27.1 VECTOR PLANNING FOR CUSTOMIZED LASIK TREATMENT INCORPORATING CORNEAL AND OPTICAL ASTIGMATISM PARAMETERS

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The analytical approach of vector planning can be merged successfully with diagnostic (corneal topography and wavefront analysis) and therapeutic (laser) aspects to provide an integrated approach to refractive surgery. This is particularly relevant for the effective treatment of astigmatism as a part of the overall sphero-cylindrical correction. In this way a customized treatment plan is employed to individualize the LASIK surgery according to the patient's unique corneal and refractive parameters.

The benefit to the patient is reduced corneal astigmatism achieved by a closer alignment of the treatment to the principal corneal meridia.[1]

Measuring Astigmatism

Astigmatism can be measured by two primary methods: the corneal shape (keratometry and topography) and by the optical correction (manifest refraction and wavefront analysis) required to establish a clear focus on the retina.

Corneal assessment: keratometry and topography

Keratometry provides a useful average value of corneal astigmatism between steepest and flattest meridia without any reference to irregularity. Corneal topography mapping (by computer-assisted videokeratography [CAVK]) displays astigmatism readings over multiple measured reference points, which also provides an average calculated value for the whole cornea, comparable to the keratometry reading.

This averaged value, the simulated keratometry, provided by the CAVK is however, a "best-fit" compromise with different devices deriving the values in various ways to provide corneal astigmatism values that are not necessarily equivalent to each other or to keratometry.

Corneal topography is an objective measurement of shape independent of subjective response, mapping the surface of the cornea to provide useful information to enable a qualitative and quantitative gauging of corneal irregularity.

Optical assessment: manifest refraction and Wavefront analysis

The manifest refraction is a subjective test dependent upon observer and subject's response that, like keratometry, provides an average overall astigmatism value. Although this method has the advantage of measuring all the optical and perceptual (non-optical) astigmatism, it has the disadvantage of being dependent upon subject and observer response, and also ambient conditions, such as inconsistencies contained in lighting, chart distance, or illumination. Wavefront analysis measures optical aberrations contained in the refractive system of the eye, as well as providing an overall objective sphero-cylindrical refractive value which parallels the manifest refraction. However, like autorefractors it does not include the perceptual influence on astigmatism so can vary from manifest refraction, and like topographers shows variability between devices.

Astigmatism Treatment

The surgical treatment of astigmatism would be considerably simplified if the corneal and optical astigmatism values coincided precisely. In reality however, variance between spectacle and corneal astigmatism, both in magnitude and orientation, is widely prevalent and unavoidable amongst individuals with regular (and irregular) astigmatism.

Refraction versus Topography

Historically, the surgical goal of achieving a plano spherical and astigmatism result has been achieved by deriving a treatment based solely on "sphericizing" either the corneal shape or manifest spectacle refraction. Where, as is usually the case, these two parameters do not coincide then an amount of astigmatism will remain in the optical system of the eye, either wholly on the cornea or in the resultant refraction according to the mode chosen for primary emphasis of corrective treatment. If the surgical goal is to eliminate the requirement for glasses, then it might, at first consideration, seem reasonable to use the refraction as the sole treatment parameter for both the cylinder and sphere. However, surgical treatment addressing refractive astigmatism alone means a spherical cornea has not been targeted. Failure to regard corneal shape in the treatment plan can leave excessive corneal astigmatism remaining[2,3,4] and potentially lead to reduced quality of vision and increased lower order aberrations.

It is apparent that inequality between corneal and optical astigmatism cannot be avoided and there are advantages in considering both in the customized treatment strategy. It is only by determining refractive and topographic targets prior to surgery that we can perform valuable tasks in astigmatism surgery.

1. Optimize the treatment according to both prevailing corneal and optical parameters.
2. Enable a valid analysis using corneal and refractive measurements by calculating target values.[2,4,5]
3. Target less corneal astigmatism by closer approximation of maximum ablation to the flat principal corneal meridia.

