Topography-Guided Excimer Laser Treatment

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ABSTRACT

The cornea constitutes the majority of the eye's refraction and may induces a significant amount of ocular aberration. Therefore, treatment options focusing on anterior corneal surface provide satisfactory results and are particularly successful in eyes with irregular corneas. Topography-guided ablations offer promising outcomes for the treatment of corneal irregularities that developed after laser-assisted in-situ keratomileusis (LASIK) interface and flap issues, penetrating keratoplasty, radial keratotomy, and other extremely irregular corneas that are mostly inappropriate for wavefront-guided ablations. Recently, the structural irregularities and refractive errors in ectatic corneal diseases have been treated with the combination of topography-guided ablation and corneal cross-linking (CXL). This combined therapy has provided encouraging results.

Keywords: Topography-guided ablation, excimer laser, irregular cornea, corneal ectasia.

INTRODUCTION

The development of ablation profiles has improved refractive surgery during the past ten years. Four generic ablation profiles have so far been established for laser vision correction. The first of all was the standard profile that only corrected lower-order aberrations (LOAs).[1] This profile is no longer widely used because it underestimated the impact of corneal curvature. This method can result in undesirable visual symptoms and vision loss due to the induced or pre-existing higher-order aberrations (HOA).[2,3] Higher-order aberrations have become more detectable as a result of the improvement in corneal imaging. Thus, different excimer laser profiles have been developed to eliminate these corneal abnormalities. Wavefront-optimized profiles have been developed in order to reduce the impact of corneal curvature and the induced spherical aberration by ablation.[4] The wavefront-guided profile, the third type of generic ablation profile, is developed to decrease the total aberrations (LOAs and HOAs) of the whole eye. Finally, topography-guided profiles have been developed to treat anterior corneal irregularities, which may be primary or secondary to trauma, corneal transplantation, or complicated refractive surgery.[5]

Since the tear film and cornea are responsible for the majority of the refractive power of the eye, refractive surgery should focus on treating this refractive surface. This is particularly proper for severely aberrated corneas after corneal transplantation, radial keratotomy, primary corneal ectasia, and complications of excimer laser treatment (decentered ablations, small optical zones, flap complications, post-LASIK ectasia).[4] Highly aberrated corneas frequently impair total wavefront analysis; therefore, wavefront technology does not always provide appropriate corneal imaging in these patients. Corneal topographic analyzes are static, more reproducible, and can provide appropriate treatment of both LOAs and HOAs.

This review provides a thorough assessment of the indications for topography-guided ablation in both regular and irregular corneas with an emphasis on the management of keratectasia in combination with collagen cross-linking (CXL).

Topographical Mapping and Ablation Profiles in Topography-Guided Ablations

There are several topography techniques and tools available for obtaining corneal elevation data and conducting the

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analysis to design the ablation profile. Topography-based ablation profiles can be obtained by applying a Zernike or Fourier matrix to a corneal elevation map. These novel profiles were created to address HOAs caused by the cornea rather than the entire eye.

The manufacturer of the excimer laser determines the topographical method and tools to be utilized based on the software used in the excimer laser device. For instance, in the Nidek Advanced Vision Excimer Laser System (NAVEX; Nidek), a topography-guided ablation algorithm is calculated with the Final Fit software (Nidek) using Placido-disk topography (OPD Scan; Nidek) (Fig. 1). The majority of laser systems currently available on the market, such as CRS-Master (Carl Zeiss Meditec), and T-CAT (Wavelight ALLEGRETTO platform; Alcon), have a similarly incorporated topography-guided treatment algorithm.

On each excimer laser platform, various topography techniques (Placido-disk or Scheimpflug-based) are employed to determine the preoperative corneal curvature. Scheimpflug image-based topography provides a better analysis when corneal irregularities are more central, while Placido disk-based topography is superior when they are more peripheral.[6] Placido disk-based topography creates a central scotoma where the camera is placed; therefore, this system has to extrapolate the central data. However, a Scheimpflug rotational camera clearly detects central data points, making this technique better to detect eyes with central abnormalities. In myopes, the two imaging technologies produce results that are basically comparable in terms of efficacy, safety, and predictability; however, a treatment based on Scheimpflug imaging offers better visual outcomes in hyperopes.[6]

Topography-based ablation profiles address abnormalities in corneal elevation as well as spherocylindrical refractive error. Algorithms aim to address abnormalities in the corneal elevation with an ablation that preserves the cornea's aspheric shape while reducing the amount of tissue that needs to be removed. The fundamental principles of

