Chapter 13

Combined Wavefront and Topography Approach to Refractive Surgery Treatments

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Recent advances in refractive surgery and diagnostic technology, together with the introduction of wavefront treatments, have given doctors a more thorough understanding of the eye's refractive characteristics than ever before. The excellent results attained with this new technology have shown the capabilities of wavefront-guided treatments in effectively reducing spherical aberration.[1–3] However, wavefront-assisted laser surgery does not address the intraocular (noncorneal) astigmatism that remains on the cornea postoperatively. With this approach, topographic values are not taken into account.

At the other end of the treatment scale, state-of-the-art topographers have allowed for an increase in the amount of data captured. However, they do not consider the fact that the amount of astigmatism at the corneal plane often differs from the refractive (second-order) astigmatism. As a result, treatments based solely on the map generated from a topographer, or aberrometer, do not usually have optimum outcomes.

Surgeons now have at their disposal a large amount of preoperative data, which would be helpful to them if they could fully integrate this into their treatment plan. Currently, they cannot take full advantage of this using refraction alone. However, by incorporating both the refractive and corneal measurements in the treatment paradigm, this may allow for improved visual outcomes.[4,5]

UNDERSTANDING REFRACTIVE VS CORNEAL ASTIGMATISM

Astigmatism treatment is prevalent in more than 60% of refractive surgery cases. By targeting zero corneal astigmatism, as well as zero refractive astigmatism, overall visual outcomes can be improved. While zero overall astigmatism is ideal, usually this result is unattainable due to the inherent differences in magnitude and/or orientation of corneal (topographic) and refractive (wavefront) astigmatism. The intraocular (noncorneal) astigmatism is gauged by the ocular residual astigmatism (ORA).[5,6] This is the vectorial difference calculated between the measured corneal and refractive astigmatism.

The ORA value is the amount of astigmatism that will remain in the eye if only refractive astigmatism is corrected. The ORA is calculated, using trigonometric principles, by doubling the angles of the refractive and corneal astigmatic axes to determine the difference between the two (Figure 13-1). The astigmatic magnitudes remain unchanged. The resultant ORA axis on the double-angle vector diagram is then halved to convert it back to a polar diagram, which represents the parameters on the eye.[4,5,7,8]

Using this approach, the maximum amount of astigmatism is treated. The distribution of any remaining ORA needs to be considered carefully. Do we leave this totally on the cornea by treating with manifest wavefront refraction, as is customary practice, or is it better to distribute the astigmatism between the two in a "favorable" optimized manner?

Certainly, it would be advantageous to be able to reduce a greater amount of corneal astigmatism by directing the treatment closer to the principal meridia, creating less "off-axis" effect and reduced torque[9] without compromising the refractive outcome. Using the vector planning technique, this is achievable and can result in a better refractive outcome associated with reduced second-order aberrations.

Limitations of Wavefront-Guided or Topographic-Guided Treatments Alone

While wavefront- and topographic-guided treatments both have much to offer, when it comes to astigmatism, neither can offer the complete picture alone. Wavefront aberrometry devices measure lower- and higher-order aberrations of the eye's optical system. The refractive guidance provided by wavefront technology to reduce spherical aberrations by achieving the most effective prolate aspheric profile may be significant and the benefits clear.[10]

However, for astigmatism, the treatment issues are more complex. There is a perceptual component to consider, which is not taken into account by the wavefront-guided approach. There is no consideration of the patient's subjective appreciation of astigmatism, which is related to the visual cortex of the brain. The visual cortex may "accept" some, or all, of the astigmatism resulting from the wavefront refraction and, as a result, the patient does not perceive any visual problem. This "acceptance" of the wavefront refraction by the visual cortex is best reflected in the manifest refraction. The inclusion in the treatment of a patient's conscious perception of his or her astigmatism is likely to lend to satisfaction.[11,12]

