double-angle vector diagram of treatment using intermediate TIA for minimum target astigmatism.

refractive TIA. The relative proximity of this intersection to either the topographic or refractive endpoints is determined by the emphasis of treatment required.

Any TIA that achieves the minimum target astigmatism for the prevailing topographic and refractive parameters must terminate on this ORA line. The target refraction and topography are oriented at 180 degrees to each other on a double-angle vector diagram; that is, they form a straight line. Thus, the sum of their magnitudes (total target astigmatism) is at a minimum length for the optical system of the eye.

Optimal Point of Termination

The optimal point of termination of the TIA with the ORA line (Figure 10B) is determined from the surgical emphasis graph (Figure 10A) according to the orientation of the target astigmatism. In this example, the meridian of target topography is 147 degrees. As it lies 57 degrees from a with-the-rule orientation of 90 degrees, the surgeon may decide to use a linear relationship as illustrated in Figure 10A and apportion 57 of 90 or

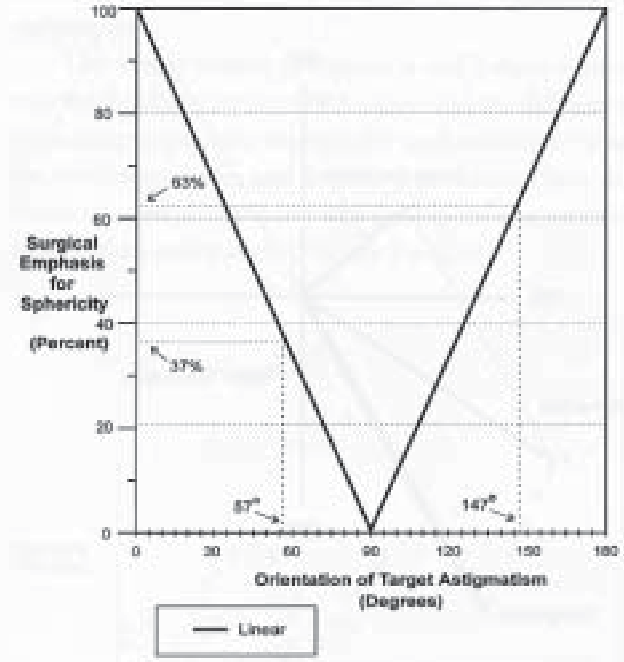
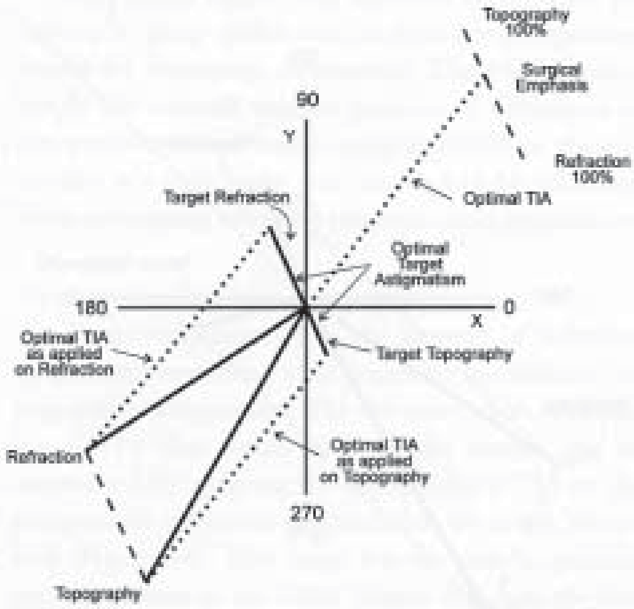


Figure 10A. (Alpins) Surgical emphasis graph for astigmatism surgery.



	Topography	Plus Cylinder Refraction	Minus Cylinder Refraction
Preop	1.70 Ax 120	+1.40 Ax 107	-1.40 Ax 17
TIA		1.56 Ax 28	
Target	0.28 Ax 147	+0.48 Ax 57	-0.48 Ax 147
Emphasis	63%	37%	

Figure 10B. (Alpins) Double-angle vector diagram of optimal TIA with treatment parameters.