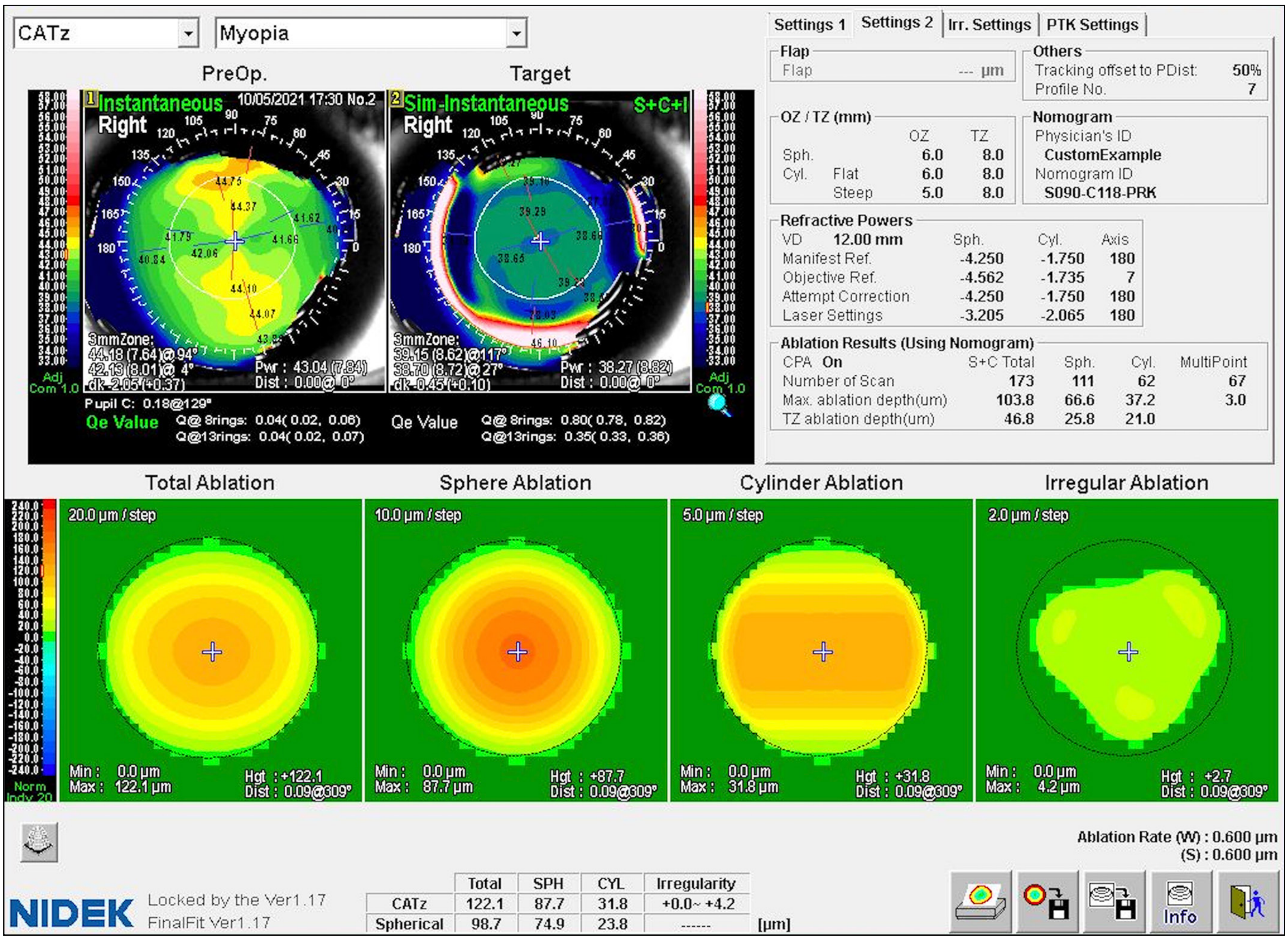

Figure 1: *Treatment planning of a topography-guided ablation on the NAVEX Laser Platform using the customized aspheric transition zone (CATz) ablation algorithm in the Final Fit software.*

topography-guided ablations are to ablate around the flatter regions to steepen the flatter area (hyperopic ablation) and to flatten the steeper regions (myopic ablation) (Fig. 2).