Figure 27.1-1
The treatment emphasis of 100% correction of refractive astigmatism would result in a spherical refraction with all the minimum remaining astigmatism (ORA) being targeted onto the cornea.

Figure 27.1-2
The treatment emphasis of 100% correction of topography would result in a spherical cornea with the minimum remaining astigmatism (ORA) being corrected in the refraction.

Figure 27.1-3
The Emphasis bar adjusts the proportion of the remaining astigmatism (ORA) that is to be corrected in corneal and refractive modalities.

Vector Planning

The fundamental technique of vector planning[3] can be used to approach any patient undergoing LASIK for astigmatism with an associated spherical correction. The key feature is the incorporation of both corneal and refractive values in the astigmatism treatment and addressing the differences between the two in a customized treatment plan.

The discrepancy between corneal astigmatism (T) and refractive astigmatism (R) at the corneal plane is described as the ocular residual astigmatism (ORA). The ORA, a vectorial value, is the calculated minimum amount of remaining astigmatism that can be achieved in any LASIK treatment of astigmatism.

Therefore, the maximum reduction of astigmatism is achieved when the remaining astigmatism is equal to the ORA – the best theoretical outcome possible. This remaining astigmatism will be refractive, topographic or a combination of both (T plus R).

Vector planning enables surgeons to calculate the ORA as well as the treatment parameters for eliminating 100% of R *(figure 27.1-1)*, 100% of T *(figure 27.1-2)*, or any combination of T and R equaling 100% *(figure 27.1-3)* to achieve the "maximum treatment".

The optimal result for each customized individual eye treatment can be determined by employing two generally accepted principles:

1. Less astigmatism is preferable to more.
2. If remaining astigmatism is unavoidable, then for distance vision a with-the-rule (WTR) orientation on the cornea is preferable to against-the-rule (ATR). Oblique astigmatism is probably the least desirable.

This technique enables the surgeon to decide on the amount of astigmatism to be left remaining on the cornea, according to how favorably, or unfavorably, its orientation lies. With a bias towards favoring WTR corneal astigmatism, a compromise of the refractive outcome would not be expected, as corneal astigmatism is better tolerated at this orientation,

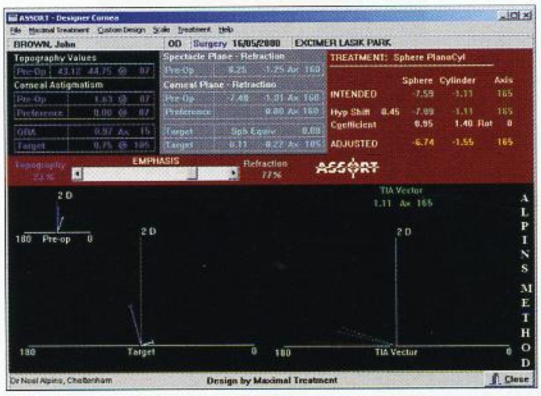

Figure 27.1-4
The ASSORT surgical planning module – with an example of a complete optimized treatment plan showing differing pre-operative corneal and refractive values.

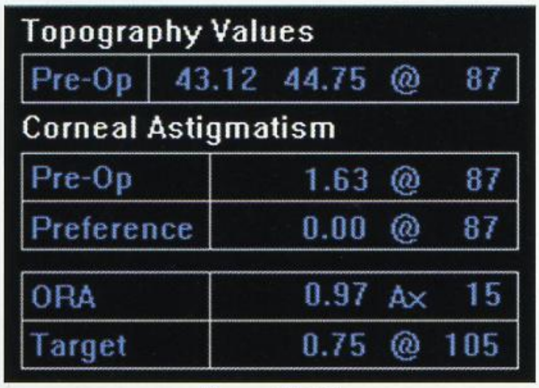

Figure 27.1-5
Located at the top left-hand side of the ASSORT screen, as displayed in figure 27.1-4, are the pre-operative topography, the preferred corneal astigmatic outcome, the ORA and target corneal values for the proposed treatment.

