CHAPTER 29

Asymmetrical Surgical Treatment Using Vector Planning

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Improving visual outcomes is the fundamental purpose of any new treatment profile in refractive laser surgery and the primary objective of all refractive surgeons. Excimer laser treatment has conventionally been based on preoperative refractive data alone. This would simplify the treatment of astigmatism and optimize outcomes if the refractive and corneal astigmatism were identical in magnitude and axis. However, differences between the magnitude and/or axis of refractive and corneal astigmatism are prevalent.[1,2] The technique of vector planning described by Alpins combines topography and refractive astigmatism parameters in the treatment plan with the potential of improving best spectacle-corrected visual acuity (BSCVA) and reducing higher-order aberrations due to less corneal astigmatism.[1-6]

The method of vector planning can be utilized in regular astigmatism and irregular astigmatism was previously discussed. This technique can be expanded upon to reduce and regularize asymmetric and nonorthogonal bow-tie patterns measured by topography in cases of irregular astigmatism.[7,8] Just as it is prevalent for the refractive astigmatism to differ in magnitude and/or axis from the corneal astigmatism, so it is for the 2 steepest astigmatism meridians of the opposite hemidivisions of the cornea to vary in magnitude and axes.

In this chapter, we present an excimer laser ablation algorithm, based on asymmetrical surgical treatment using vector planning, applied to nonorthogonal and asymmetrical differences in astigmatism between the superior and inferior hemidivisions of the cornea. This technique can achieve any desired corneal shape to improve visual outcomes in cases of irregular astigmatism.

The treatment paradigms for irregular corneas using photoastigmatic refractive keratectomy (PARK) in previous studies have included decentered ablations over the cone in patients with keratoconus,[9] treatments based entirely on corneal parameters such as computer-assisted videokeratography (CAVK)[10] and, most commonly, pupil-centered ablations dependent exclusively on manifest refraction.[11,12] The visual outcomes of these studies have shown only a partial decrease in refractive astigmatism, and in some cases an increase in the corneal irregularity.[10,12,13] In one of these study where the corneal astigmatism was reported postoperatively,[10] there was still a significant amount of astigmatism remaining on the cornea, which impacted adversely on the unaided visual acuity results. Due to the irregular shape of the cornea in these patients, larger differences occur between refractive and corneal astigmatism values than would be expected in normal eyes.[6,7,14] This difference is known as ocular residual astigmatism (ORA),[1-6] and can be quantified by calculating the vectorial difference between refractive and corneal astigmatism. The ORA is also known as intraocular,[15] lenticular,[16] and noncorneal astigmatism.[17]

Recognizing and addressing differences between corneal shape based on topography, and visual function based on refraction, is an essential step to realizing the maximum potential vision for an astigmatic eye. If a relatively high ORA has been calculated for a particular case (eg, 2.20 D), it is important that the surgeon and patient understand that the outcome may be less than ideal due to this uncorrectable amount of astigmatism remaining in the visual system of the eye postoperatively. No matter how accurate the surgery, the ORA is the amount of astigmatism that will remain in the optical system of the eye due to these unavoidable differences between refractive and corneal astigmatism. The patient may, as a consequence, be advised against refractive laser surgery.

In irregular astigmatism the topographical map can take on various appearances: asymmetrical, nonorthogonal, or both. Even in grossly asymmetrical corneas, it is possible to detect one half of the bow-tie pattern, indicating the presence of both semimeridians of the astigmatism. The limitations of treatments based on manifest and wavefront refraction, or topographic parameters alone have been discussed previously in this book as well as in the literature.[4-6,18] Limitations of simulated keratometry values by topography deserver further investigation.

The simulated keratometry is a best-fit value, or a mean achieved over a number of measured constant reference points of the topography map. Variations exist in the dioptric magnitude and orientation of the astigmatism on each of the 2 parts, called hemidivisions, of the cornea.[7] There may also be a nonorthogonal relationship between the 2 astigmatism values. The orientation of the simulated keratometry can be determined using any 1 of the 3 axes on the same cornea: an orientation aligned with either one of the 2 nonorthogonal meridians, or another intersecting the two. A more accurate approach would be to divide the cornea into 2 equal hemidivisions, and determine the flattest and steepest meridian for each half. In our experience, the power measured by topography in the 5-mm zone of the cornea displays a more accurate description of the overall shape of the cornea than either the 3- or 7-mm zone.

