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Noel Alpins

The Basics of Astigmatism and how to deal with it

INTRODUCTION

Addressing the correction of astigmatism is an essential element for the refractive surgeon as the majority of patients have significant preoperative cylinder. Ninety percent of the population has detectable astigmatism, with 25% having more than 1.0 D.[1] An uncorrected astigmatic error of 1.0 D will, on average, decrease visual acuity to the level of 20/30 or 20/40 depending on its orientation.[2] As well as this blurring of vision, uncorrected astigmatism can also cause distortion, glare, asthenopia, headaches, and monocular diplopia.

CLASSIFICATION OF ASTIGMATISM

Astigmatism may be classified as "with-the-rule" or "against-the-rule" depending on the orientation of the steepest corneal meridian. With-the-rule astigmatism occurs where the steepest meridian is closer to a vertical orientation, and is the more favorable orientation in terms of clarity of distance vision according to Javals rule.[3] In addition to this there are three differing categories of astigmatism; naturally occurring regular astigmatism (Fig. 10.1A), naturally occurring irregular

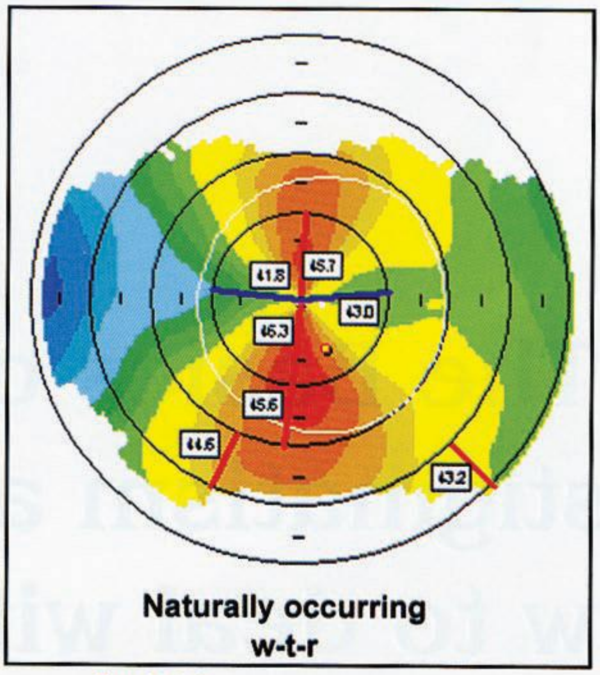

Fig. 10.1A: Regular astigmatism

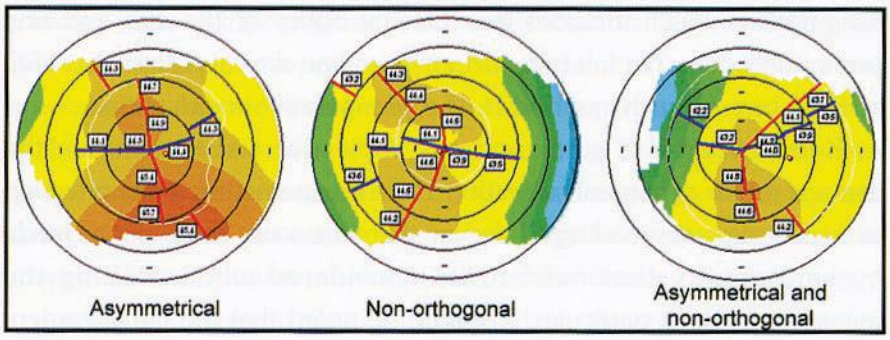

Fig. 10.1B: Naturally occurring irregular astigmatism

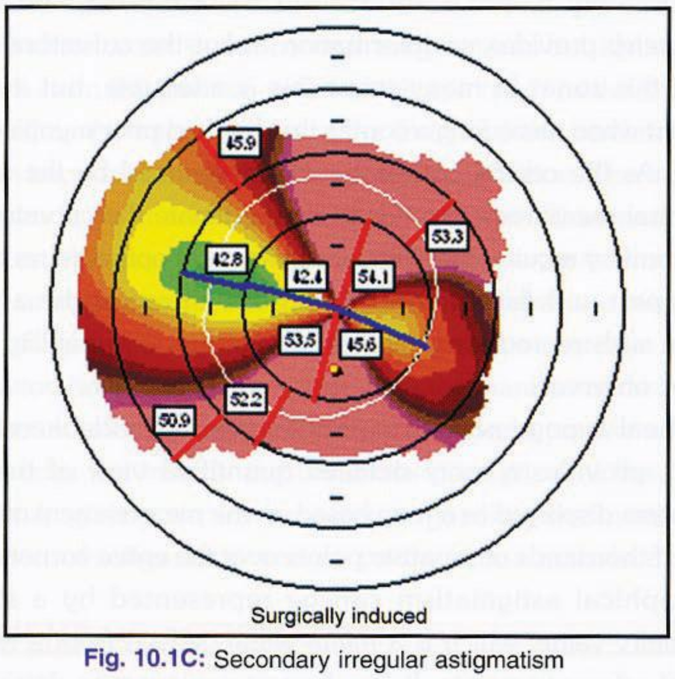

Fig. 10.1C: Secondary irregular astigmatism

astigmatism (Fig. 10.1B) which is further classified into asymmetrical, non-orthogonal, or both, and secondary irregular astigmatism associated with ocular trauma, disease, infection or previous ocular surgery (Fig. 10.1C).[4]

DIAGNOSIS AND MEASUREMENT OF ASTIGMATISM

There are many different ways to measure astigmatism, some assessing corneal astigmatism only, and the others measuring refractive astigmatism which includes the internal optics of the eye and any perceptual component. It is important in routine clinical practice to utilize at least one of each method in the preoperative examination.

Keratometry is a quick and easy objective test to measure the average radius of corneal curvature. The measurement is then converted to a corneal power reading. However, there are some assumptions made by keratometry that need to be considered when utilizing the measurements. In particular, it should be noted that the measurement is a paracentral one based on data obtained from only 4 points at an approximately 3 mm zone around the center of the cornea.[5] Keratometry provides no information about the curvature inside or outside this zone. In many cases this is adequate, but it becomes important when measuring a cornea that has had prior myopic refractive surgery. As the central cornea has been flattened by the surgery, a paracentral measurement tends to over-estimate the curvature.[6] Also, as keratometry requires the manual alignment of optical mires to identify the steepest and flattest corneal meridia, there can be a potential problem with reproducing reliable results due to variability between different observers.