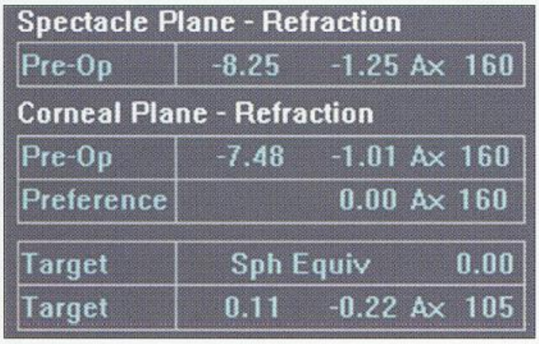

Figure 27.1-6
Located at the central top section of the ASSORT screen, as displayed in figure 27.1-4, is the pre-operative refraction data at the spectacle plane that is then converted to the corneal plane, the preferred refractive astigmatism outcome, the target spherical equivalent and calculated target refractive (spherical & cylindrical) values for the proposed treatment.

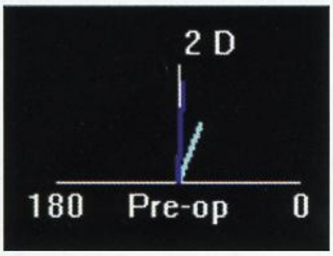

Figure 27.1-7
Polar display of pre-operative corneal astigmatism (dark blue line) and refractive astigmatism (light blue line) at power axis of cylinder values.

with lesser amounts of cylindrical power required to correct it.[3] This is commonly referred to as Javal's Rule.[6]
An example is given to explain the steps for a vector planning treatment paradigm. The ASSORT® program treatment planning module is used to illustrate the steps required in the calculation of the treatment parameters.

An example of the ASSORT surgical planning screen is shown in *figure 27.1-4*.

Simulated keratometry values of topography *(figure 27.1-5)* and refraction *(figure 27.1-6)* pre-surgery measurements are shown. The refractive values can be taken from either manifest refraction or sphero-cylindrical values from the wavefront analysis device. Values from both pre-operative modes of measurement are then used to generate an optimized treatment plan. *Figure 27.1-7* shows a polar diagram, the pre-op astigmatism for topography (dark blue line) of 1.63D at a meridian of 87 degrees and refractive astigmatism (light blue line) of +1.01D (corneal plane) at 70 degrees (160 degrees less 90 degrees to convert to the power axis of the negative cylinder).

The surgical emphasis will determine the relative desire to achieve either a spherical cornea or refraction specified as

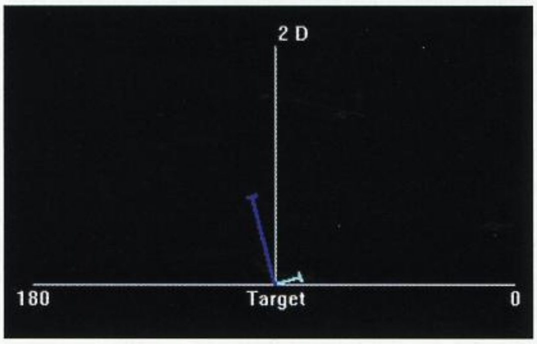

Figure 27.1-8
The calculated target results are shown in a polar diagram. The topography target (dark blue line) is shown as 0.75D at a meridian of 105 degrees and the resulting refractive astigmatism target (light blue line) is shown as +0.22D at an axis of 15 degrees.

"preference" in *figures 27.1-5* and *27.1-6*, or a treatment intermediate to these extremes. *Figure 27.1-1* illustrates the treatment emphasis set at 100% correction of refractive astigmatism in order to achieve a spherical refraction, however the topographic target will be 0.97D at a meridian of 105 degrees. At the opposite extreme, *figure 27.1-2* displays the desire to achieve 100% correction of corneal astigmatism with a zero spherical equivalent and a spherical cornea, with a resulting refractive target of sphere +0.49D, cylinder –0.97D and axis 105 degrees.

