Chapter 12

Planning Keratorefractive Treatments Using Wavefront and Corneal Topography Data

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The differences that frequently exist between corneal parameters measured by keratometry or topography and the refractive astigmatism values, as measured by manifest or wavefront techniques, have become increasingly evident to the practicing refractive surgeon. The importance of preoperatively quantifying this parameter is a key ingredient in successful refractive astigmatism treatment. The ocular residual astigmatism (ORA), defined as the vectorial difference between the corneal and refractive astigmatism, singly takes into account the angular as well as the magnitude difference.[1-5] This should form part of any routine eye assessment prior to performing refractive surgery that includes astigmatism treatment.

In the excimer laser field, the perplexing decision whether to treat based on refractive, topographic, or a combination of both parameters continues to be of relevance.[6-8] This is because treatment by refractive parameters alone will leave the neutralization of this internal optical aberration (ORA) on the cornea. In approximately 7% of cases, this amount can be worse than the preoperative corneal astigmatism,[1] potentially leading to increased aberrations and associated visual symptoms, particularly under mesopic conditions. Equally, treatment by topographic parameters alone will leave all the ORA postoperatively remaining in the manifest refraction, again reducing the potential satisfactory visual outcome.

Ideally, a treatment paradigm incorporating both refractive and topographic parameters in a systematic manner would leave the minimum possible total astigmatism in the eye, distributed in an optimal proportion between the cornea and refraction.

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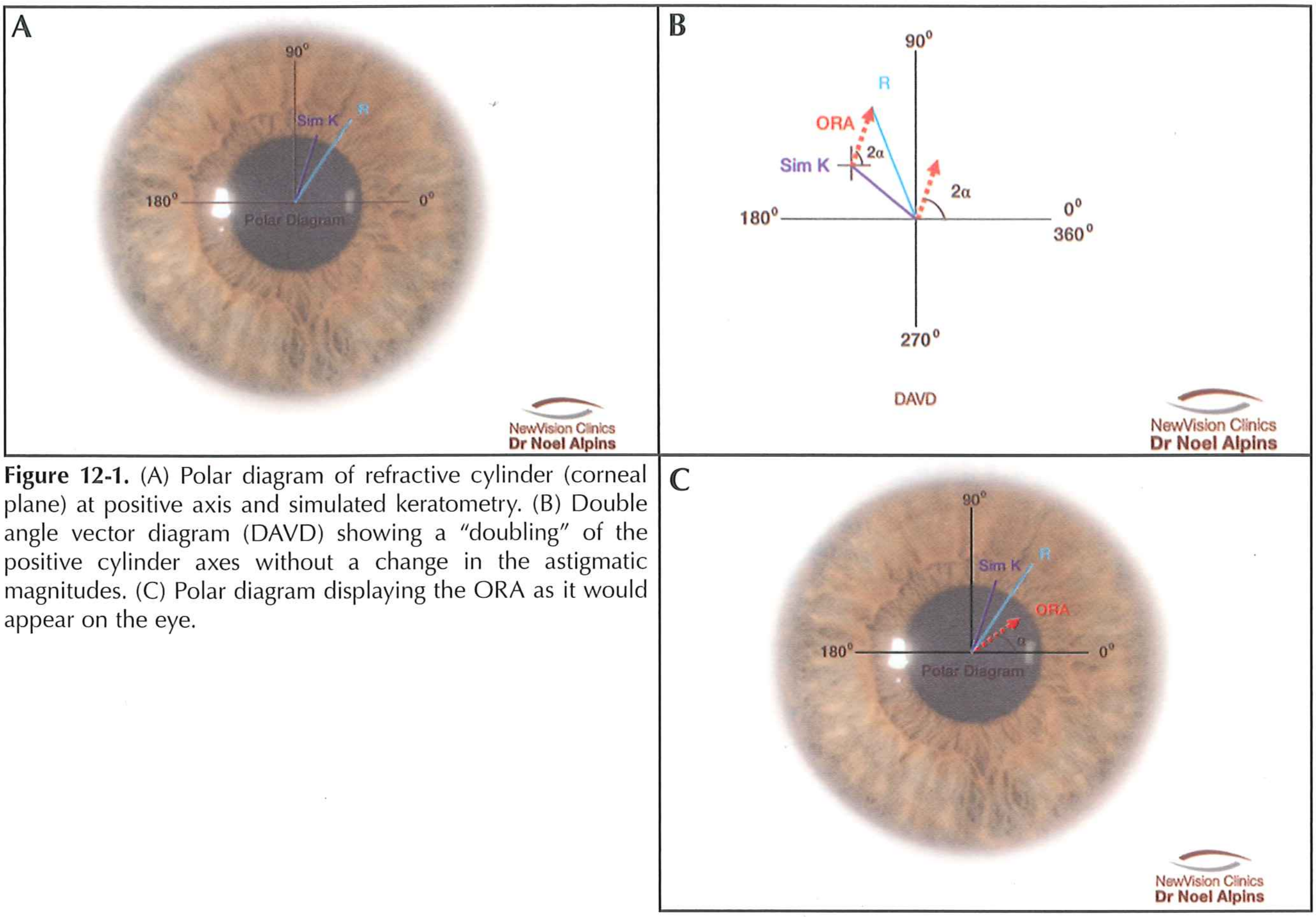