Topography-Guided Treatment for Regular Corneas

Traditional laser vision correction leads to formation of corneal HOAs, mostly increased in spherical aberration. Improved treatment approaches were required due to visual problems including halos, glare, and decreased contrast sensitivity.[2,3] In order to reduce the induction of spherical aberration during laser refractive surgery, customized correction methods of corneal HOAs, such as wavefront-guided, wavefront-optimized, and topography-guided ablation, have been established.[7-9]

Topography-guided customized ablation for the primary correction of myopia and astigmatism has demonstrated similar clinical results to wavefront-guided customized ablations.[10-12] A randomized contralateral eye-to-eye comparison study of wavefront-guided and topography-guided photorefractive keratectomy (PRK) showed comparable visual results and contrast sensitivity in patients with low to moderate simple myopia or compound myopic astigmatism.[13] Figure 3 has demonstrated that total HOAs were not induced in a patient with high myopia who underwent topoguided PRK with CATz mode.

Wavefront-optimized treatment and topography-guided treatment are differ from each other in various aspects. First of all, topography-guided therapies focus on the corneal vertex rather than the pupil center. Therefore, topography-guided ablations perform better than wavefront-guided ablations in cases of higher angle kappa.[14] Aberrometer may provide inaccurate data in significantly aberrated eyes or those with corneal opacities in wavefront-optimized technique, so the accurate measurement obtained by topography-guided therapy is another advantage. Moreover, lenticular and vitreous opacities do not impair topography-based treatments.[15,16] Finally, the measurement area can be wider in topography-based ablation since the pupil is not