Corneal topography, or computer assisted videokeratography (CAVK), provides a more detailed quantified view of the corneal astigmatism displayed as a map based on the measurement of refractive power of thousands of separate points over the entire cornea. Average topographical astigmatism can be represented by a simulated keratometry value, which is a mean value derived from a number of constant reference points. It is a best fit compromise determined in various ways by the different types of topographers, and its orientation may be difficult to identify consistently in lower levels and non-orthogonal astigmatism.

Early topographers were based on the Placido disk, which only measure the anterior surface of the cornea. More advanced topographers incorporate slit-scanning technology with the Placido disk (Orbscann II) to measure both the anterior and posterior cornea.[7,8] These systems provide the surgeon with more information including the thinnest corneal point and elevation topography. It should be noted, however, that all topographers utilizing the Placido disk (including the Orbscan II) also give a paracentral measurement of corneal curvature in a similar fashion to keratometry. The latest topography systems such as the Pentacam (Oculus USA) use a rotating Scheimpflug camera system to provide measurements of both anterior and posterior corneal surfaces.[5] One of the advantages of this system is that it is able to provide corneal power measurements at the center of the cornea.

Lastly, astigmatism may be measured by the manifest subjective refraction. This is a measure of the spherocylindrical correction required for the patient's perception of their best vision. The principal contribution to the cylindrical error is the corneal astigmatism, but also includes astigmatism from the internal optics of the eye (such as the crystalline lens) as well as the interpretation of the image by the cerebral cortex, which is an important component for patient satisfaction. The measured result depends on many variables such as chart illumination and contrast, test distance and room lighting. The newer technology of wavefront analysis provides a spatially oriented refractive map of the pathway of light through the eye, which provides a greater amount of information on the refractive system than the manifest refraction data alone. It too includes the internal optics of the eye, but unlike subjective responses does not include the conscious perception of the cerebral cortex, thus giving no information regarding the non-optical interpretation of astigmatism images on the retina and visual cortex.