Figure 12-1. (A) Polar diagram of refractive cylinder (corneal plane) at positive axis and simulated keratometry. (B) Double angle vector diagram (DAVD) showing a "doubling" of the positive cylinder axes without a change in the astigmatic magnitudes. (C) Polar diagram displaying the ORA as it would appear on the eye.

CALCULATION OF ORA

Figure 12-1A shows on a polar display the second-order spherocylinder of the wavefront or the positive cylinder of the manifest refraction measurements, together with the topography or keratometry measurements for corneal astigmatism. Doubling the axes of the astigmatism while leaving the magnitudes unchanged allows for the conversion of polar coordinates to Cartesian coordinates (Figure 12-1B). The ORA, determined on the double-angle plot, is then transferred to the origin (x=0, y=0) and halved to simulate how it would exist within the eye (Figure 12-1C—polar diagram). This vectorial difference, measured in diopters and degrees and calculated using simple trigonometric principles, has a proportional relationship to astigmatism—meaning that, while the astigmatic differences between refractive and corneal astigmatism increases in either magnitude and/or angle difference, so too increases the magnitude of the ORA. As a result, treatment using refractive parameters alone neutralizes the internal ocular astigmatism quantified by the ORA on the front corneal surface, leading to increased aberrations and a reduction in the quality of vision achieved.[9,10]

There are currently software programs available that will calculate the ORA (Figure 12-2, www.assort.com) from simulated keratometry parameters exported directly from topography and refractive cylinder at the corneal plane. Conveniently, these can be used directly from the analytical outputs generated within the topography device.

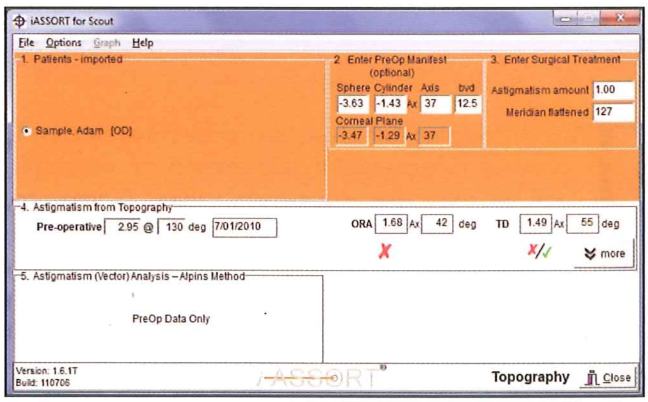

Figure 12-2. The iAssort software program for corneal astigmatism analysis. Simulated keratometry parameters are exported from the topography system (in this example, 2.95 D @ 130) and are compared to the refractive astigmatism (-1.29 D x 37 at the corneal plane) to calculate the ORA, which in this case is 1.68 D Ax 42. This is high in magnitude as displayed by the red cross, which indicates that it lies outside the normal range of 0.00 D to 1.00 D.

