Fifty Four

New Horizons of Optimizing Astigmatic Parameters in LASIK Treatments using Vector Planning

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INTRODUCTION

Refractive surgeons are constantly refining methods and techniques, seeking new technology for diagnosis and treatment, so endeavouring to make the patient's experience of corrective refractive surgery a positive one. All these steps in the laser vision correction process have the goal of improving visual outcomes and patient satisfaction. Much attention in recent times has been given to wavefront technology in achieving this end, with a lot more still to discover about the impact of higher order aberrations on daily visual tasks. The fundamental parameters depicting the success of refractive surgery still involve minimizing the amount of refractive sphere and cylinder remaining postoperatively in the visual system. This requirement should include corneal as well as refractive astigmatism.

LIMITATIONS OF WAVEFRONT OR TOPOGRAPHIC-GUIDED TREATMENTS 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.[1] However, wavefront-assisted laser surgery does not address the neutralization of the intraocular (noncorneal) astigmatism that is left remaining on the cornea postoperatively. If treatment were performed by refraction parameters alone, an excessive and unnecessary amount of corneal astigmatism would be left remaining. 'Sculpting' one cylinder (refractive astigmatism) onto a second cylinder (corneal astigmatism) of different magnitude and/or axis can result in a third cylinder with greater magnitude than the original preoperative astigmatism.[2,3]

Consequently, lower second-order astigmatic aberrations and third-order coma and trefoil would not be minimized by treatment. This would potentially compromise visual acuity and contrast sensitivity outcomes particularly under mesopic conditions. Unfortunately with this approach, topographic values are not taken into account.

Furthermore, there is no consideration of the patient's subjective appreciation of astigmatism, which is related to the visual cortex of the brain. The cortical perception 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 and hence the need to cross-check the manifest with the wavefront refraction to ensure that the spherical and astigmatic components of each are comparable. The inclusion in the treatment of a patient's conscious perception of their refractive astigmatism is likely to benefit their satisfaction.[4,5]

However a further 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.[4] In order to obtain the best possible astigmatic outcome, it would be advantageous to have a regular cornea with orthogonal and symmetrical orientation.[6] It is important to note that even eyes with normal (emmetropic) vision can suffer from aberrations that affect functional vision.[7]

At the other end of the treatment scale, state-of-the-art topographers have allowed for an increase in the amount of data captured and are essential not only as a diagnostic tool for detection of irregular or keratoconic corneas, but also for determining at which part of the cornea the treatment needs to be applied. Topography-guided ablations are derived from an objective measurement of the corneal astigmatism. 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 entirely on the map generated from a topographer or aberrometer may not achieve the full potential of optimum outcomes.

Refractive Versus Corneal Astigmatism

Astigmatism treatment is prevalent in more than 60% of refractive surgery cases. By targeting the two ultimate outcomes of 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. This intraocular (non-corneal) astigmatism is gauged by the ocular residual astigmatism (ORA).[2,8] The ORA value is also equivalent to the amount of neutralising astigmatism that will remain on the cornea if only refractive astigmatism is corrected.

Calculation of ORA

Consider the example in Figure 54.1. The wavefront refraction displays astigmatism of –2.80DC Ax 109 at the corneal plane (i.e. power axis at 19 degrees). The corneal astigmatism is 1.80D @ 29 shown by the simulated keratometry from the topography measurement. The wavefront refraction cylinder (R) and the corneal astigmatism (Sim K) are represented on a polar diagram in Figure 54.2A.

The ORA is the vectorial difference between the measured corneal and refractive astigmatism. It can be calculated by doubling the angles of the refractive

Topography valves

Pre-Op	43.10 44.90 @ 29

Corneal astigmatism

Pre-Op	1.80 @ 29
Preference	0.00 @ 29
ORA	1.10 Ax 2
Target	0.74 @ 92

Speciacle plane - Wavefront

Pre-Op	43.10 44.90 @ 29

Corneal plane - Wavefront (BVD: 12.5)

Pre-Op	-1.64 -2.60 Ax 109
Preference	0.00 Ax 109
Target	Sph Equiv 0.00
Target	0.18 -0.35 Ax 92

Fig. 54.1: Wavefront refraction and topography values are used to calculate the ocular residual astigmatism (ORA). The wavefront refraction must be converted to the corneal plane before this calculation occurs