Despite a substantial amount of information obtained from topographers and aberrometers, no studies to our knowledge have quantified the change in corneal irregularity effectively on irregular corneas from before to after excimer laser treatment. Perhaps this is due to uncertainty in how the corneal irregularity is effectively quantified.

The condition of corneal irregular astigmatism can be quantified in diopters (D) as the topographic disparity (TD).[7] The TD is calculated as the dioptric distance between the displays of superior and inferior topographical values on a 720-degree double-angle vector diagram (DAVD). The TD quantifies both the nonorthogonal and asymmetrical component of corneal irregularity as a single number with an axis. It is a precise convenient way of assessing the variable of irregularity.

There is a direct proportional relationship between increasing ORA and TD. The greater the topographic disparity, the greater the ORA.[7] This relationship was shown to be statistically significant in a group of 100 healthy, astigmatic corneas prior to surgery, as shown in Figure 29-1.[7] It is therefore of crucial importance when treating irregular corneas that the topography values for astigmatism be incorporated into the treatment plan, as treatment based on the manifest refraction or the wavefront aberrometry cylinder alone leaves the cornea with excess avoidable astigmatism.[1,2,4-6]

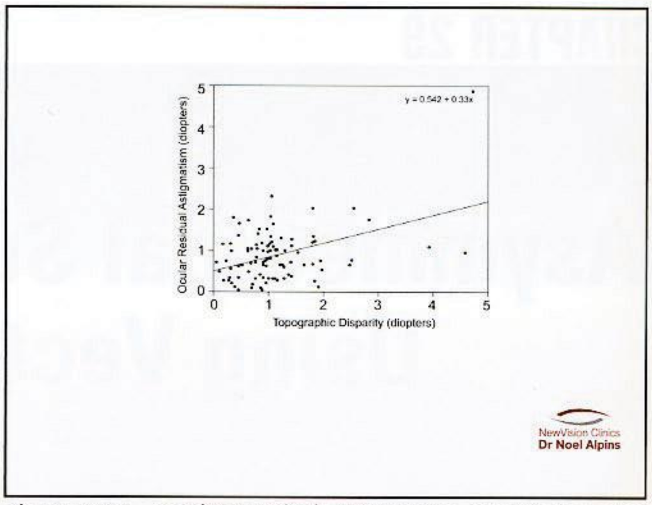

Figure 29-1. Ocular residual astigmatism magnitude versus topographic disparity magnitude ($P < 0.0001$).

Calculation of Topographic Disparity

Figure 29-2A displays the steep superior and inferior meridians measured by topography in the 5-mm zone of an eye with irregular astigmatism, such as that shown in Figure 29-3, as they would appear on the eye (polar diagram). The meridia are then doubled on a mathematical construct (DAVD) to enable vectorial calculation of the difference between the superior and inferior topography, the TD. The superior topography goes to 320 degrees and the inferior topography to 600 degrees on a 720-degree DAVD. Note, however, that the topography magnitudes remain unchanged (Figure 29-2B) during this calculation. Using trigonometric principles, the TD is calculated to be 3.87 D in this example, and the orientation is, by convention, in the direction of superior to inferior topography. Placing this vector at the ($x = 0$, $y = 0$) origin, the axis is calculated as 206 degrees. The axis of the TD is then halved (103 degrees) to display its orientation on the eye in a polar diagram (Figure 29-2C).

Asymmetrical Treatments Between Two Corneal Hemidivisions

It is the target-induced astigmatism (TIA) vector that allows us to determine the astigmatic target of the surgery being performed and provide the means to achieve any amount or orientation of corneal astigmatism, as well as an objective astigmatic analysis of the outcome. When there are 2 distinct preoperative topography values for each hemidivision, there will be differing calculated