By quantifying the vectorial difference between the corneal and the refractive astigmatism using the ORA, the maximum possible correction of astigmatism can be determined. The distribution of the remaining ORA, which is the best outcome possible for an individual eye, needs to be considered carefully. Caution needs to be given to whether to treat the eye as is customary practice, leaving the astigmatism totally on the cornea by treating with manifest or wavefront refraction, or ascertaining if it is better to distribute the unavoidable remaining astigmatism between the two in an optimized manner to achieve the most favorable outcome.

Vector Planning

The Alpins method of vector planning directs the treatment closer to the principal corneal meridian, thereby correcting a greater amount of corneal astigmatism. This results in less corneal induced aberrations and a greater potential for improvement in best-corrected visual acuity.[5,9,11,12] The reduction in corneal astigmatism substantially exceeds the increase in measurable refractive cylinder that might theoretically occur. This has the overall effect of minimizing the total amount of astigmatism (refractive plus topographic) remaining after laser surgery, effectively gaining "something for nothing."

This method of vector planning can be used employing any combination, either of keratometry or topography values and manifest wavefront or cycloplegic refraction parameters, to determine the ORA amount present. The importance of vector planning when preoperatively assessing an astigmatic patient for refractive laser surgery cannot be overemphasized. In cases where the ORA is high (>1.00 D), the patient needs to be advised that all of the astigmatism in the optical system cannot be corrected no matter how perfect the surgical treatment applied so that expectations of a perfect outcome are adjusted to a realistic level.

There are several limitations of wavefront-guided treatments. Wavefront-guided treatments do not address the excessive and unnecessary amount of corneal astigmatism that would be left remaining (equal to the ORA) on the cornea postoperatively. This would potentially compromise visual acuity and contrast sensitivity outcomes, particularly under mesopic conditions. No recognition of topographic astigmatism values are taken into account during treatment with this approach.

They also do not consider the patient's subjective appreciation of astigmatism. The inclusion in the treatment of a patient's conscious perception of his or her refractive astigmatism is likely to benefit satisfaction.[3,13]

Wavefront-guided treatments could result in corneal surface irregularities[3] if all aberrations measured are corrected on the corneal surface. It is important to note that even eyes with normal (emmetropic) vision can suffer from aberrations that affect functional vision.[14]

Alternatively, topography-guided treatments do not consider that the amount of corneal astigmatism often differs from the refractive (second-order) astigmatism. Omitting this phenomenon during planning can result in refractive astigmatism surprises.

The advantages of preoperatively addressing both corneal and refractive astigmatism reduces the level of astigmatism that is left on the cornea compared to using refractive parameters alone, and, as a result, fewer second- and third-order aberrations are likely to remain.[2,3,9]

Vector Planning Studies Applied to Keratoconus and Wavefront-Guided Treatments

Two studies have shown the benefits of combining corneal and refractive parameters.[9,12] The first is a retrospective study of 45 eyes with forme fruste and mild keratoconus. These patients underwent surface ablation laser surgery.[12] All photoastigmatic refractive keratectomy (PARK) treatments were optimized to leave minimum remaining corneal astigmatism, favoring a bias to a with-the-rule orientation. Postoperative results at 12 months showed that, on average, for every eye in the group, the corneal cylinder was reduced by an additional 0.59 D compared to results that would have been attained by treating refractive values alone. A mean 1.61 D for each patient in the study group would have remained on the cornea postoperatively compared to the 1.02 D achieved. This was achievable without compromising the refractive outcome. In fact, it was enhanced with a better-than-predicted refractive astigmatism reduction. The expected mean refractive target was 0.59 D compared to the mean achieved at 12 months postoperatively of 0.43 D, demonstrating a clear net gain when assessing both corneal and refractive modes.

No problems or adverse signs such as increase in corneal irregularity and curvature or progression of ectasia resulting in a reduction of uncorrected or best-corrected visual acuity were detected.

