ADVANCES IN PLANNING REFRACTIVE LASER AND CATARACT SURGERY

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When performing ablative laser or incisional surgery the goal is to minimise the postoperative refractive error including the astigmatic component. Understanding the effect of incisions in cataract surgery, or treating astigmatism optimally in refractive laser surgery, are key factors to improving visual outcomes.

Refractive Laser Surgery

Astigmatism treatment is prevalent in more than 60% of refractive surgery cases[1]. 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 (non-corneal) astigmatism is gauged by the ocular residual astigmatism (ORA)[2]. This is the vectorial difference measured between the corneal and refractive astigmatism (Figure 1) and is the amount of astigmatism that will remain in the eye if only refractive astigmatism is corrected.

The principal of vector planning directs the treatment closer to the principal meridia, creating less "off-axis" effect. A greater reduction of corneal astigmatism can be achieved than if treating by refractive parameters alone, without compromising the refractive outcome.

Wavefront aberrometry devices measure lower- and higher-order aberrations of the eye's optical system. There is no consideration of the patient's subjective appreciation, of astigmatism, which is related to the visual cortex of the brain. To correct all ocular aberrations at the corneal surface would result in corneal surface irregularities. It is important to note that even eyes with normal (emmetropic) vision can suffer from aberrations that affect functional vision[3].

Manifest refraction incorporates 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.

Topographyguided ablations do 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 best-corrected visual acuity.

Using the vector planning method, both wavefront and topographic information can be taken into account. A reduced level of[1][2][3][4].

astigmatism is left on the cornea compared to using refractive parameters alone and, as a result, fewer second and third order aberrations may remain [1][2][3][4].

Consider a sphero-cylindrical refraction as measured by aberometry at the spectacle plane of -2.22DS / -2.17DC Ax 96. Topographic data shows simulated keratometry values to be 1.10D of astigmatism at the steepest meridian of 10 degrees.

The amount of uncorrectable astigmatism (ORA) in this patient's eye is 0.93D Ax 1 (Figure 2). 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' 0.93D at a near vertical meridian of 91 degrees 90 degrees away from the ORA axis to neutralize the internal (non corneal) error and results in zero astigmatism in the post-operative refraction (shown as the light blue 'Target').

At the other extreme, if we treat this eye by topography values alone, 0.93DC will remain in the refraction post-operative. Incorporating a proportion of each into the overall treatment, by shifting the emphasis for astigmatism reduction "to the left," increasing the proportion of corneal astigmatism correction, results in the treatment being more closely aligned to the principal corneal meridia. Figure 3, shows the emphasis placed at 40% topography and 60% refraction.

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

When measurements were in fact taken at two months post-operatively, simulated keratometry showed 0.50D at 85 while wavefront refraction measured -0.24D Ax 49. 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 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 otherwise. The overall astigmatism was still reduced from 0.93D, 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.

Cataract and Incisional Surgery.

With micro-incisional cataract surgery (MICS) whether bimanual or coaxial- becoming more popular, the effect of the incision on the corneal shape tends to be forgotten. Many surgeons would claim their incisions are "astigmatically neutral" and therefore are not concerned with the placement of the incision. However, in reality even micro-incisions do impact on the corneal shape. This becomes even more critical when using Toric IOLs or limbal relaxing incisions (LRIs).

Astigmatism may be broken into two components: the magnitude and the direction (meridian). The incision may affect one or both of these components depending on where it lies in regards to the steepest corneal axis. It is therefore important to define the goal of the surgery before placing the incision. If the goal is to achieve the maximum reduction of the corneal astigmatism, this is achieved by flattening the cornea at the steepest meridian. That is, the incision coincides exactly with the steepest corneal axis, and the corneal astigmatism is maximally reduced but the meridian remains unchanged. Due to the slightly ovoid shape of the cornea the amount of flattening will depend on the position of the steepest meridian, with a larger effect on vertical meridia as seen in Figure 4.