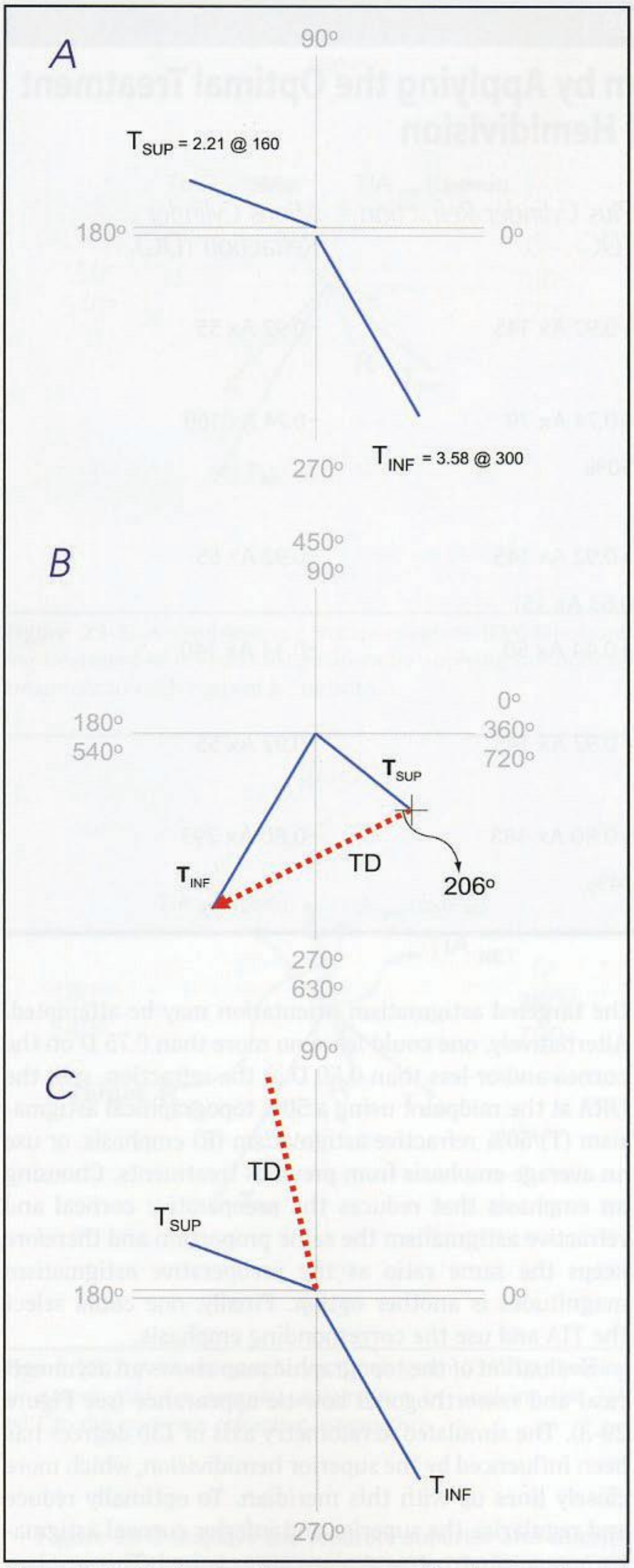

Figure 29-2. (A) A polar diagram representing the superior and inferior topography in the corresponding corneal hemidivision. (B) A double-angle vector diagram (DAVD) in which the topographic meridia are doubled but magnitudes unchanged. This vectorial difference equals the topographic disparity (TD). (C) A polar diagram of the TD as it would appear on the eye.

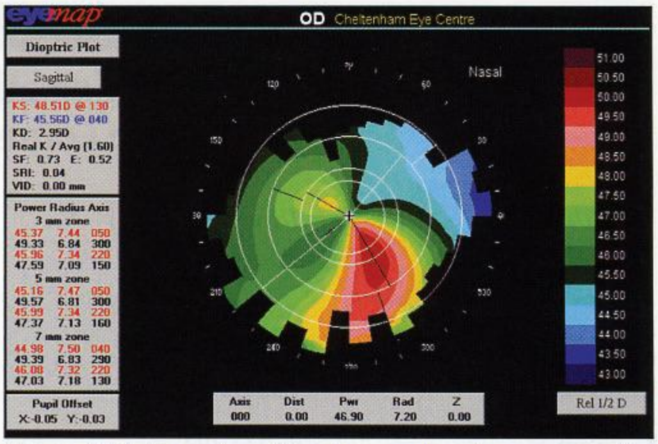

Figure 29-3. Example of the topography of an asymmetric, nonorthogonal bow tie in irregular astigmatism. The various powers, together with their axes, are shown over the 3-, 5-, and 7-mm zones in the table left of the map.