In the second study, 21 eyes of 14 patients were distributed into 2 groups in a prospective double-masked study.[9] One group was treated by wavefront parameters alone, the other by wavefront combined with topography values (WF&VP) using vector planning. For the WF&VP combined group, the treatment profile was calculated using simulated keratometry readings from the topography (Humphrey Atlas) and second-order Zernike coefficients Defocus 4, Astigmatism 3, and 5 from the wavefront display (WaveScan Wavefront) of the entire eye.

Results showed a trend to greater correction of corneal astigmatism in the WF&VP combined group, with better visual outcomes in low-contrast mesopic conditions, a

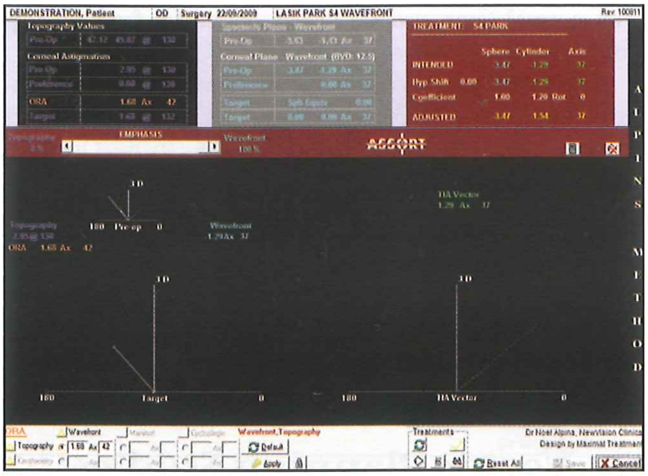

Figure 12-3. The ASSORT treatment screen displays both the manifest refraction and the corneal astigmatism by topography. The emphasis shown here is that of conventional treatment, 0% topography/100% wavefront refraction leaving all the ORA on the cornea as displayed by the "Target = 1.68 @ 132."

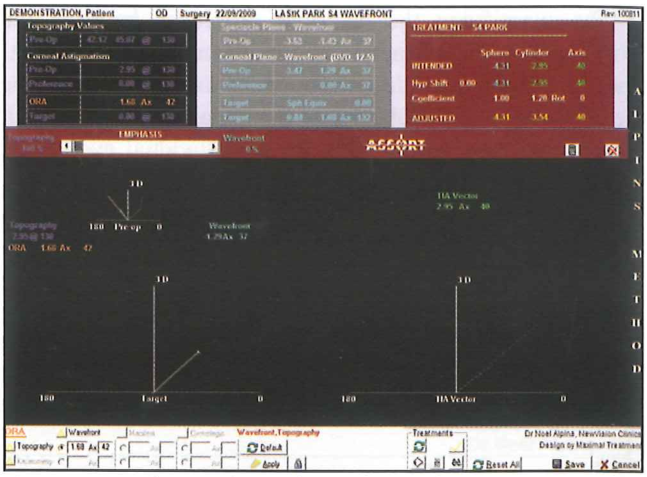

Figure 12-4. The emphasis shown here relates to topography-guided treatment where all the ORA (1.68 D) remains in the manifest refraction (100% topography/0% wavefront refraction), shown as the "Target = 0.84/-1.68 x 132."

greater reduction in horizontal coma, and greater potential for improvement in best-corrected visual acuity.

Vector Planning: A Case Study

The Alpins Statistical System for Ophthalmic Refractive Surgery Techniques (ASSORT) program developed at NewVision Clinics uses vector planning and analysis in a paradigm that maximally reduces overall astigmatism and has the option to favor a bias to with-the-rule astigmatism. This software has been used in this chapter for all calculations.

Using the example referred to in Figure 12-2, the ASSORT laser treatment module in Figure 12-3 displays the second-order spherocylindrical wavefront refraction, as measured using aberrometry, to be -3.63 DS/-1.43 DC x 37 at vertex distance of 12.5 mm and -3.47 DS/-1.29 DC x 37 at the corneal plane.

The topographic data of the same astigmatic eye display a simulated keratometry value of 2.95 D of astigmatism at the steepest meridian of 130 degrees. The total of corneal and refractive (corneal plane) together is 4.24 D, the corneal astigmatism making up 70% of it.