TREATMENT OF ASTIGMATISM

Ablative surgical treatments that incorporate astigmatic correction include photoastigmatic refractive keratectomy (PARK), laser in situ keratomileusis (LASIK), and laser assisted sub-epithelial keratomileusis (LASEK) including epi-LASEK. These procedures have been shown to be effective at correcting low to moderate levels of astigmatism.[1,9,10]

The forces that act to influence change in the corneal toric shape throughout the course of refractive surgery are flattening, steepening, and torque. The underlying principle of refractive surgery when treating astigmatism is to flatten the cornea at the steepest meridian, or steepen it at the flattest meridian, or a combination of both to reduce the magnitude of the astigmatism. However, in a misaligned, or "off-axis" treatment, the component of torque also exerts an influence on the astigmatism in two ways: it acts to increase the magnitude, and also to rotate the meridian in a clockwise or counterclockwise direction.[12] It is, therefore, important when including astigmatism in the refractive laser surgical plan, that the treatment is aligned correctly to minimize the effects of the unwanted torque force that plays no part in reducing existing astigmatism.

The underlying cause for off-axis treatments may be something as simple as a slight misalignment of the patients head. There are, however, other factors that need to be considered such as cyclotorsion of the patients eyes as they move from the seated to supine position, which is typically between 2 to 7 degrees.[11] Therefore, the meridian of the astigmatism measured by the keratometer or topographer where the patient is seated upright may significantly change as the patient lies down for surgery, resulting in a treatment that may be misaligned by up to 7 degrees. This is well outside the recommended 2 degree limit for a wavefront guided ablation which demands a high level of precision.[11] A misaligned wavefront treatment may produce the opposite result than desired and actually increase the amount of higher order aberrations. Many laser machines now incorporate tracking systems to account for cyclotorsion by identifying iris landmarks and rotating the treatment accordingly from the wavefront diagnostic device to the laser machine.

THE ASTIGMATIC TARGET

The intended target for the spherical component of the treatment is not always emmetropia, particularly if aiming for monovision. However, concerning the astigmatic component of the treatment, the universal primary goal is to achieve the maximum reduction of astigmatism. The secondary goal is to ensure any remaining cylinder unable to be eliminated from the optical system is optimized towards a more favorable with-the-rule orientation. Most surgeons think of astigmatism as the refractive component measured by the manifest subjective refraction or the wavefront device. However, this approach does not account adequately for the corneal astigmatism. It is important to note that a complete elimination of astigmatism from the optical system is very rarely achieved. This is because the refractive component very rarely coincides with the corneal component measured by topography or keratometry.

The amount of astigmatism unable to be eliminated from the system is termed the ocular residual astigmatism (ORA). It is also known as intraocular (non-corneal) astigmatism as it incorporates the astigmatic contribution from the internal optics of the eye as well as the interpretation of the image by the cerebral cortex. For instance, a subjective refraction reveals 1.80 DC at a meridian of 109°, but the topography measures 2.80 DC @ 29°. It is easy to see that treating the refractive cylindrical component of 1.80 DC will not entirely eliminate the greater amount of corneal astigmatism. If the treatment is based on the refractive astigmatism alone, the entire ORA (to neutralize the astigmatic contribution by the internal optics and cerebral cortex perception) will be left as corneal astigmatism. The ORA can be taken into consideration when planning the treatment to ensure a more even distribution between the refractive and corneal astigmatism, and likely less overall astigmatism. Therefore, neither the corneal or refractive astigmatic target is zero if incorporating the corneal as well as refractive astigmatism in the surgical plan.