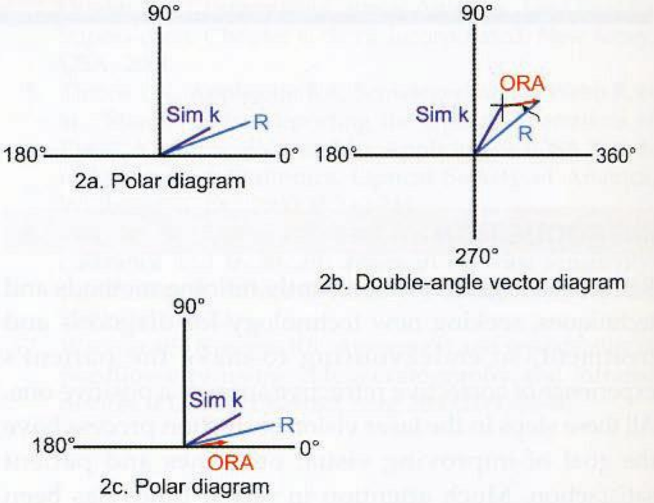

Fig. 54.2: Calculation of ORA: A. Polar diagram displays corneal and refractive astigmatism magnitude and direction, B. Double-angle vector diagram to calculate the ORA and C. Polar diagram as the ORA would appear on the eye

(38 degrees) and corneal (58 degrees) astigmatic axes (shown in Figure 54.2B double-angle vector diagram - DAVD) and leaving the magnitudes unchanged. Using trigonometric principles to determine the difference between the two, the ORA on the DAVD = 1.10D Ax 4. This ORA vector is then taken to the origin (x = 0, y = 0) and halved to convert it back to a polar diagram (Fig. 54.2C, ORA = 1.10D Ax 2), which represents the parameters within the optical system of the eye.[2,6,9,11]

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 'favourable' 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 corneal meridia, creating less "off-axis" effect and reduced torque[3] without compromising the refractive outcome. Using the vector planning technique, this in fact is achievable, and can result in a better refractive outcome, a greater potential for improvement in best corrected visual acuity and reduced second-order aberrations, coma and trefoil.

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 pre-operatively 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 may remain.[2,6,9,11]

Outcomes Using Combined Topographic and Refractive Parameters to Optimally Treat Astigmatism

Two studies have been recently undertaken at our centre to determine the outcomes of this vector planning approach:

The first is an ongoing study consisting at this stage of a group of 45 eyes with form fruste or mild keratoconus (nonprogressive) treated using the Alpins Method of vector planning for the treatment of astigmatism. Treatments were performed on the VISX STAR S1 and subsequently VISX STAR S2 excimer laser systems. Due to the irregular shape of these corneas, as reflected by inferior/superior asymmetry of greater that 1.50 D on topography and higher than average ORA values with a mean of 1.34 D (compared with normal corneas where the ORA has been shown to be 0.73D[2] and 0.81D[6]), surface ablation with PhotoAstigmatic Refractive Keratectomy (PARK) was performed in each case.

All treatments were optimized to leave minimum remaining corneal astigmatism favouring a with-the-rule orientation. Postoperative results at 12 months showed that, on average, we were able to reduce the corneal cylinder by an additional 0.68 D, compared to results that would have been attained by treating refractive values alone. This was achievable without compromising the refractive outcome.

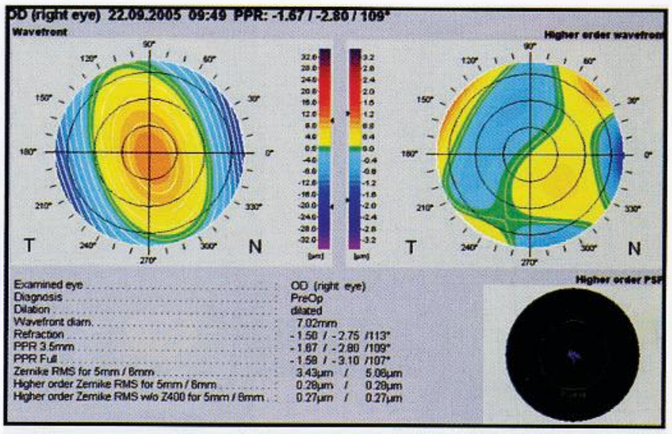

Fig. 54.3: Wavefront map (B&L Zywave) displaying the PPR at 3.5 mm, total and higher order aberrations

In a second study 21 eyes with myopia and astigmatism were prospectively randomized into 2 groups prospectively: one group was treated with wavefront parameters alone, the other with wavefront parameters combined with topography measurements using vector planning to optimise treatment parameters. This was a collaborative study completed in October 2006. All treatments were performed using LASIK on the VISX STAR S4 excimer laser. The wavefront and vector planning group showed a greater reduction in corneal astigmatism, greater improvement in visual outcomes under mesopic conditions, lower higher order aberrations and greater potential for improvement in BCVA.