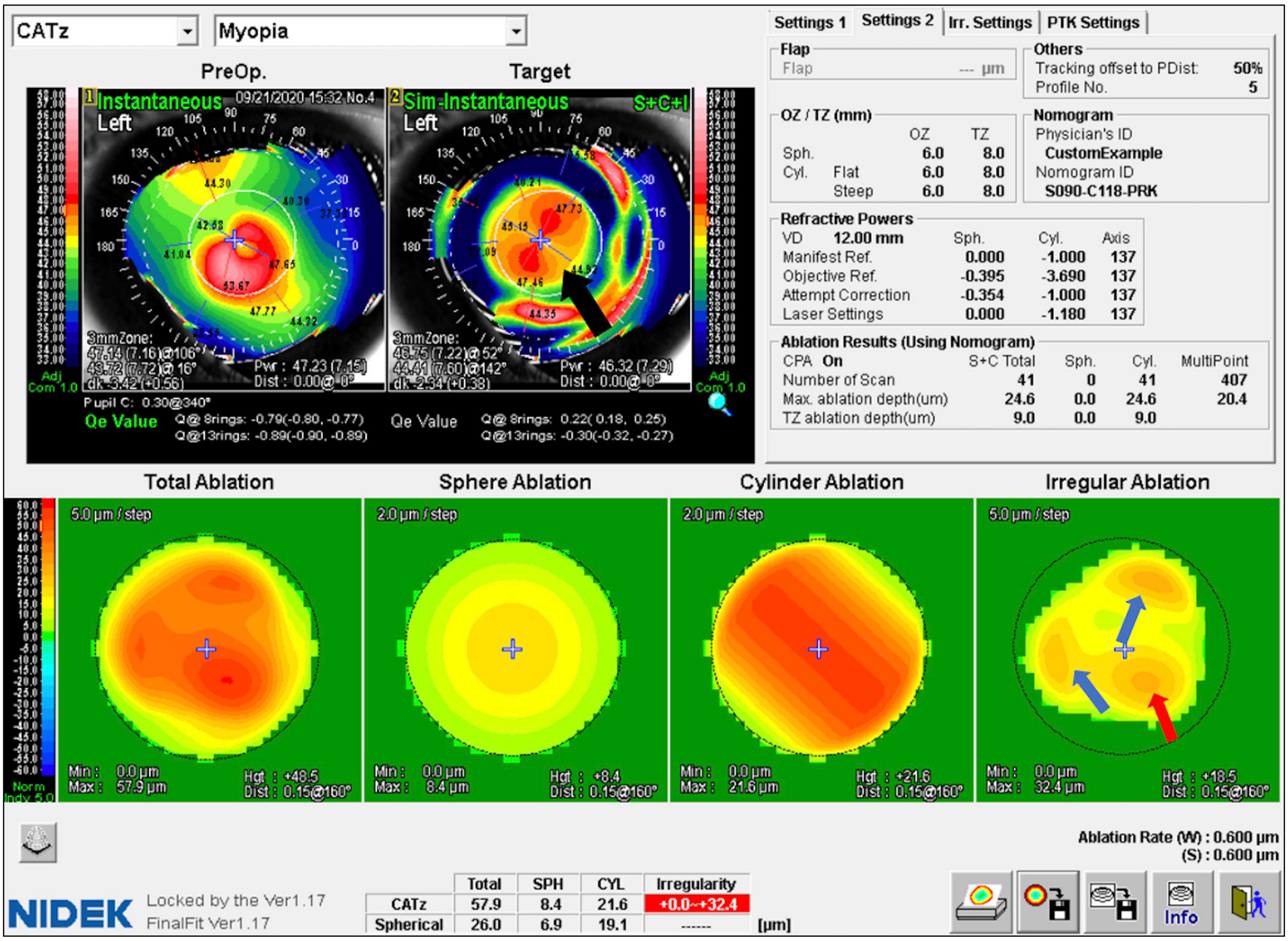

Figure 2: *Simulation map of topography-guided treatment obtained with Final Fit software (Nidek). Myopic ablation over the apex of the cone allows flattening (red arrow) and an arcuate hyperopic mid-peripheral ablations steepen the flatter cornea regions (blue arrows), providing a more regular anterior corneal curvature (black arrow).*