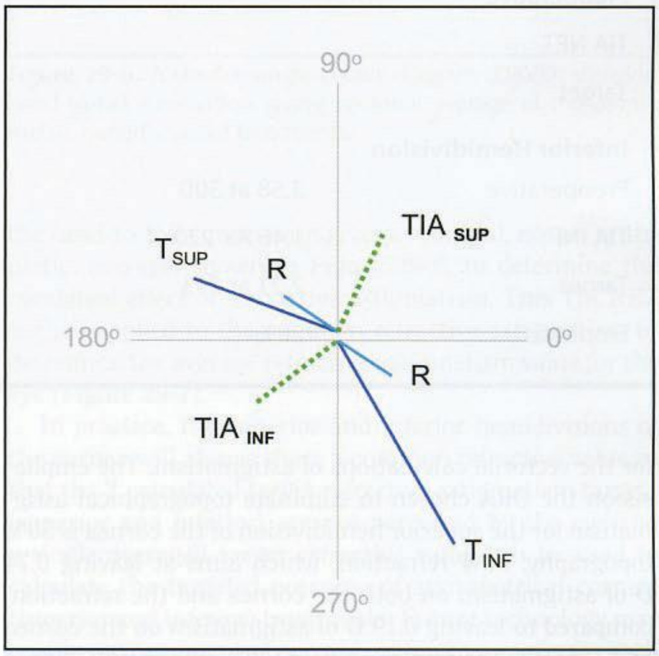

Figure 29-4. A polar diagram of the treatment of irregular astigmatism by applying the asymmetric treatment to each corneal hemidivision.

target values of refractive and topographical astigmatism after asymmetrical treatment. The different orientations of these upper and lower targets, which are decided by the surgeon, determine the emphases placed on eliminating corneal or refractive astigmatism in the treatment plan for the 2 hemidivisions. There is an assumption that there is no influence on the opposing corneal hemidivisions when treatment is calculated for one half of the cornea.

The diagram in Figure 29-4 shows the polar astigmatism and surgical vector parameters as they would appear schematically on an eye. The hemidivision is drawn at 180 degrees to display a flat and steep meridian superiorly and inferiorly. The mathematical construct of a DAVD allows

TABLE 29-1

Treatment Plan of Irregular Astigmatism by Applying the Optimal Treatment to Each Corneal Hemidivision

	Topography (D)	Plus Cylinder Refraction (DC)	Minus Cylinder Refraction (DC)
Superior Hemidivision			
Preoperative	2.21 at 160	+0.92 Ax 145	−0.92 Ax 55
TIA SUP	1.52 Ax 66		
Target	0.74 at 169	+0.74 Ax 79	−0.74 Ax 169
Emphasis	50%	50%	
Averaged Treatment Vector			
Preoperative		+0.92 Ax 145	−0.92 Ax 55
TIA NET		0.63 Ax 151	
Target		+0.44 Ax 50	−0.44 Ax 140
Inferior Hemidivision			
Preoperative	3.58 at 300	+0.92 Ax 145	−0.92 Ax 55
TIA INF	1.46 Ax 220		
Target	2.27 at 293	+0.80 Ax 383	−0.80 Ax 293
Emphasis	26%	74%	

for the vectorial calculations of astigmatism. The emphasis on the ORA chosen to eliminate topographical astigmatism for the superior hemidivision of the cornea is 50% topography, 50% refraction, which aims at leaving 0.74 D of astigmatism on both the cornea and the refraction, compared to leaving 0.19 D of astigmatism on the cornea and 1.29 D in the refraction if we follow the optimal linear treatment (Table 29-1).

For the inferior cornea the emphasis in the surgical plan follows the linear relationship of the emphasis versus the orientation of the *target* astigmatism. endeavoring to leave 2.27 D of astigmatism on the cornea and 0.80 D in the refraction. It is important to understand that no matter what emphasis is chosen (0% topography to 100% refraction), the treatment of astigmatism is optimal, that is, the minimum amount of unavoidable astigmatism (the ORA) is being targeted postoperatively as a total of the corneal and refractive astigmatism.