However, in many cases the surgeon chooses to place the incision at the polar axes (vertical 90° or horizontal 180°) which often does not coincide with the corneal axis. In these "off-axis" situations the corneal shape changes both in magnitude and direction. The cornea is *flattened* (resulting in a reduction in magnitude) or *steepened* (resulting in an increase in magnitude) at the intended axis. There is also a component that is ineffective in changing the magnitude and instead results in a clockwise or counterclockwise movement that is termed *torque*[5].

The change induced by the surgery at the intended axis is known as the *flattening effect* (FE) and is measured in dioptres. The effective proportion of achieved flattening is the *flattening index* (FI) and is equal to the flattening effect divided by the TIA[5].

The relationship between flattening, steepening and torque forces is evident in Figure 5. The amount of flattening is maximum when the incision is at the steepest corneal axis (ie 0° misalignment). As the incision moves away from the steepest axis, the amount of flattening reduces until at 45° off-axis the magnitude of the astigmatism does not change at all. In this situation the ineffective torque is maximised. If the incision lies more than 45° away from the steepest corneal axis, there is a negative flattening effect. In other words the cornea is steepened at the intended axis, and the astigmatic magnitude in increased as well as the meridian changing through the torque force[5]. The amount of flattening or steepening and torque may be determined through vector analysis, an example of which is displayed in Figure 6. Here the treatment has been applied 15 degrees off-axis, resulting in a FE of 86.6% of the intended TIA (correlating with Figure 5).

It is crucial to consider these forces when using toric IOLs or LRIs. If the cataract incision is placed off-axis, both the magnitude and meridian of the astigmatism changes. If the surgeon ignores this change and places the toric IOL or LRI at the pre-operative meridian the astigmatic outcome is compromised. This may explain some adverse outcomes with these types of surgery, and is now being used to improve results.

Summary

The Alpins Method of vector planning utilizes information from both corneal topography and manifest refraction/wavefront data to target less post-operative corneal astigmatism. 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. Vector analysis is also used when planning cataract surgery to account for changes in corneal astigmatism from the effects of the cataract incision. Greater understanding of this will result in tighter outcomes when using toric IOLs or LRIs. This also allows the surgeon to manipulate the astigmatism magnitude and meridian to give optimal outcomes for every case.

1. Alpins, NA. New method of targeting vectors to treat astigmatism. *J Cataract Refract Surg*. 1997; 23:65-75.
2. Duke-Elder, S, ed. System of Ophthalmology. Vol 5: *Ophthalmic Optics and Refraction*. St Louis, MO: Mosby; 1970:275-278.
3. 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: S 554-S 559.
4. Alpins, NA. Astigmatism analysis by the Alpins Method. *J Cataract Refract Surg*. 2001; 27:31-49.
5. Alpins, NA. Vector analysis of astigmatism changes by flattening, steepening and torque. *J Cataract Refract Surg*. 1997; 23:1503-1514.

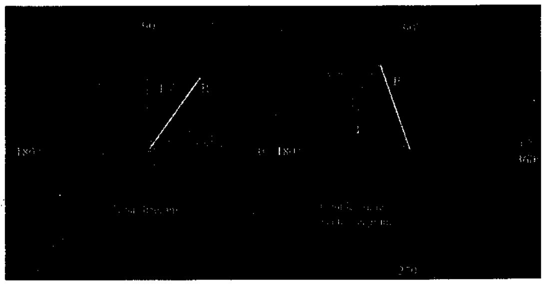

Figure 1. The ORA is calculated by doubling the angles of the refractive and corneal astigmatic axes (polar diagram), to determine the difference between the two. The astigmatic magnitudes remain unchanged. The resultant ORA axis on the double-angle vector diagram is then halved to convert it back to a polar diagram, which represents the parameters on the eye.