Vector Planning—A Case Study

The calculations performed in this chapter utilize the *ASSORT*® program (Alpins Statistical System for Ophthalmic Refractive surgery Techniques) developed at NewVision Clinics. The program uses vector planning and analysis in a paradigm that has the option to favor with-the-rule astigmatism. With this method corneal astigmatism is taken into account and reduction in post-operative refractive astigmatism is optimized.[2,6,9-11]

The sphero-cylindrical refraction as measured by the wavefront device (Fig. 54.3) at the spectacle plane is –1.67DS / –2.80DC Ax 109. The aberrations are quantified as root-mean-square (RMS) values at the bottom of the display. Higher-order aberrations comprise 0.28 microns of the total aberrations (5.06 microns), indicating that the majority of the treatment lies in correcting (second order) spherical and cylindrical components.

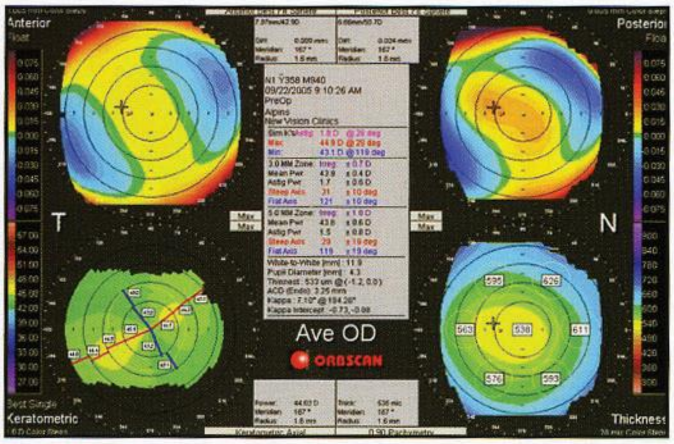

Fig. 54.4: Topography (B&L Orbscan) displays the simulated keratometry and the bow-tie shape of the astigmatism on the keratometric map

Figure 54.4 displays the topographic data of the same astigmatic eye. The 'Keratometric' map in the lower left hand corner shows the typical bow-tie appearance of the regular corneal astigmatism. The simulated keratometry values show 1.80D of astigmatism at the steepest meridian of 29 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 astigmatism values that we are targeting (Fig. 54.5).

The topography simulated K's are displayed in the upper left quadrant and the wavefront refraction in the middle section. The amount of uncorrectable astigmatism in this patient's eye is 1.10D Ax 2 (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% second-order wavefront refraction, all of this (ocular) residual astigmatism will remain neutralized on the cornea. This is shown as the 'Target' 1.10D at a meridian of