Another drawback of the wavefront-guided approach is that if practitioners attempt to correct all ocular aberrations at the corneal surface, it would result in corneal surface irregularities.[11] In order to obtain the best possible astigmatic outcome, it would be advantageous to have a regular cornea with orthogonal and symmetrical orientation.[4] It is important to note that even eyes with normal (emmetropic) vision can suffer from aberrations that affect functional vision.[13]

Manifest refraction also needs to be brought into the picture. By measuring manifest refraction, we incorporate input from the visual cortex as well as the contribution from corneal astigmatism and internal optics (lens) of the eye. In most cases, the refractive cylinder is different in orientation and/or magnitude from the corneal astigmatism, as measured by topography. If treatment were performed by refraction parameters alone, an excessive and unnecessary amount of corneal astigmatism would be left behind. Consequently, lower second-order astigmatic aberrations and third-order coma would not be minimized by treatment. This would potentially compromise visual acuity and contrast sensitivity outcomes.

Meanwhile, topography-guided ablations are derived from an objective measurement of the corneal astigmatism. One problem, however, is that treatment directed principally on this basis does not take into consideration the likely difference in astigmatism magnitude and/or axis from that present on the manifest or wavefront refraction. However, corneal topographic analysis is essential not only as a diagnostic tool for detection of irregular or keratoconic corneas, but also for determining where the total treatment is applied. Incorporation of the corneal status into the treatment plan provides potential for improvement in BCVA.

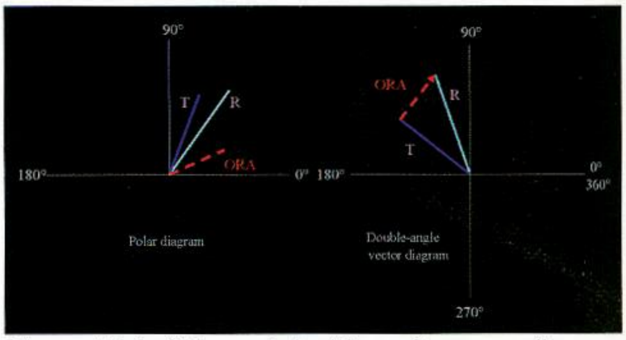

Figure 13-1. Polar and double-angle vector diagrams showing ORA vector.

It isimportant to note that directly combining the wavefront-guided approach and disregarding the topographic surface is not a favorable option. If we try "sculpting" one cylinder (refractive astigmatism) onto a second cylinder (corneal astigmatism) of different magnitude and/or axis, this can result in a third cylinder with greater magnitude than the original preoperative astigmatism.[5,9]

Combining Wavefront and Topographic Data Using Vector Planning

With the vector planning method, both wavefront and topographic information can be taken into account. The advantages of addressing both corneal and refractive astigmatism preoperatively are clear—this approach can improve visual outcomes of spherocylindrical treatments by combining the topographic and refractive astigmatic components. A reduced level of astigmatism is left on the cornea compared to using refractive parameters alone and, as a result, fewer second- and third-order aberrations may remain.[4,5,7,14]

The calculations performed in this chapter utilize the ASSORT program (Alpins Statistical System for Ophthalmic Refractive Surgery Techniques) developed by Dr. Alpins. The program uses vector planning and analysis in a paradigm that favors with-the-rule astigmatism. With this method, corneal astigmatism is taken into account and reduction in postoperative refractive astigmatism is optimized.[4,5,7,8,14]

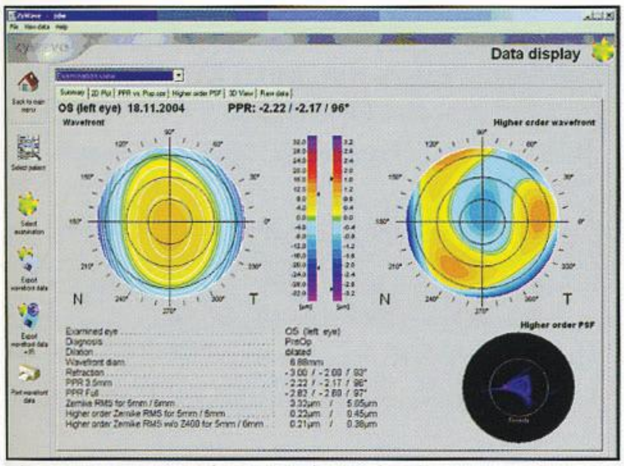

Figure 13-2. Wavefront analysis display.