In *figure 27.1-3* the treatment emphasis in this eye of 23% topography and 77% refraction indicates the balance directed to the two targeted zero astigmatism goals.

With this emphasis the topographic target is 0.75D at a meridian of 105 degrees (dark blue line in *figure 27.1-8*) and the target refraction values are sphere 0.26D, cylinder –0.22D and axis of 105 degrees. (Displayed as light blue line at power axis of 15 degrees).

The Astigmatism Treatment – Target Induced Astigmatism Vector (TIA)

The TIA *(figure 27.1-9)* necessary to achieve the results targeted in *figure 27.1-8* is shown in green. The light blue line shows the TIA 1.01D Ax 160° that would be required to achieve a zero refractive astigmatism target *(figure 27.1-1)*. The dark blue line shows the TIA 1.63D Ax 177° that would achieve a zero topographic target *(figure 27.1-2)* as a spherical cornea. As in the example displayed *(figure 27.1-3)*, the proposed astigmatism treatment lies intermediate to the corneal and refractive extremes so that the magnitude of the astigmatism treatment is shown as 1.11D and the axis of maximum ablation determined to be at 165 degrees on a polar vector diagram as it would be applied to the eye.

When using this method of treatment, the maximum correction of astigmatism is achieved, at all positions of treatment emphasis (0-100%) that can be chosen by the surgeon. The remaining topography plus the refractive (T plus R) astigmatism values are at a minimum and orientated at 90 degrees to each other in *figure 27.1-8* and their sum is equivalent to the ORA, which is the minimum achievable astigmatism outcome for any one customized treatment. In this example the goal is to avoid excessive remaining corneal astigmatism, so it is limited to 0.75D to minimize consequent lower order aberrations. Moving the icon to the left would move the treatment closer to the principal corneal meridia. This would reduce corneal astigmatism further, but might result in an unacceptable net increase in the remaining refractive astigmatism *(figure 27.1-2)*. The treatment required to achieve the chosen topographic and refractive astigmatism targets are shown on the top right hand side of the screen within the red area *(figures 27.1-4 and 27.1-10)*. The TIA chosen according to the emphasis selected is displayed in green as 1.11 D Ax 165.

Spherical hyperopic shift caused as a result of plano-cylindrical myopic astigmatism treatment mode can be allowed for by reducing the amount of spherical myopic treatment according to a calculated ratio determined from the manufacturer or previous surgical experience.

The nomogram adjusted value can then be entered into the laser – so that separate calculated spherical and cylindrical adjustments can also be applied when necessary, also according to past treatment performance of the individual laser. In this case *(figure 27.1-10)* nomogram adjustments allow for an initial 5% of spherical over-correction and 40% of astigmatism undercorrection. The adjusted treatment is then entered into the laser as the patient's calculated corneal plane treatment with adjustments for spherical shifts and under- or over-correction of sphere and cylinder.

Benefits of this Approach

By aligning the astigmatism treatment closer to the principal corneal meridian and magnitude than would occur if the refractive values *(figure 27.1-1)* were selected, one would achieve less remaining corneal astigmatism[1,2,3] *(figure 27.1-4)*. Clinical results have shown an imbalance in excessive corneal astigmatism remaining after treatment can be attributed to refractive astigmatism values being the sole consideration in treatment planning.[2]

Bringing corneal values into the treatment plan will result in less overall corneal astigmatism remaining, giving an advantageous clinical outcome without necessarily increasing the overall resultant refractive astigmatism.