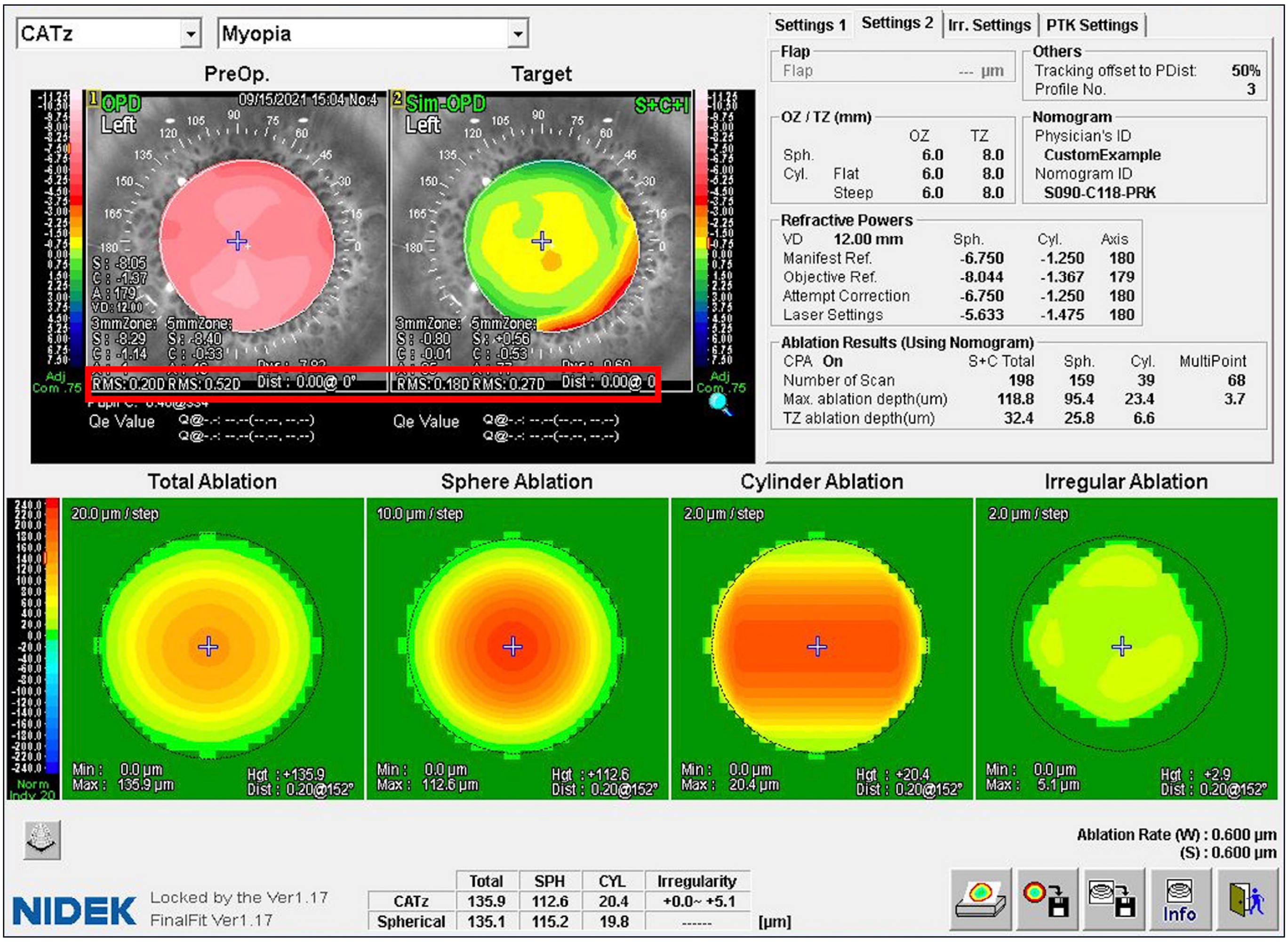

Figure 3: *OPD simulation map of a patient with compound myopic astigmatism who underwent topography-guided PRK with CATz mode. Note the preoperative and postoperative target RMS values.*

a limitation. This advantage provides an opportunity to detect and treat peripheral corneal abnormalities which are thought to be the main cause of HOAs.

Topography-Guided Treatment for Irregular Corneas

Topography-guided ablations were first developed to treat corneal abnormalities.[17-20] One of the main focuses of this treatment is irregular astigmatism following refractive surgery. Numerous articles have discussed the use of topography-guided ablation for irregular corneas such as those with flap interface problems, small or decentered optic zones, post-keratoplasty, post-radial keratotomy, and both idiopathic and iatrogenic keratectasia.[21-26]

Chen et al.[25] have stated that seventeen eyes with LASIK flap interface problems could be safely and successfully treated with topography-guided ablations. A cohort of eleven eyes with visual loss due to decentered ablation were studied by Kymionis at al.[24] A significant improvement in corrected visual acuity was achieved after topography-guided customized ablation. In addition, Lin et al.[22] reported the safety and efficacy of topography-guided treatment in eyes with small optic zones and decentered ablation zones following LASIK.

Penetrating keratoplasty (PKP) cases with highly irregular corneas have shown favorable outcomes after topography-guided ablation treatment.[27,28] High corneal astigmatism and irregular astigmatism are common after PKP, which may impair vision and cause contact lens intolerance. Repeat PKP may be utilized to restore these corneas, although this does not always result in improved vision and requires an additional period of postoperative recovery. On the other side, refractive surgery offers a faster recovery, can improve vision with eyeglasses, and can facilitate contact lens wear. However, in the past, these eyes with PKP were not always suitable for refractive surgery due to the severe abnormalities that made wavefront analysis impossible. Topography-guided ablation is now the preferred procedure because most visual problems in transplanted corneas are caused by the abnormalities in the cornea. Ohno[28] reported the favorable results of topography-guided ablations in five corneas with high HOAs or high astigmatism following PKP. All patients experienced an increase in both uncorrected and best-corrected visual acuity.

Motwani et al.[29] have demonstrated an increase in corrected visual acuity and an improvement in topographic regularity after topography-guided treatment in four eyes with highly irregular corneas caused by either prior surgery or trauma.

Combined Topography-Guided Ablation and Corneal Cross-Linking in Corneal Ectasia

Corneal CXL improves corneal stiffness and halts the progression of keratectasia effectively in keratoconus, post-LASIK ectasia, and pellucid marginal degeneration (PMD).[30] However, CXL alone cannot improve functional visual acuity. It can be used with refractive techniques to overcome this limitation.[31] The treatment of corneal ectatic disorders currently involves a novel procedure called "CXL plus" that combines two surgical methods. Corneal cross-linking is the primary technique used in CXL plus, which is combined with refractive procedures including transepithelial phototherapeutic keratectomy (PTK), topography-guided PRK, intracorneal ring segments, or different combinations of these techniques.[31,32] It has been shown that combining CXL with the refractive procedures, such as topography-guided PRK, is a safe and efficient technique to stabilize the cornea and improve functional visual acuity with just minor possible side effects.[16] The first CXL plus method with excimer laser ablation was topography-guided PRK combined with CXL (the Athens protocol) and it is considered as a safe and effective treatment for keratectasia.[31] Figure 4 has demonstrated the changes in corneal topography of a patient treated with the Athens protocol.