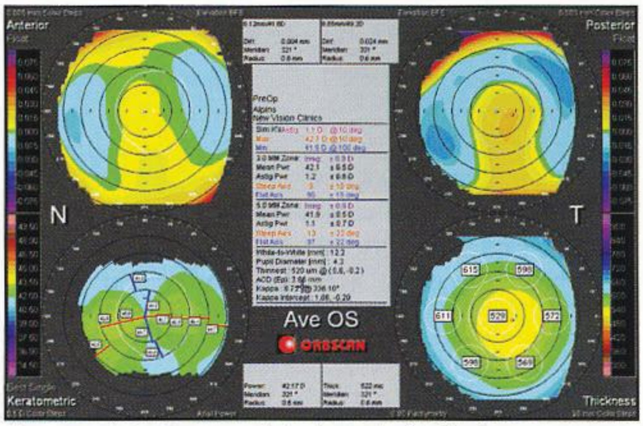

Figure 13-3. Topographical analysis display.

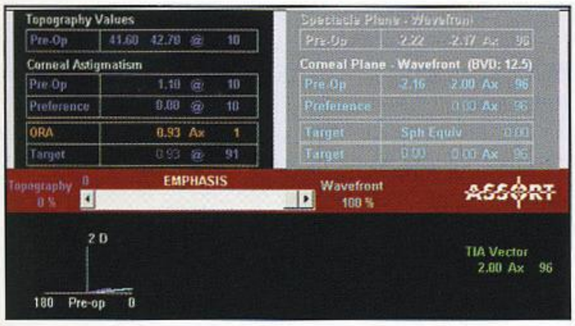

Figure 13-4. The ASSORT surgical planning module with emphasis to 100% reduction of refractive astigmatism.

Consider the following example:

Figure 13-2 shows a wavefront data display. The spherocylindrical refraction as measured by the wavefront device at the spectacle plane is –2.22 –2.17 x 96 (corneal plane is –2.16 –2.00 x 96 with BVD 12.5 mm). The aberrations are quantified as root-mean-square values at the bottom of the display. Higher-order aberrations comprise 0.45 microns of the total aberrations (5.05 microns), indicating that the majority of the treatment lies in correcting (second-order) spherical and cylindrical components.

Figure 13-3 displays the topographic data of the same astigmatic eye. The "keratometric" map in the lower left corner shows the typical bowtie appearance of the regular corneal against-the-rule astigmatism. The simulated keratometry values show 1.10 D of astigmatism at the steepest meridian of 10 degrees.

Combining this topographic information into the treatment module of the ASSORT program allows us to view the optimal treatment and resultant spectacle and corneal astigmatic targets for which we are aiming (Figure 13-4).

The topography-simulated K values are displayed on the left, and the wavefront refraction is on the right. The amount of uncorrectable astigmatism in this patient's eye is 0.93 x 001 (ORA). The distribution of this is reflected in the "Emphasis" bar, where 100% indicates treatment of refractive astigmatism alone and 0% shows the contribution of topographic astigmatism to the treatment.

If we treat conventionally, that is with 100% second-order wavefront refraction, all of this residual astigmatism will remain on the cornea. This is shown as the "Target" 0.93 D at a near vertical meridian of 91 degrees, which is 90 degrees away from the ORA axis to neutralize the internal (noncorneal) error and results in zero astigmatism in the postoperative refraction (shown as the light blue "Target"). The target-induced astigmatism vector (TIA) being employed is 2.00 D x 96.