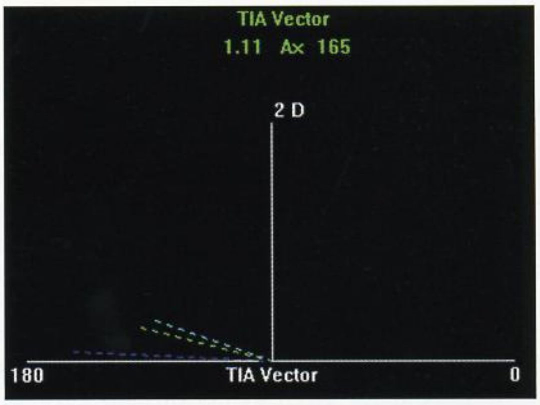

Figure 27.1-9
The treatment (TIA) vector (light green) applied to this eye lies between the treatment to "sphericize" the refraction (light blue) and the treatment to "sphericize" the cornea (dark blue). Note: Vectors are displayed as dashed lines and the TIA lies closer (77%) to the refractive astigmatism correction line.

TREATMENT: Sphere PlanoCyl

	Sphere	Cylinder	Axis
INTENDED	-7.59	-1.11	165
Hyp Shift 0.45	-7.09	-1.11	165
Coefficient	0.95	1.40 Rot	0
ADJUSTED	-6.74	-1.55	165

Figure 27.1-10
The intended treatment at the cornea comprises the spherical treatment, to achieve a zero spherical equivalent (pre-op corneal plane sphere −7.48 to the targeted sphere +0.11), and the astigmatism treatment (TIA). The final adjusted treatment to be applied to the cornea requires modifications for spherical shift and spherical and astigmatic nomogram adjustments.

Irregular Astigmatism

This technique described addresses only symmetrical spherocylindrical treatments that are currently commonly practiced. Employing vector planning for the treatment of naturally occurring irregular astigmatism introduces greater complexity in the calculation of the treatment parameters. The corresponding ablation patterns required for calculated asymmetrical sphero-cylindrical treatments are not readily available.

Astigmatism reduction

In addition to differences between refractive and topographic astigmatism there may also be asymmetry of the dioptric magnitude and non-orthogonal orientation of topographic astigmatism across the hemidivisions of the cornea. This results in the necessity to apply separate surgical plans to each hemidivision. In practice, the superior and inferior hemidivisions of the cornea will share a common refractive value, as measured by manifest refraction or wavefront analysis. The technique described in *figures 27.1-3* to *27.1-10* can be duplicated on both sides of the cornea.[7]

Astigmatism re-arrangement

It is also possible to regulate naturally occurring irregular corneal astigmatism by making it orthogonal and symmetrical using asymmetrical treatment.[7] Likewise, the least favorable corneal meridian may be rotated toward the more favorably placed orientation to achieve improved topographical alignment while regulating the corneal topography. This may provide the opportunity for improved best corrected visual acuity or unaided visual acuity, without necessarily causing a change in the refractive condition.[7] This treatment is directed by reducing the topographic disparity, a precise vectorial value that quantifies irregularity in diopters, to zero.

Astigmatism reduction and re-arrangement

Concurrent customized astigmatism reduction and re-arrangement has the future potential for improved visual performance of the eye - in recent times termed "super normal vision". The introduction of wavefront technology has made it possible to provide a map of refraction and accurately quantify higher-order aberrations in addition to the sphero-cylindrical refractive error. However, there are major theoretical and practical obstacles to the dependence upon wavefront values being used alone as a treatment modality. Any attempt to neutralize all internal optical aberrations of the eye on the surface of the cornea could induce the potential for increased surface irregularity.

Conclusion

Vector planning is a valuable addition to the surgical treatment process. It has the facility to give corneal astigmatism values an equal standing with optical astigmatism while concurrently avoiding unfavorable astigmatism and maximally reducing the amount measured by both modes of astigmatism assessment. This would result in less astigmatism being directed to the corneal surface with consequent reduced lower order aberrations and enhanced clinical outcomes.

Terms

ORA – Ocular Residual Astigmatism
The difference between refractive and corneal astigmatism calculated in vector terms which quantifies the best possible outcome for the minimum remaining astigmatism correction at corneal or refractive modes.

TIA – Target Induced Astigmatism Vector
The astigmatism treatment (relative steepening) as applied at the cornea.

TD – Topographic Disparity
A precise vectorial dioptric value quantifying corneal irregularity.

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