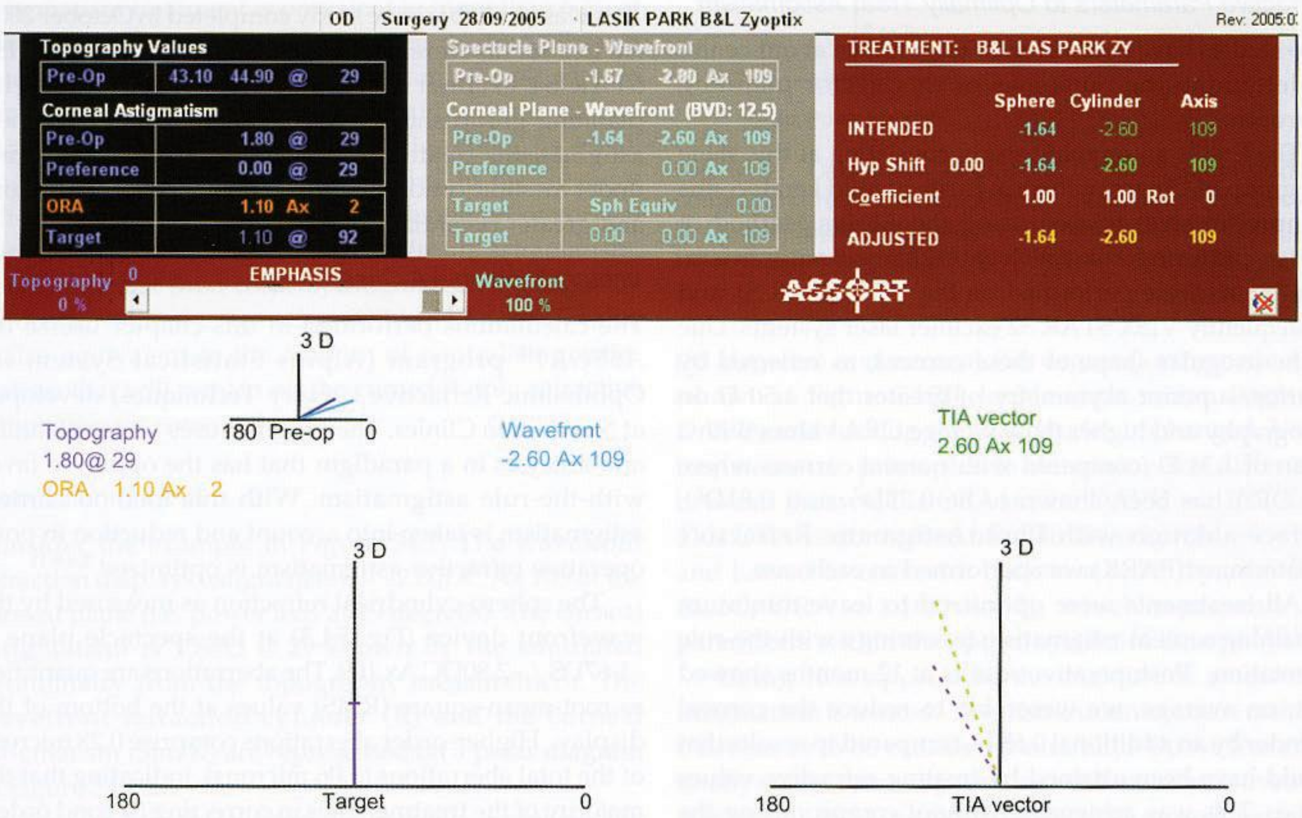

Fig. 54.5: The ASSORT treatment screen displays both the wavefront refraction and the corneal astigmatism by topography. The emphasis shown here is that of conventional treatment, 0% topography / 100% wavefront refraction