At the other extreme, if we treat this eye by topography values alone, –0.93 DC x 91 will remain in the postoperative refraction. Incorporating a proportion of each into the overall treatment, by shifting the emphasis for astigmatism reduction "to the left" and increasing the proportion of corneal astigmatism correction, results in the treatment being more closely aligned to the principal corneal meridian, more flattening effect, and reduced corneal astigmatism and torque.[9] Figure 13-5 shows the emphasis placed at 40% topography and 60% refraction.

The patient's ORA is still 0.93 D, but it is apportioned between the refraction and the cornea. Here, less corneal astigmatism is targeted, with 60% of 0.93 D (0.56 D) targeted at the same meridian of 91, and the remaining 40% (0.37 D) of the emphasis placed refractively in a spherical equivalent of zero (+0.19 –0.37 x 91). This remaining refractive astigmatism is not perceptually evident.

When measurements were in fact taken at 2 months postoperatively, simulated keratometry showed 0.50 D @ 85 degrees, while wavefront refraction measured –0.24 DC x 49. This minimal amount of astigmatism was not detected by the perceptive system as the manifest refractive astigmatism was plano, gaining less overall astigmatism.

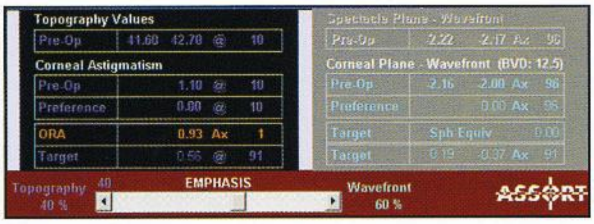

Figure 13-5. The ASSORT planning module with emphasis placed at 40% topography and 60% refraction.

Table 13-1

Forme Fruste and Mild Keratoconus Outcomes

Mean Astigmatism	Preoperative	Postoperative (3 months)
Corneal	1.92D ± 1.44	1.11D ± 0.72
Refractive	1.65DC ± 1.25 (corneal plane)	0.51DC ± 0.56

Mean ORA = 1.22 D ± 0.85

Mean postoperative spherical equivalent was 0.00 D ± 0.62.

N = 33

The fact is that even though all the astigmatism could not be removed from the system, with some apportioned to the refractive astigmatism and the rest to the remaining corneal astigmatism, results with this technique were still significantly better than they would have been by employing wavefront parameters alone. The overall astigmatism was reduced from 3.10 D (1.10 D corneal +2.00 DC wavefront) to 0.74 D (0.50 D corneal –0.24 DC wavefront refraction). This is lower than the uncorrectable amount of 0.93 D calculated by the ORA. The data also showed that by taking care of corneal astigmatism as well, there was a large reduction in remaining lower-order aberrations, with a RMS of 0.94 microns.

Study Using Combined Topographic and Refractive Data to Treat Astigmatism

To determine if this vector planning approach could benefit patients, a study was recently launched. A group of 33 eyes with subclinical (forme fruste) or mild keratoconus (nonprogressive) were treated using the Alpins method of vector planning. Due to the irregular shape of these corneas, as reflected in asymmetry of greater than 1.50 D on topography and higher than average ORA values (0.73 D[4] and 0.81 D[5]), photoastigmatic refractive keratectomy (PARK) was performed in each case (Table 13-1).

All treatments were optimized to leave minimum remaining corneal astigmatism toward with-the-rule orientation, with 40% of the emphasis placed on topography and 60% on refraction. Postoperative results at 3 months showed that, on average, the corneal cylinder was reduced by 0.75 D, compared to results that would have been attained by treating refractive values alone. This was done without compromising the refractive outcome.

In the future, we envision developing software to use this method of vector planning and to optimize treatment for each separate hemi-division of the cornea in cases of irregular astigmatism. This should result in a more orthogonal, regular cornea[4,15,16] with its ensuing benefits to vision.