63.3% emphasis to a topography-based goal of zero astigmatism.

The axis of 147 degrees for the target topography is taken of the abscissa in Figure 10A, and this intersects the linear emphasis line at the value of 63%. This topographic astigmatism axis of 147 degrees places 63% emphasis on the correction of topographic astigmatism and by the same process, the refractive astigmatism axis of 57 degrees places 37% emphasis on the correction of the refractive astigmatism. The resultant optimal TIA is plotted in Figure 10B, with its parameters shown in the chart at the bottom, and is positioned closer to the topographic TIA (Figure 8A) than to the refractive TIA (Figure 8B).

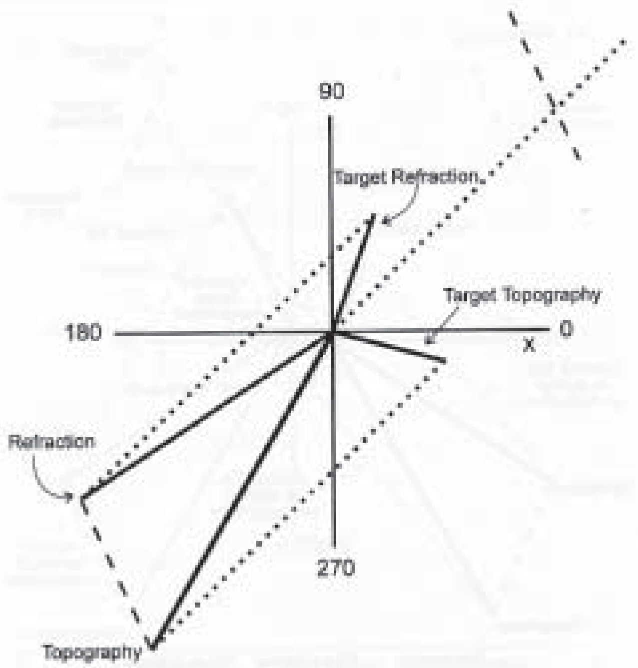
If the combined magnitude of the remaining astigmatism will be greater than the initial ORA, the surgery fails to achieve the maximum astigmatism treatment. Figure 11 gives examples of this.

Overtreatment and Undertreatment

Figure 11A shows a TIA that overshoots the surgical emphasis line. The two targets are determined by applying the TIA to the preoperative topography and refraction values and joining their endpoints with the origin of the graph to determine their respective target magnitudes and axes. When the two target values are added to give the total target astigmatism, the result can be shown to be greater than the minimum target astigmatism.

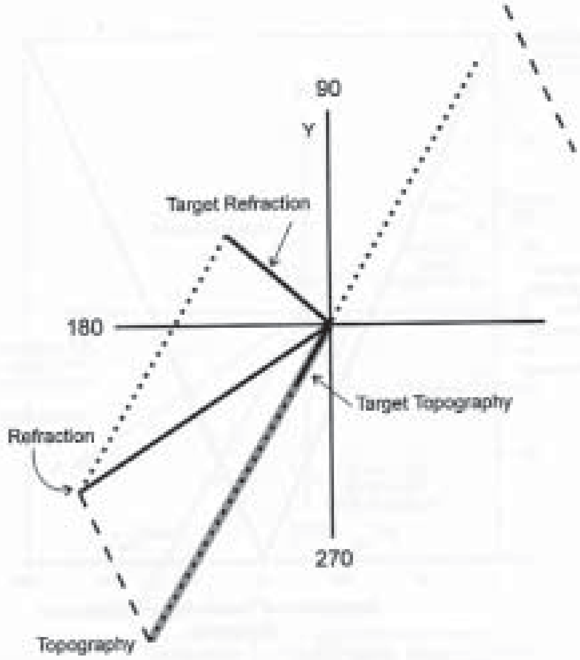
Similarly, a TIA may be chosen that is shorter than that required to reach the ORA line (Figure 11B). This may, for example, be the case when the refractive magnitude is chosen with the topographic meridian to so-called "hedge" on the astigmatism treatment values, choosing one value from each parameter. The resulting total target astigmatism is again greater than the minimum achievable, as the refractive and topographic targets are not aligned at 180 degrees to each other.