The amount of uncorrectable astigmatism in this patient's eye is 1.68 D Ax 42 (ORA). The distribution of this is reflected in the "emphasis" bar, where 100% indicates a goal of completely eliminating refractive astigmatism and 0% shows the emphasis on completely reducing topographic astigmatism by the treatment.

If we treat conventionally, that is, with 100% reduction of manifest refractive astigmatism as shown in Figure 12-3, all of this (ocular) residual astigmatism will remain neutralized on the cornea. This is shown as the "Target" 1.68 D at a meridian of 132 degrees, which is 90 degrees away from the ORA axis to neutralize the internal (noncorneal) error and results in the calculated zero astigmatism in the postoperative refraction (shown as the light blue "Target"). The target-induced astigmatism vector (TIA) is the amount of astigmatism that we are attempting to correct, and for this treatment to sphericize the refraction is 1.29 D Ax 37.

At the other extreme in the planning process, if we treat this eye emphasizing the complete reduction of topographic astigmatism values alone (Figure 12-4), 1.68 D of the unavoidable residual ORA will theoretically remain in the postoperative refraction in conjunction with a spherical cornea. However, taking an optimized view of the situation and incorporating a proportion of each into the overall treatment by shifting the emphasis for astigmatism reduction "to the left" increases the proportion of a preference for complete corneal astigmatism correction, resulting in the maximum ablation of treatment being more closely aligned to the principal corneal meridian. Consequently, there is less "off axis" effect to the corneal astigmatism, with more astigmatism reduction and less torque and meridian shift.[15]

Figure 12-5 shows the optimal treatment as determined from the surgical emphasis graph (Figure 12-6), which displays a linear relationship between the emphasis and the orientation of the target astigmatism. Figure 12-6 is based on the notion that with-the-rule corneal astigmatism is favorable and against-the-rule astigmatism is relatively unfavorable, so that more corneal astigmatism is reduced when its orientation is not favorable, which might also include oblique astigmatism. The placement of the emphasis on total corneal or refractive astigmatism correction is a decision that is guided by the surgeon.

In this example, the meridian of the target topography is 132 degrees. As it lies 42 degrees from a favorable with-the-rule orientation of 90 degrees, 42/90 or 47% can preferentially be apportioned to a topography-based goal of zero astigmatism. By the same process, the refractive

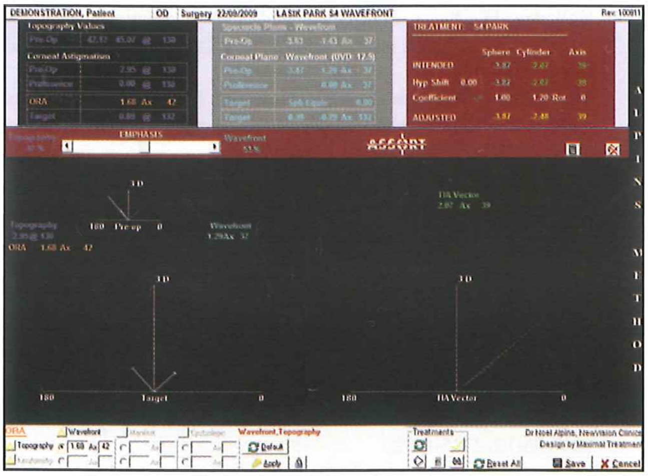

Figure 12-5. ASSORT Treatment Planning shows how the ORA of 1.68 D Ax 42 is apportioned 47% to eliminating the topography astigmatism and 53% to the refractive cylinder. The ORA is neutralized by an equivalent 0.89 D at the cornea and -0.79 DC at the spectacle refraction but at an orientation 90 degrees away of 132 degrees.