Topography-guided ablation was first described by Kanellopoulos and Binder to improve visual acuity in a cross-linked eye.[33] In a later study with a large cohort (232 eyes), the stability of the disease and decreased corneal irregularity were observed in long-term follow-up with the Athens protocol.[34] These results were supported by other studies, with demonstrating the treatment's safety and efficacy.[35-37] Kymionis et al.[37] have reported favorable outcomes of the Athens protocol in 31 eyes along with a significant improvement in refractive errors and keratometry values, leading to increase in visual acuity at 20 months. Only grade 1 haze was observed in half of the corneas.

Along with keratoconus, post-LASIK ectasia and PMD are other conditions in which the combination of CXL and topography-guided ablation has effectively been

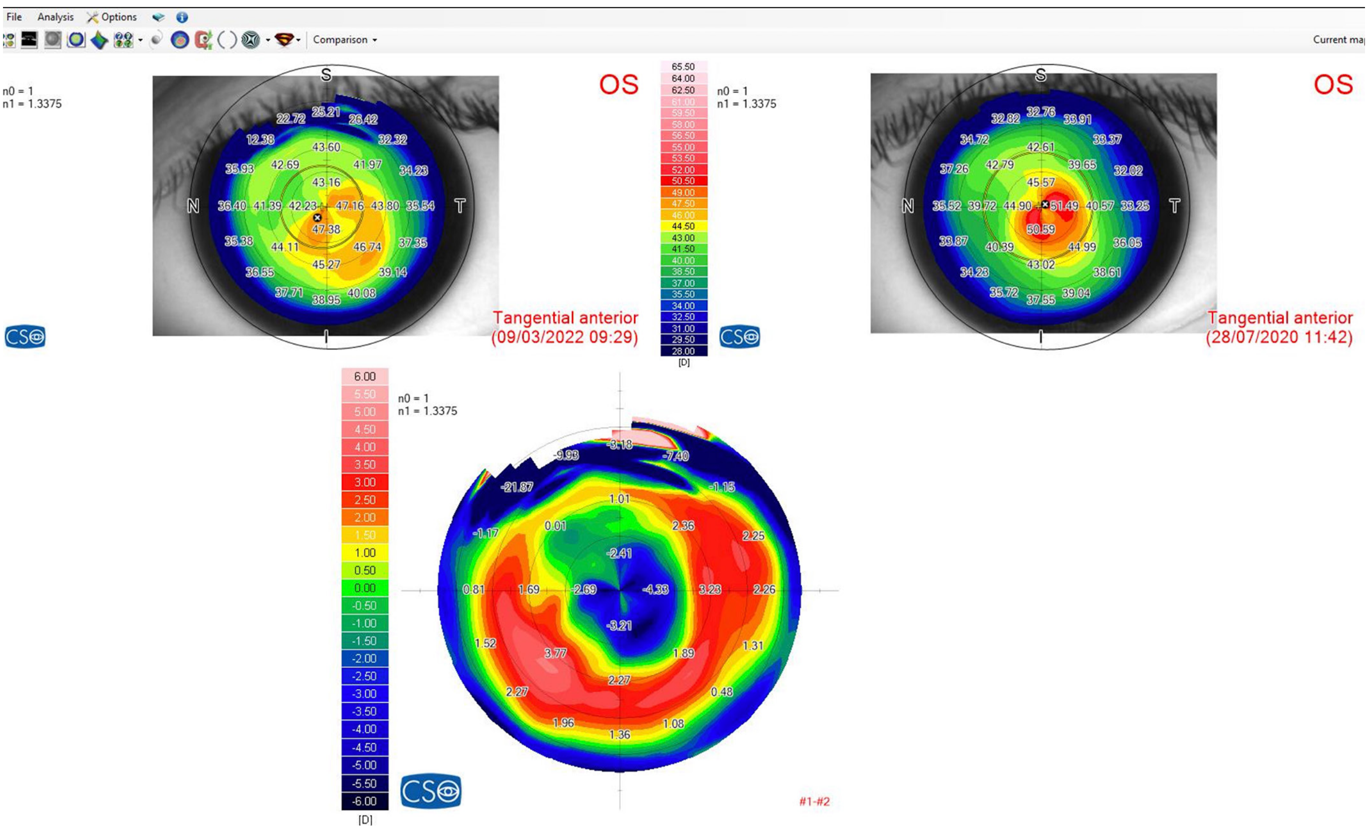

Figure 4: *Changes in the corneal topography of a patient treated with the Athens protocol. Note the stability of the disease and the reduction of corneal irregularity.*

performed. It has been demonstrated in both disorders that the progression of the diseases has arrested and the topographical and refractive outcomes have improved.[38,39] Kymionis et al.[38] performed topography-guided PRK in combination with CXL in a patient with gradually worsening visual acuity after LASIK. They found that the patient's topographic and visual parameters as well as astigmatism had all significantly improved. Stojanovic et al.[40] treated six patients with PMD and found similar results. The analysis of their data also revealed that patients with PMD appeared to improve similarly to those with keratoconus.