Which orientations are considered favorable and how much postoperative astigmatism to leave on the cornea compared to the refraction is the surgeon's decision. There are a number of options from which to choose. An optimal treatment where the *emphasis* is determined using a linear, cosine, or cosine-squared relationship to the targeted astigmatism orientation may be attempted. Alternatively, one could leave no more than 0.75 D on the cornea and/or less than 0.50 D in the refraction, split the ORA at the midpoint using a 50% topographical astigmatism (T)/50% refractive astigmatism (R) emphasis, or use an average emphasis from previous treatments. Choosing an emphasis that reduces the preoperative corneal and refractive astigmatism the same proportion and therefore keeps the same ratio as the preoperative astigmatism magnitudes is another option. Finally, one could select the TIA and use the corresponding emphasis.

Evaluation of the topographic map shows an asymmetrical and nonorthogonal bow-tie appearance (see Figure 29-3). The simulated keratometry axis of 130 degrees has been influenced by the superior hemidivision, which more closely lines up with this meridian. To optimally reduce and regularize the superior and inferior corneal astigmatism, separate treatment plans are required. This involves combining the topographic magnitude and meridian value of each hemidivision with the common refractive astigmatism magnitude and axis value. The target astigmatism for each hemidivision can then be calculated and the superior and inferior TIAs determined.

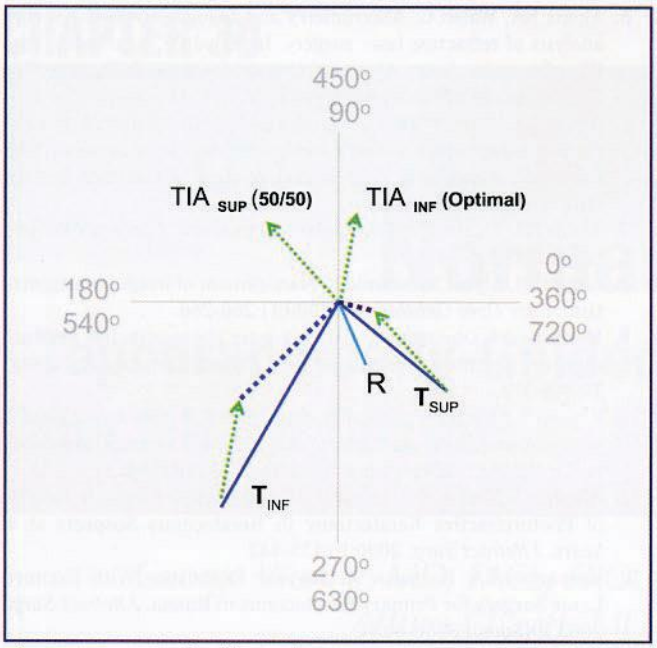

Figure 29-5. A double-angle vector diagram (DAVD) showing treatment of irregular astigmatism by applying the optimal treatment to each corneal hemidivision.

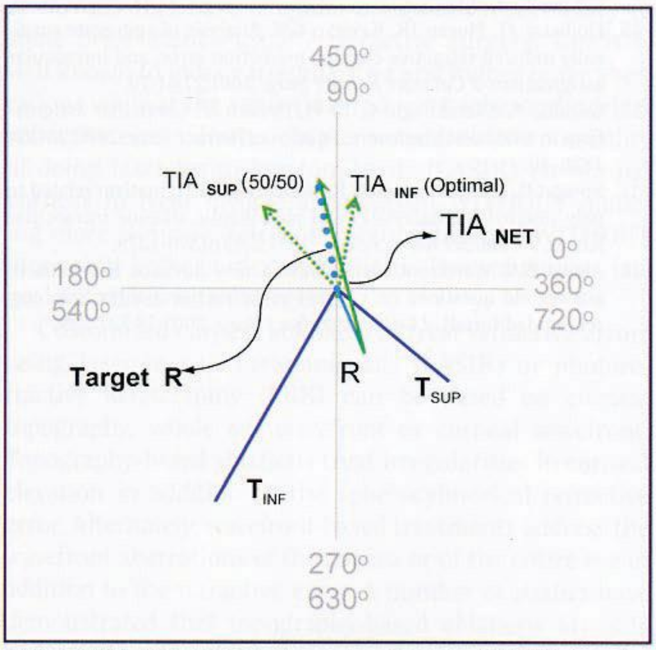

Figure 29-7. A double-angle vector diagram (DAVD) showing treatment plan for irregular astigmatism by applying the TIA NET to the common refractive astigmatism.