As shown in Figures 11A and 11B, overtreatment and undertreatment do not refer to the amount of astigmatism correction achieved compared with the amount attempted. This is the correction index, which is a measure of the ratio between the surgically induced astigmatism vector when divided by the TIA; a value of 1.0 indicates achievement of the targeted change. Fig-



	Topography	Plus Cylinder Refraction	Minus Cylinder Refraction
Preop	1.70 Ax 120	+1.40 Ax 107	-1.40 Ax 17
TIA		1.90 Ax 22	
Target	0.54 Ax 172	+0.58 Ax 35	- 0.58 Ax 125

Figure 11A. (Alpins) Double-angle vector diagram of treatment by TIA without regard to minimum target astigmatism (e.g., overtreatment).



	Topography	Plus Cylinder Refraction	Minus Cylinder Refraction
Preop	1.70 Ax 120	+1.40 Ax 107	-1.40 Ax 17
TIA		1.40 Ax 30	
Target	0.30 Ax 120	+0.63 Ax 69	-0.63 Ax 159

Figure 11B. (Alpins) Double-angle vector diagram of treatment by TIA without regard to minimum target astigmatism (e.g., undertreatment).

ures 11A and 11B show less desirable treatments and a comparison between the TIA used and what might be a preferable choice to achieve the maximum correction of astigmatism.

Determining Surgical Emphasis

The surgical emphasis of treatment shown in Figure 10 is the relative proximity of the chosen TIA in relation to topographic and refractive TIAs and is expressed as a percentage. The maximum correction of astigmatism is possible when the surgical emphasis line overlies the ORA line connecting the ends of the topographic and refractive TIAs (Figures 8 and 9), and any chosen TIA terminates at its point of intersection with this line.

Refractive surgeons should choose how much emphasis to give to eliminating either topographic or refractive astigmatism as this will determine how the astigmatism that unavoidably remains will be distributed. Most current astigmatism surgery using incisional or nonincisional techniques is performed with the chosen TIA at either extreme of surgical emphasis.

As a general rule, the overriding surgical principle is to approach the goal of corneal sphericity when an astigmatism target's orientation becomes increasingly unfavorable. The model in Figure 10 is based on the commonly held notion that with-the-rule astigmatism is favorable and against-the-rule is unfavorable. For this, the surgeon may choose an emphasis that adheres to linearity, as in Figure 10A, or some other formula such as the square of the cosine of the target astigmatism axis.

Alternatively, the surgeon may choose to vary surgical emphasis according to prevailing knowledge or understanding at that time of how much degradation is imposed upon the perceived visual image according to the orientation of the existing corneal astigmatism. The greater the known degradation for any astigmatism orientation, the more emphasis given to corneal sphericity.

This may be the case, for example, for oblique astigmatism (45 or 135 degrees). The effect on the quality of this perceived image is also likely to be influenced by the associated spherical equivalent. The trend seen in the scatterplot in Figure 3 suggests a possible relationship between the axis of corneal astigmatism and visual function; further investigation of the effect of astigmatism orientation could significantly add to knowledge for the benefit of astigmatism treatment.

Optical Correction of Refractive, Topographic, and Ocular Residual Astigmatism

The optical correction of refractive errors can be performed with either spectacles or contact lenses.

Spectacle correction. When spectacles are used to correct astigmatism, the subjective astigmatism is determined by manifest testing at the spectacle plane. This ocular *refractive* astigmatism value provides a measure of the total net astigmatism of all the refracting surfaces of the eye; that is, the net astigmatic effect encountered by light during its passage through the optical system of the eye, which includes the anterior and posterior corneal surfaces, the lens, and the vitreous. The subjective test will also be influenced by retinal tilt and the conscious perception of this retinal image by the visual cortex of the occipital lobe.