There is still disagreement over the "ideal" recommended treatment protocol. The sequencing of the two treatments (sequential or simultaneous), the highest recommended ablation depth, and the intraoperative use of mitomycin C (MMC) are the key points of discussion regarding the method.[41]

Sequential versus simultaneous cross-linking with topography-guided ablation

Kanellopoulos[42] compared the sequential and simultaneous approaches in topography-guided PRK combined with CXL treatment. The author suggested that simultaneous PRK and CXL is a superior therapeutic option compared with sequential PRK administered 6 months or one year after CXL in progressive keratoconus with severely irregular corneas. Simultaneous treatment (PRK and CXL) has two important advantages over sequential treatment (PRK following CXL); first, the laser ablation does not damage the cross-linked cornea, and secondly, the possibility of corneal scarring is reduced.[38,42] Moreover, the tissue ablation rate in virgin eyes would be expected in comparison to cross-linked corneas, making simultaneous treatment more predictable.[42]

In conclusion, simultaneous treatment in appropriate patients has currently proven to be a more effective and safe method compared to the sequential approach due to more reliable and superior refractive and visual results as well as less post-operative haze, and rapid post-operative recovery.

Stromal ablation depth

Simultaneous treatment should be preferred for keratoconus patients with a minimum corneal thickness of 450 microns preoperatively. In addition, some clinical studies have also recommended that the intraoperative residual stromal bed thickness should be at least 350 microns after laser ablation.[42,43]

Although the highest ablation is usually 50 microns, ablations up to 80 microns have been successfully performed in eyes with a minimum corneal thickness (with epithelium) above 450 microns prior to treatment.[35] The minimal threshold of 350 microns of residual stromal bed should be maintained if any additional ablation beyond 50 microns is planned.[42,44] An optic zone of 5.5 mm can be used to preserve as much tissue as possible because the treatment's goal is corneal surface regularization rather than refractive error correction.[40,43] Refractive error correction should not be considered as a priority. Thus, it is possible to create an ablation profile to address the corneal abnormalities using both myopic and hyperopic ablation. Then, refractive error correction may be planned according to the remaining corneal tissue. A 30% undercorrection of the refractive error is recommended to compensate the flattening effect and subsequent myopic shift induced by CXL.[44]

Intraoperative use of mitomycin C

The formation of haze after combination treatment has been one of the minor disadvantages. The effectiveness of intraoperative MMC in lowering postoperative haze incidence is unknown. Some studies have recommended administering 0.02% MMC for 20-40 seconds intraoperatively. Kanellopoulos[42] administered 0.02% MMC for 30 seconds after laser ablation; also Al-Tuwairqi and Sinjab[45] used the same dosage. On the other hand, CXL also causes keratocyte apoptosis in anterior stroma, which may decrease the possibility of haze after ablation. For this reason Kim et al.[46] and Kymionis et al.[38] did not prefer the use of MMC.

Long-term clinical results of the Athens protocol

Numerous authors have demonstrated an increase in both uncorrected and corrected visual acuity, as well as a concomitant topographical improvement of the anterior corneal surface.[31-47] The refractive results have also been demonstrated to be stable over time. Kanellopoulos[47] has recently reported the 10-year long-term clinical results of the Athens protocol in keratoconus patients. There was an increase in visual acuity along with the stability of disease progression. Progressive flattening resulting with hyperopic shift was seen in only 3.5% of eyes after combination treatment.

The preliminary study from our clinic have also shown promising clinical results of the Athens protocol. A mean increase of 3 Snellen lines in both uncorrected and best-corrected visual acuity and a significant decrease in corneal irregularity parameters were observed at 1-year follow-up (Fig. 5). No patients with vision-reducing haze or hypermetropic shift due to overtreatment were noted (unpublished data).