Figure 29-5 displays the separate superior and inferior topographical targets that are calculated by applying the optimal superior TIA to the superior topography and the optimal inferior TIA to the inferior topography. When the TIA between the 2 hemidivisions differs, a summation of the TIAs (TIA NET) or average needs to be calculated. Note

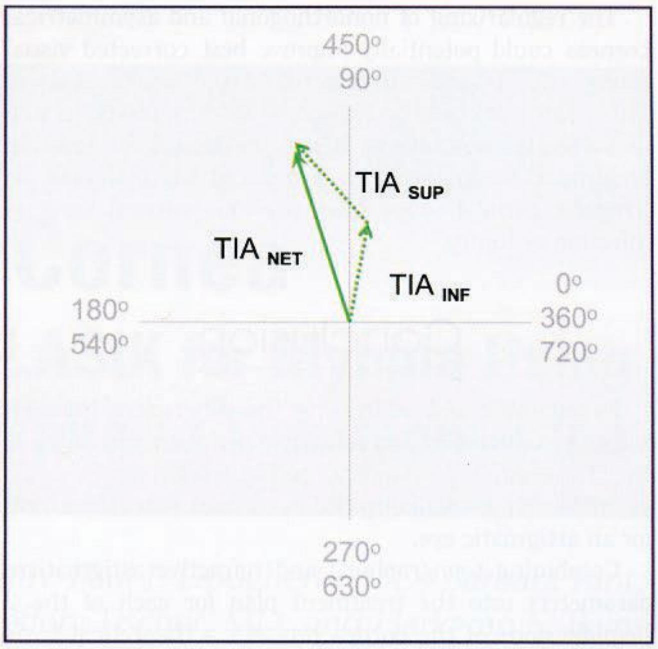

Figure 29-6. A double-angle vector diagram (DAVD) showing head-to-tail summation giving vectorial average of the asymmetric hemidivisional treatments.

the head-to-tail summation gives a vectorial, not an arithmetic, average, shown in Figure 29-6, to determine the combined effect on refractive astigmatism. This TIA NET is then applied to the common refractive astigmatism to determine the average refractive astigmatism value for the eye (Figure 29-7).

In practice, the superior and inferior hemidivisions of the cornea will always share a common refractive value so that the 2 calculated target refractive astigmatism targets (superior and inferior) are not perceived by the eye and a single averaged target refractive value can be used to calculate the targeted outcome of asymmetrical corneal (superior and inferior) treatments. Future technology may enable measurement of separate refractive errors for each hemidivision of the cornea using devices, such as aberrometers, which would potentially improve visual outcomes further.

Further variations to this optimal treatment may give the surgeon the means to change the corneal shape. These include:

1. Achieving orthogonal, symmetrical astigmatism without changing the refractive astigmatism—hence, the TIA NET is 0.00 D.
2. Achieving orthogonal, symmetrical astigmatism by rotating 1 topography semimeridian to match the other semimeridian topography in magnitude but at an orientation 180 degrees away.
3. Achieving orthogonal, symmetrical astigmatism in a preferred orientation chosen by the surgeon. With-the-rule astigmatism is usually preferred.

The regularizing of nonorthogonal and asymmetrical corneas could potentially improve best corrected visual acuity (BCVA) and uncorrected visual acuity (UCVA). This treatment could be applied by ablative lasers, as well as incisional keratotomy. It may be useful for treating amblyopia, keratoconus, or a reduced BCVA due to an irregular corneal shape from previous corneal surgery, infection or injury.

Conclusion

Recognizing and addressing the differences between not only topography and refractive astigmatism, but also the 2 corneal topographical semimerdian values is an essential step to realizing the maximum potential vision for an astigmatic eye.

Combining topographical and refractive astigmatism parameters into the treatment plan for each of the 2 hemidivisions of the cornea provides a theoretical basis for changing the relative shape of the cornea and makes improved visual performance possible. Furthermore, this method presents a means for merging the topographical shape, refraction, and therapeutic devices.

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