Summary

The Alpins method of vector planning utilizes information from both corneal topography and manifest refraction/wavefront data to target less postoperative corneal astigmatism and reduced torque. Using this combined approach, second- and third-order (coma and trefoil) astigmatic aberrations are minimized. As a result, there is the potential for improvement in BCVA and contrast sensitivity.

Neither of these two approaches, either topographic or refractive alone, can attain the same results in most astigmatic patients. Topographic-guided lasers play an important role in customizing treatments for irregular postoperative or traumatized corneas—enabling comprehensive mapping in situations where subjective wavefront refractions may be inadequate to provide a smoother corneal surface.

Wavefront-guided laser refractive surgery has certainly been of benefit in correcting aberrations of the eye, in particular helping to maximize low-light and night vision. However correction of the second-order astigmatic aberrations needs to be more fully explored to increase overall patient satisfaction.

Together, using the vector planning technique, information from these two approaches can help to minimize astigmatism from the system and ultimately to optimize results in many cases.

References

1. Carones F, Vigo L, Scandola E, et al. Expanded range custom cornea algorithms for myopia and astigmatism: one-month results. *J Refractive Surg.* 2004;20(5):S619–S623.
2. Winkler von Mohrenfels C, Huber A, Gabler B, et al. Wavefront-guided laser epithelial keratomileusis with the wavelight concept system 500. *J Refractive Surg.* 2004; 20(5):S565–S569.
3. Mastropasqua L, Nubile M, Ciancaglini M, et al. Prospective randomized comparison of wavefront-guided and conventional photorefractive keratectomy for myopia with the Meditec MEL 70 laser. *J Refractive Surg.* 2004;20(5): 422–431.
4. Alpins NA. Astigmatism analysis by the Alpins method. *J Cataract Refract Surg.* 2001;27:31–49.
5. Alpins NA. New method of targeting vectors to treat astigmatism. *J Cataract Refract Surg.* 1997;23:65–75.
6. Duke-Elder S (ed). *System of Ophthalmology. Vol 5: Ophthalmic Optics and Refraction.* St Louis, MO: Mosby; 1970:275–278.
7. Alpins NA. A new method of analyzing vectors for changes in astigmatism. *J Cataract Refract Surg.* 1993; 19:524–533.
8. Alpins NA, Goggin M. Practical astigmatism analysis for refractive outcomes in cataract and refractive surgery. *Surv of Ophthal.* 2004;49:109–122.
9. Alpins NA. Vector analysis of astigmatism changes by flattening, steepening, and torque. *J Cataract Refract Surg.* 1997;23:1503–1514.
10. Munger R. New paradigm for the treatment of myopes by refractive surgery. *J Refractive Surg.* 2000;16:S651–S655.
11. Alpins NA. Wavefront technology: a new advance that fails to answer old questions on corneal vs. refractive astigmatism correction (editorial). *J Cataract Refract Surg.* 2002;18:737–739.
12. Kohnen T. Combining wavefront and topography data for excimer laser surgery: the future of customized ablation? (editorial). *J Cataract Refract Surg.* 2004;30:285–286.
13. Williams D, Yoon GY, Porter J, Guirao A, Hofer H, Cox I. Visual benefit of correcting higher-order aberrations of the eye. *J Refract Surg.* 2000;16:S554–S559.
14. Alpins NA, Walsh G. Aberrometry and topography in the vector analysis of refractive laser surgery. In: Boyd BF, Agarwal A, eds. *Wavefront Analysis, Aberrometers and Corneal Topography.* Panama: Highlights of Ophthalmology;2003:313–322.
15. Goggin M, Alpins N, Schmid L. Management of irregular astigmatism. *Curr Opin Ophthal.* 2000;11:260–266.
16. Alpins NA. Treatment of irregular astigmatism. *J Cataract Refract Surg.* 1998;24:634–646.