ANALYZING ASTIGMATIC OUTCOMES AND CUSTOMIZING CONSTANTS

By tracking all outcomes from previous cases for both the spherical and cylindrical components of the treatment, it allows the surgeon to analyze how the treatment has been working, and to customize their nomogram adjustment constants to tighten future outcomes. Vector analysis is an accurate method for analyzing the outcomes, in particular the astigmatic componen.[2,12-15]

Example: The Basics of Vector Analysis

As astigmatism has both magnitude and direction it may be represented by vectors. Let's look at an example to demonstrate. A patient scheduled

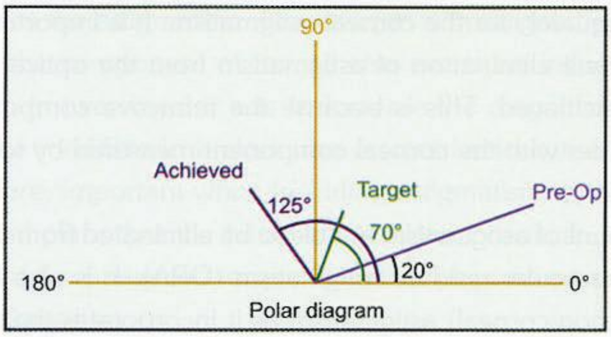

Fig. 10.2: Polar diagram displaying astigmatism as it appears on the eye

for Lasik has 1.52 D corneal astigmatism at 20°. The surgeon sets a postoperative target of 0.50 D at the more favorable meridian of 70°. Uncomplicated surgery is performed, but postoperatively the corneal astigmatism is measured at 0.77 D at 125°. Does this represent an over or under correction of the astigmatism? How does the surgeon know what surgical changes have happened?

A polar diagram is a simple way to display the astigmatism as it appears on the eye, as seen in Figure 10.2. The preoperative value of 1.52 @ 20° is shown by the light blue line, and similarly the target value of 0.50 D @ 70° and postoperative value of 0.77 D @ 125+ are displayed as light green and dark blue lines.

In order to analyze these values, the polar diagram must be converted to a mathematical construct. This is easily done by creating a double angle vector diagram (DAVD) where all the magnitudes remain the same but all the angles are doubled as seen in Figure 10.3. Thus, the angles subtended by the preoperative, target, and postoperative have been doubled to 40°, 140°, and 250° respectively, but the length of the lines has not changed.

We may now use this DAVD to provide the vectors that will be used for the analysis. The target induced astigmatism vector (TIA) is the astigmatic change the surgery was intended to induce, and is displayed as the vector joining the preoperative value to the target value. In Figure 10.3, the measured length of the TIA is 1.68 and it subtends an angle of 200°. The surgically induced astigmatism vector (SIA) is the astigmatic change actually induced by the surgery, and is the vector joining the

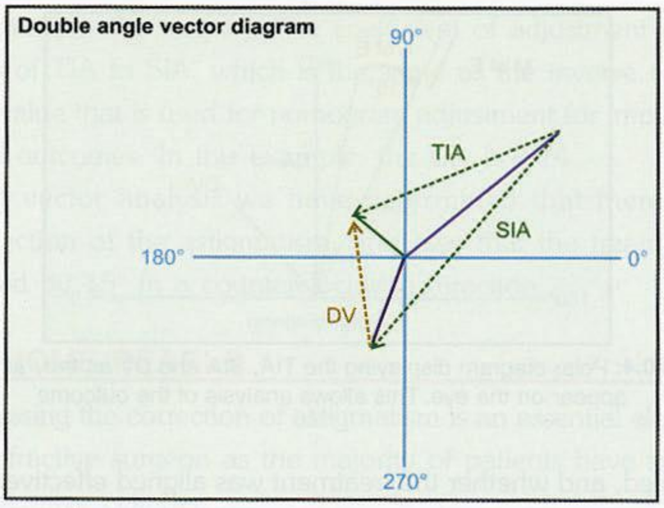

Fig. 10.3: Double angle vector diagram displaying the TIA, SIA and DV

preoperative value to the postoperative value. The SIA is measured as 2.27 @ 230° in Figure 10.3. The difference vector (DV) is the vector joining the SIA to the TIA, and represents the astigmatic change that is required in order to achieve the initial target intended by the surgery. In this example the DV is measured as 1.02 @ 98°. The DV is an absolute measure of success and is preferably zero. The index of success (IOS) is a relative measure of success (calculated by dividing the DV by the TIA) and is also preferably zero.

However, all angles in this diagram have been doubled to allow the mathematical construct. In order to represent the situation as it actually appears on the eye and analyze the outcome, the DAVD must now be converted back to a polar diagram. To do this, the angles subtended by the TIA, SIA and DV must all be halved without changing the magnitudes. This is seen in Figure 10.4, where the pre- and post-operative and target values have been removed for simplicity.