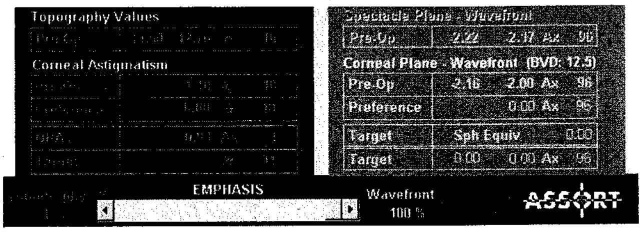

Figure 2. The ASSORT surgical planning module with emphasis to 100% reduction of refractive astigmatism. The polar diagrams on the left display the pre-operative and target vectors while the surgical vectors (TIA) are displayed on the right.

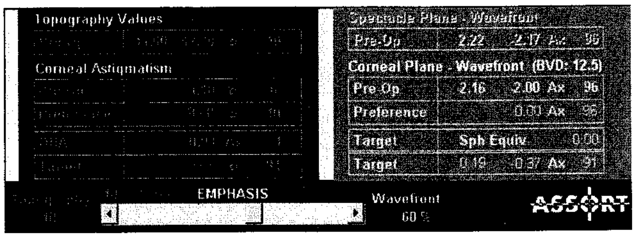

Figure 3. The ASSORT planning module with emphasis 40% topography and 60% refraction.

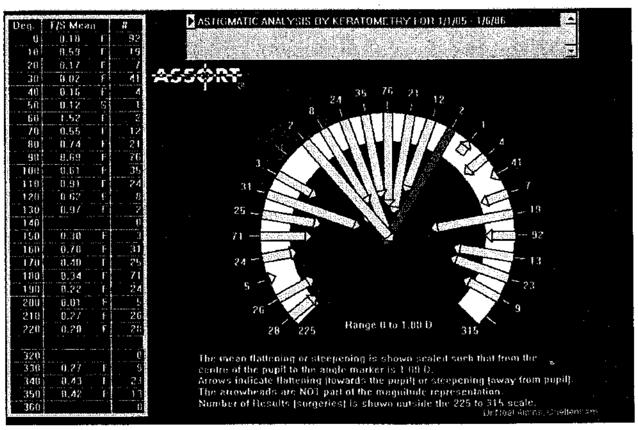

Figure 4. Analysis of flattening and steepening for different meridia. There is a greater effect for the incisions around the vertical axis due to the natural ovoid shape of the eye.

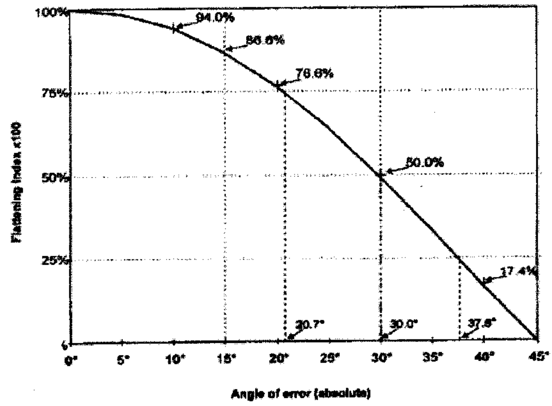

Figure 5. Effect of misaligned astigmatism treatment on flattening index

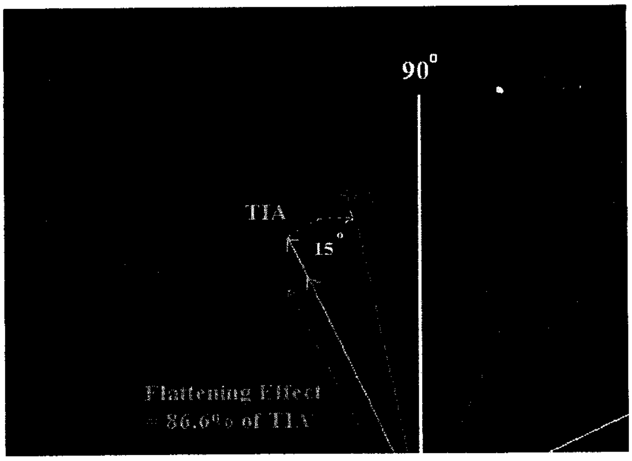

Figure 6. Polar diagram of a treatment applied 15% off-axis resulting in a FE of 86.6% of the intended TIA