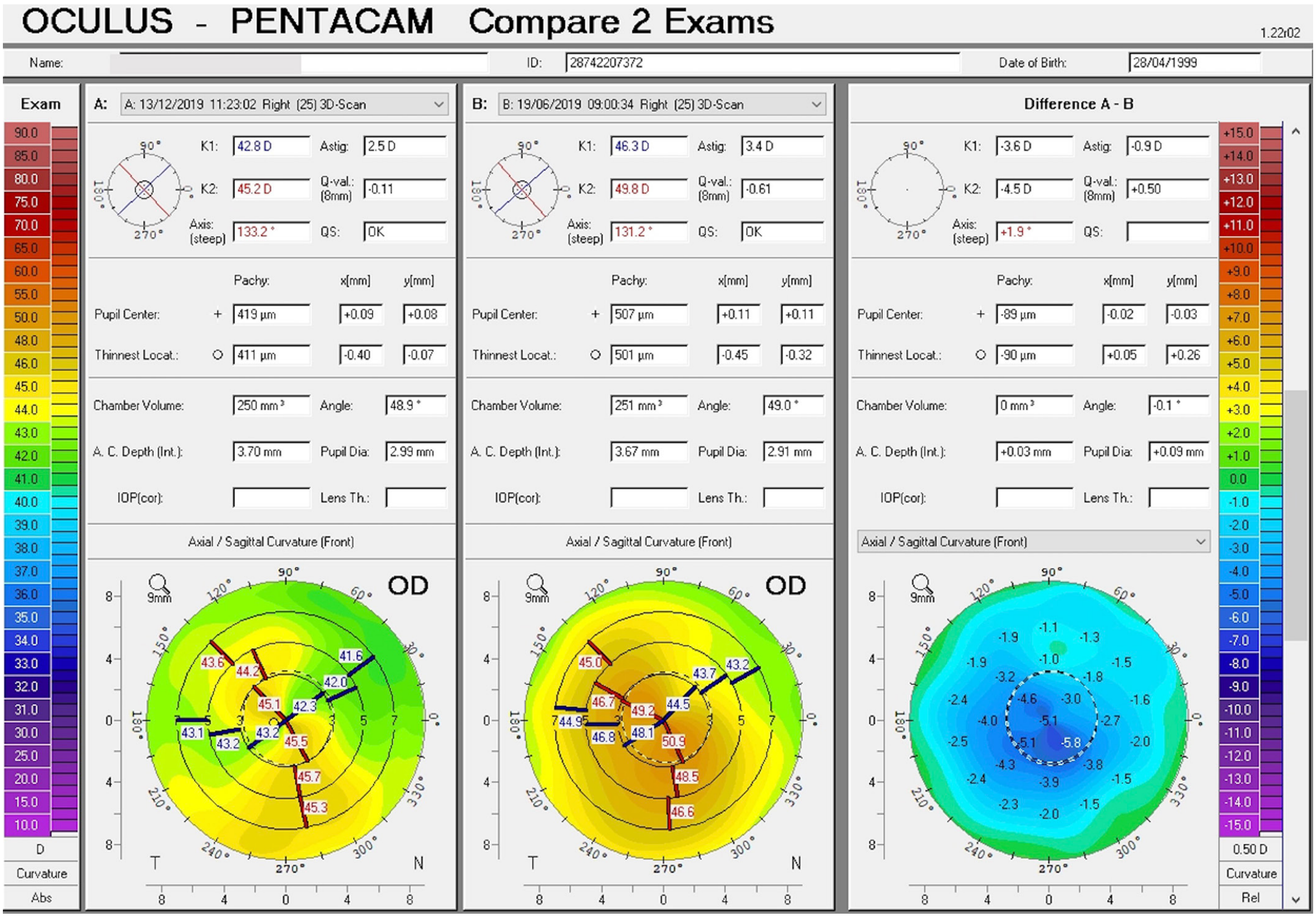

Figure 5: *Corneal topography images of a patient who underwent CXL combined with topography-guided PRK. Postoperative best spectacle-corrected visual acuity (Snellen) increased from 0.4 to 1.0 with a corneal regular astigmatism pattern.*

CONCLUSION

Customized topography-guided ablations offer an alternative treatment option for highly irregular corneas. This approach is especially appropriate for highly aberrant eyes that could not be treated optimally with customized ablation with wavefront guidance. Recent studies have shown that treatment of corneal ectasia with CXL plus prevents the progression of corneal irregularity and also improves vision. With this combined therapy, it may be expected that contact lens usage and the need for corneal transplantation will reduce.

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