The anterior surface of the cornea is the major refracting surface of the optical system of the eye. The differences between values of the corneal astigmatism and the refractive astigmatism at the corneal plane are responsible for the ORA (i.e., *residual* astigmatism)[6] (Figure 4B) that cannot be eliminated from the eye's optical system.

The variations between topographic and refractive astigmatism cannot be dismissed, nor can the ORA be loosely called lenticular astigmatism. If this term were an adequate description for these differences, one would expect corneal and refractive astigmatism to coincide in magnitude and axis after cataract extraction and spheric lens implantation.

The existence of two modalities for measuring astigmatism—subjective and objective—together with multiple measuring devices within each group, will ensure the perpetuation of these differences and the need to address them in treatment.

Contact lens correction. Theoretically, when refractive error is corrected by a soft contact lens providing only a spherical correction, a topographical image obtained from the front of the surface of the contact lens in place on the cornea would be equivalent to that image obtained from the front surface of the cornea without the contact lens and would provide a measure of topographical astigmatism. A manifest refraction, performed with or without this lens in place, provides a measure of refractive astigmatism at the spectacle plane. The situation is equivalent to that in Figures 4A and 4B.

Toric soft contact lenses are prescribed with the refractive astigmatism magnitude corrected for back vertex distance at the appropriate axis. When this contact lens is of the same refractive index as the cornea and is actually situated on the cornea at the prescribed meridian, the topographic image obtained would theoretically be that of the ORA magnitude from the front surface of the contact lens since it lies on the cornea in an equivalent position to that shown in Figure 8B. A manifest overrefraction should not detect any refractive astigmatism error.

A hard contact lens with spherical surfaces when in place on the cornea effectively spherifies the eye's anterior refractive surface so that the manifest overrefraction[7] provides a measure of the magnitude and axis of ORA equivalent to that shown in Figure 8A.

Discussion

There is a conflict between the two treatment models that use only one of the two preoperative astigmatism values, topography or refraction, to determine surgical treatment. This conflict can be resolved by using the orientation of the target astigmatism as the determinant rather than either of the two preoperative astigmatism values. In this way, all surgeons, whether they use blade or laser technology, will be operating under the same guiding principle.

Only by determining refractive and topographic targets before surgery can we perform two essential tasks in astigmatism surgery: (1) optimize the treatment according to prevailing parameters; (2) enable a valid analysis by knowing where the targets lie. The process of setting precise goals will enable us to gauge our success, determine errors, and make the various adjustments necessary to improve future procedures.

When performing excimer laser surgery for myopia and astigmatism, one may ask that if the goal is to eliminate the need for spectacles, why not use refraction as the only treatment parameter for both cylinder and sphere? The answer lies in the targeting of a zero spherical equivalent for the correction of myopia, which would adequately eliminate the need for spectacles.

However, the penalty for sculpting the spectacle astigmatism onto the cornea is that all ORA would remain as SRA on the cornea. This is contrary to established and conventional principles of corneal surgery that require corneal shape be considered in surgical planning. The potential exists for increased spherical aberrations with degradation of the perceived image.[8] The eye's optical system that is independent of spectacle correction will continue to depend on optimal regularity of the shape of the anterior corneal surface.

Another surgical choice is to share the emphasis between topography and refraction equally, leaving equal astigmatism targeted to refraction and topography. This could be referred to as splitting the difference. As the separation between topographic and refractive astigmatism values increases, there is an accompanying decrease in the TIA magnitude. This is more evident for midpoint treatment when the two preoperative magnitudes are similar.

Another phenomenon is that the maximum astigmatism treatment of the chosen TIA (shown in Figure 9) at any chosen orientation is always less than if an alternate treatment were performed at the same orientation of the chosen TIA, with a magnitude obtained by terminating this TIA on a straight line drawn between refractive and topographic TIA values in Figure 4A. Thus, the method described here effectively addresses treatment when differences exist in the two preoperative parameters of astigmatism by reducing the astigmatism treatment as these differences increase.