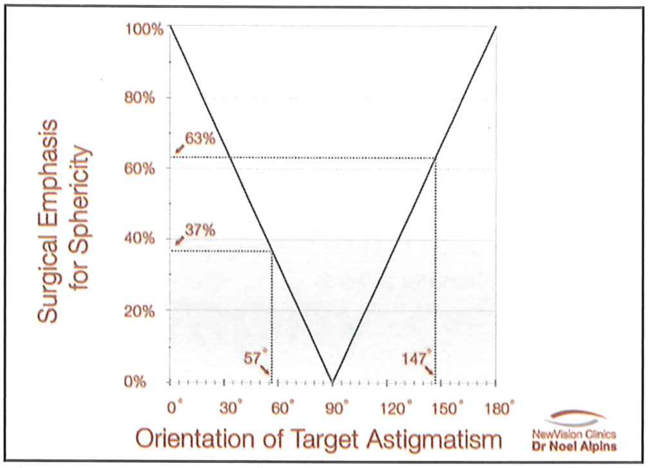

Figure 12-6. Linear relationship of surgical emphasis for sphericity versus orientation of target topography based on the notion that with-the-rule astigmatism is favorable and against-the-rule is unfavorable. This graph displays that, as the targeted corneal astigmatism approaches 90 degrees, the target refractive cylinder is reduced, so if the targeted corneal astigmatism is at 90 degrees, all the ORA will be corrected on the cornea.

astigmatism power axis of 42 degrees is 48 degrees away from 90 degrees and hence places 53% emphasis to a correction of refractive astigmatism. The TIA here is greater than before at 2.07 D Ax 39.

The overriding surgical principle is to approach corneal sphericity when the orientation of the target corneal astigmatism to remain becomes increasingly unfavorable. It is a surgical decision guided by which orientation is more favorable than others. Thus, the surgical emphasis needs to be apportioned accordingly, using a linear relationship or other formula. For most astigmatism treatment, the emphasis of 60% to refractive astigmatism (rather than 100% conventional) is a safe choice, gaining a reduction in remaining corneal astigmatism of 40%. In some cases, another option is maintaining the proportion of corneal to refractive astigmatism (70%/30%) after the surgery as existed before surgery was undertaken with an emphasis of 70% to refractive astigmatism.

The patient's ORA is still 1.68 D but is now apportioned between the refraction and the corneal parameters. The corneal astigmatism targeted in this example is 53% of 1.68 D (0.89 D) and the remaining 47% (0.79 DC) of the emphasis placed refractively in a spherical equivalent of zero (+0.39 DS/-0.79 DC Ax 132). This remaining refractive astigmatism with a spherical equivalent of zero may not be fully perceptually evident to the patient, as shown in a previous study,[12] providing a net benefit of less remaining astigmatism.

It is important to highlight that no matter what the percentage chosen on the "emphasis" bar, the maximal treatment enables the minimum amount of astigmatism to be targeted, equal to the ORA. If the combined magnitude of the targeted remaining astigmatism is greater than the initial ORA, the surgery then fails to achieve the maximum astigmatism treatment, and the astigmatism is either under- or overtreated, leaving an excess amount of astigmatism remaining.[1]

As technology advances with future possibilities, each and every point that is measurable on the cornea by topography, together with wavefront aberrometry, could be "vector planned," resulting in the ultimate ablation profile with smooth, even transitions and an optimized amount of corneal astigmatism remaining with the maximal treatment.

Conclusion

Refractive treatments based completely on either extreme of topographic or refractive data alone can not attain the same optimal results in most astigmatic patients as vector planning, which combines both parameters in a balanced optimized manner. Wavefront-guided laser refractive surgery has certainly been of benefit in correcting, on the cornea, the internal aberrations of the eye. However, the correction of higher-order aberrations in cases where there is a significant ORA needs to be more fully explored to increase overall patient satisfaction, The ORA is the key parameter that quantifies the amount of excess corneal astigmatism to neutralize the internal ocular second-order aberrations.

Topographic-guided lasers provide comprehensive mapping in situations of corneal irregularity where manifest and wavefront refractions may be inadequate to provide a smoother corneal surface.

Using the Alpins method of vector planning to combine information from the refraction (manifest or wavefront) as well as the topography can help minimize astigmatism remaining on the cornea and in the optical system of the eye. This optimizes visual outcomes, particularly in low light and reduced-contrast environments. The ORA and the resultant astigmatism remaining on the cornea are the essential parameters to guide the astigmatism optimization in the vector planning process.

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