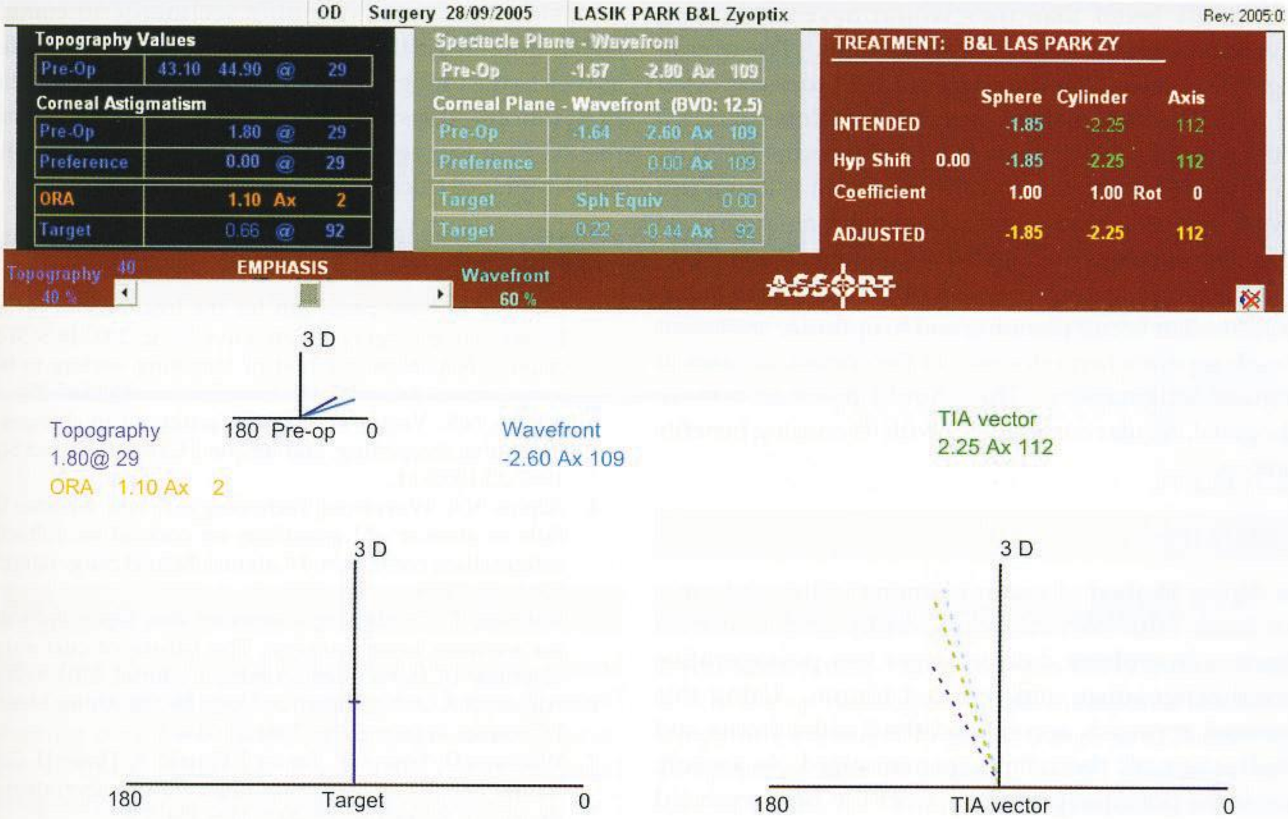

Fig. 54.6: The ASSORT treatment screen displays the treatment emphasis as 40% topography and 60% refraction

92 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) being employed is 2.60D Ax 109.

At the other extreme, if we treat this eye emphasising the reduction of topography values alone, –1.10D of the unavoidable residual ORA will theoretically remain in the postoperative refraction. Incorporating a proportion of each into the overall treatment, by shifting the emphasis for astigmatism reduction "to the left," increasing the proportion of complete corneal astigmatism correction, results in the treatment being more closely aligned to the principal corneal meridian, less "off axis" effect reduced corneal astigmatism and torque.[9] Figure 54.6, shows an emphasis placed on the residual astigmatism (i.e. the ORA) of 40% topography and 60% refraction.

The target induced astigmatism vector (TIA) here is slightly less than before at 2.25D Ax 112.

The patient's ORA is still 1.10D but it is apportioned between the refraction and the cornea readings. Here less corneal astigmatism is targeted, with 60% of 1.10 (0.66D targeted at the same meridian of 92 and the remaining 40% (0.44DC) of the emphasis placed refractively in a spherical equivalent of zero (+0.22DS/ –0.44DC Ax 92). This remaining refractive astigmatism may not be fully perceptually evident to the patient.

When measurements were in fact taken at six months in a current study at our centre, incorporating corneal as well as refractive astigmatism parameters on a Bausch & Lomb Technolas Z100 laser), simulated keratometry showed 0.50D@85 degrees while wavefront refraction measured –0.24DC Ax 79. This minimal amount of astigmatism was not detected by the perceptive system as the manifest refractive astigmatism was plano.

The fact is that even though all the astigmatism is not removable 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 using conventional totally refractive techniques. The overall astigmatism was still reduced from 1.10D, to be expected had refractive astigmatism been treated alone to 0.74D (0.50D corneal + 0.24D wavefront refraction). 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 0.94 microns.

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 corneae[6,12,13] 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 best-corrected visual acuity and contrast sensitivity.

Neither of these two approaches at each extreme, either completely prioritizing topographic or refractive goals, can attain the same results in most astigmatic patients. Topographic-guided lasers play an important role in customizing treatments for irregular post-operative 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.

Using the vector planning technique to combine information from the refraction (wavefront or manifest) as well as the topography can help minimize astigmatism from the optical system of the eye and ultimately optimize results in a larger proportion of cases where existing topographic-refractive differences require it.

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