The optimal treatment of astigmatism is achieved not only when the sum of the topographic and refractive astigmatism equals the minimum target value achievable for that optical system, but also when this remaining astigmatism is appropriately apportioned to topography and refraction components according to the orientation of the target astigmatism. The optimal treatment of astigmatism would seek to achieve less corneal astigmatism than if treating by refraction parameters alone, with an attempt to influence its orientation favorably.[9–11]

The orientation of the target corneal astigmatism optimally determines the amount of surgical treatment emphasis apportioned to topography and refraction in the treatment plan. However, this apportionment may be directed according to how the cortical perception of the image degrades according to its orientation. If the image suffers maximum degradation, the goal of a spherical cornea would be preferable and the ORA would best be directed to the refraction. Should the targeted astigmatism fall in the orientation where the image is minimally degraded, any ORA optimally remains on the cornea and no astigmatic error remains in the refractive correction.

It may be demonstrable in a laboratory or clinical setting that oblique astigmatism may, in fact, be the least favorable option. If so, the surgical emphasis could be apportioned accordingly. If the associated spherical equivalent of the eye is not zero, the value that coexists with the corneal astigmatism must be considered because one of the two astigmatic images will be closer to the retinal plane.

Conclusion

When differences prevail between topography and refraction, ORA unavoidably remains in the eye's optical system. This is either wholly in topography or refraction, or shared between the two leaving non-zero targets at both surfaces. This ORA quantifies the maximum correction achievable by the surgeon.

In the past, the ORA has been largely disregarded in the surgical planning process. The consequences of excluding topography from the surgical plan, as is widely practiced in excimer laser surgery, inevitably assigns this ORA to the cornea, maximizing the ensuing corneal astigmatism and the potential for increased aberrations with resulting degradation of the perceived image. This paper sought to address the management of this remaining astigmatism by apportioning it in a measured way between topography and refraction and thereby providing the immediate benefit of reduced corneal astigmatism and gaining predictive value in surgical planning.

Recognizing and addressing differences between the shape (topography) and the function (refraction) is an essential step to realizing the maximum potential vision for an astigmatic eye. However, including topography in the surgical plan makes the surgical decision-making process even more complex. There is then a need to address the differences of symmetry in the two separate halves of the cornea in addition to the differences between topography and refraction.

References

1. Alpins NA. A new method of analyzing vectors for changes in astigmatism. J Cataract Refract Surg 1993; 19:524–533
2. Spigelman AV, Albert WC, Cozean CH, et al. Treatment of myopic astigmatism with the 193 nm excimer laser utilizing aperture elements. J Cataract Refract Surg 1994; 20:258–261
3. Kim YJ, Sohn J, Tchah H, Lee CO. Photoastigmatic refractive keratectomy in 168 eyes: six-month results. J Cataract Refract Surg 1994; 20:387–391
4. Pender PM, Excimer Laser Study Group. Photorefractive keratectomy for myopic astigmatism: phase IIA of the Federal Drug Administration study (12 to 18 months follow-up). J Cataract Refract Surg 1994; 20:262–264
5. McDonnell PJ, Moriera H, Clapham TN, et al. Photorefractive keratectomy for astigmatism; initial clinical results. Arch Ophthalmol 1991; 109:1370–1373
6. Duke-Elder S, ed. System of Ophthalmology. Vol 5: Ophthalmic Optics and Refraction. St Louis, Mosby, 1970; 275–278
7. Abrams D. Duke-Elder's Practice of Refraction, 10th ed. New York, Churchill Livingstone, 1993; 259
8. Seiler T, Reckmann W, Maloney RK. Effective spherical aberration of the cornea as a quantitative descriptor in corneal topography. J Cataract Refract Surg 1993; 19: 155–165
9. Eggers H. Estimation of uncorrected visual acuity in malingerers. Arch Ophthalmol 1945; 33:23–27
10. Friedman B. Acceptance of weak cylinders at paradoxic axes. Arch Ophthalmol 1940; 23:720–726
11. Sawusch MR, Guyton DL. Optimal astigmatism to enhance depth of focus after cataract surgery. Ophthalmology 1991; 98:1025–1029

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