ANALYSIS OF THE OUTCOME

So now we have a TIA of 1.68 @ 100°, a SIA of 2.27 @ 115°, and a DV of 1.02 @ 49° as displayed in Figure 10.4. It is these values that allow analysis of the outcome as the various relationships between the SIA and TIA can determine whether too much or too little treatment

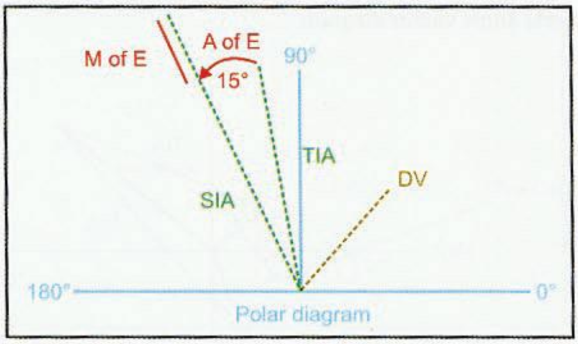

Fig. 10.4: Polar diagram displaying the TIA, SIA and DV as they actually appear on the eye. This allows analysis of the outcome

was applied, and whether the treatment was aligned effectively or not. For instance, the angle of error (AE) is the angle subtended between the SIA and TIA, and represents the amount of misalignment in an off-axis treatment. The AE is positive if the SIA lies in a counterclockwise (CCW) direction to the axis of the TIA, and similarly the AE is negative if the SIA lies in a clockwise (CW) direction relative to the TIA. In Figure 10.4, the AE is 15°, indicating the treatment was applied 15° off-axis in an counterclockwise direction. The magnitude of error (ME) is the difference in length between the SIA and TIA, and is 2.27-1.68 which equals 0.59.

An over or under correction is gauged by the Correction Index (CI), which is the ratio of SIA to the TIA. The CI is equal to 1.0 if a full correction of astigmatism occurs. If the CI is greater than 1.0 an overcorrection has occurred, and a CI of less than 1.0 indicates an undercorrection. In this example the CI is 2.27 divided by 1.68, which equals 1.35, indicating an overcorrection. It is a common misconception to regard a misaligned treatment as causing an undercorrection in the magnitude of the astigmatism. However, this is not strictly correct as this is referring to a comparison of the postoperative and preoperative astigmatism magnitudes. In a misaligned treatment the magnitude of the SIA is in fact unaffected as it is independent from the meridian of the applied treatment, and therefore the CI is also unaffected. Instead a misaligned treatment results in a shift of the orientation of the existing astigmatism (through the ineffective part of the SIA that is not reducing the astigmatism–the torque). The coefficient of adjustment (COA) is the ratio of TIA to SIA, which is the same as the inverse of the CI. It is this value that is used for nomogram adjustment for improvement of future outcomes. In this example, the CA is 0.74.

Using vector analysis we have determined that there was an overcorrection of the astigmatism, and also that the treatment was misaligned by 15° in a counterclockwise direction.

TAKE HOME PEARLS

- Addressing the correction of astigmatism is an essential element for the refractive surgeon as the majority of patients have significant preoperative cylinder.
- Astigmatism may be classified as "with-the-rule" or "against-the-rule". It may be regular or irregular in shape. Irregular astigmatism may be naturally occurring or secondary to trauma or surgery.
- Astigmatism may be thought of as consisting of two modes: refractive and corneal. Refractive astigmatism is measured by the subjective manifest refraction or wavefront device. Corneal astigmatism may be measured by keratometry or corneal topography.
- It is important to note that a complete elimination of astigmatism from the optical system is very rarely achieved because the refractive component very rarely coincides exactly with the corneal component.
- A misalignment of the astigmatic treatment may occur through the effects of cyclotorsion as the patient moves from the seated position for the measurement of astigmatism to the supine position for the treatment.
- Astigmatic outcomes can be analyzed by vector analysis, and this method can be used to develop nomogram adjustments to tighten future outcomes.
- The various relationships between the SIA and TIA can determine whether too much or too little treatment was applied, and whether the treatment was aligned effectively or not.

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