Review Article

Topography-guided treatment in regular and irregular corneas

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Over the last decade, refractive surgery has been revolutionized by advancements in ablation profiles, available for the treatment of both regular and irregular corneas. Advances in corneal imaging have helped highlight the presence of higher-order aberrations, the correction of which could result in a better quality of vision. Topographic measurements being static are more repeatable and pupil independent and therefore provide the ideal platform for correction of both lower and higher-order aberrations and could result in improved visual quality even in patients with seemingly regular corneas. The combination of topography-guided treatment with collagen cross-linking has further increased the scope of treating irregular corneas like keratoconus, post-laser *in-situ* keratomileusis ectasia, and pellucid marginal degeneration. This review delves into the current literature and guidelines available for the topographic treatment of regular and irregular corneas.

Key words: Ablation, cornea, corneal topography, ectasia, excimer, keratoconus

Access this article online

Website:
www.ijo.in

DOI:
10.4103/ijo.IJO_2119_20

Quick Response Code:

The cornea is a major refractive surface of the eye; therefore, corneal aberrations result in suboptimal vision. Keratorefractive procedures allow the correction of lower-order aberrations to provide refractive error correction. However, higher-order aberrations (HOA), induced or preexisting cause unwanted visual symptoms and loss of visual clarity.[1,2] Hence, excimer ablation profiles including topography-guided laser have evolved to reduce corneal irregularities. This review offers a comprehensive overview of the indications for topography-guided ablation profiles in both regular and irregular corneas, treatment parameters, and analysis of outcomes in terms of safety and efficacy.

Topography-Guided Treatment in Regular Corneas

Conventional laser *in-situ* keratomileusis (LASIK) included ablation profiles with resultant corneal HOA induction. Subsequent visual symptoms including nighttime glare, halos, starbursts, and reduced contrast sensitivity warranted the need for improved treatment modalities.[1,2] Customized correction of corneal HOAs entails aberrometry-guided modalities including wavefront-guided and wavefront-optimized (WFO) profiles and topography-guided ablation.[3-5]

The cornea is the major refractive surface of the eye and is responsible for a large proportion of the innate and acquired ocular aberrations. While WFO treatment aims at reducing the treatment-induced spherical aberrations without altering the pre-existing HOAs, topography-guided treatment profiles additionally correct preexisting corneal surface irregularities.[6] Conventionally used to treat irregular corneas, topography-guided platforms have also shown safety and efficacy in treating primary myopia and astigmatism.[7-11]

Topography-guided treatment differs from wavefront-optimized treatment in various aspects. Topography-guided ablation allows the creation of an ideal corneal curvature as against a planar wavefront with the WFO platform.[12] Corneal curvature evaluation is not pupillary size-dependent, as are wavefront measurements, thus making topography-guided ablation independent of pupil centroid shift errors.[13] Additionally, preoperative assessment entails the measurement of greater corneal points allowing treatment of the peripheral cornea which is responsible for most HOAs. Another advantage of the topography-guided treatment is its use in highly aberrated eyes or those with corneal opacities wherein inaccurate measurements may be produced with aberrometer. This makes the data obtained from topography more repeatable and reliable than wavefront data.[14]

Although the regularization of the surface is a result of the elevation data, the clinical manifest refraction and the wavefront data decide the final target corneal surface. The basic idea in topography-guided ablation is to target the excimer laser spots to flatten the steeper portions and steepen the flatter areas which is achieved by ablating around the flatter areas. This combination of myopic and hyperopic ablation consumes a lesser amount of tissue while at the same time maintaining a prolate cornea. Also, in topography-guided ablation, centration

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Received: 28-Jun-2020 Revision: 10-Oct-2020
Accepted: 17-Oct-2020 Published: 23-Nov-2020

Cite this article as: Ramamurthy S, Soundarya B, Sachdev GS. Topography-guided treatment in regular and irregular corneas. Indian J Ophthalmol 2020;68:2699-704.

is based on the corneal apex and not on the pupil center, thus negating the angle kappa issue. As topography-guided ablation treats only the corneal aberrations, it is not surprising that there is concern that this may unmask the lenticular HOAs, which could in turn result in reduced visual quality outcomes following the procedure.[14]

Safety and Predictability

Clinical refraction has been used for correction in most of the laser vision correction treatments. However, at times the refractive data may differ from the topographic data with respect to the magnitude and axis of astigmatism. Topography-guided treatments are thus based on both corneal topography as well as refractive measurements of the eye as topography cannot furnish data regarding the spherical error. Thus, combining clinical refraction and topographic data in the form of topography-modified refraction (TMR) was put into clinical use. The contralateral eye study by Kanellopoulos and co-workers included 50 patients who underwent clinical refraction-based ablation versus TMR treatment. Significantly better visual outcomes in terms of uncorrected and corrected distance visual acuity and postoperative residual astigmatism were seen in the TMR group.[15] Wallerstein *et al*. in a comparative analysis demonstrated outcomes in eyes treated with TMR-based topography-guided LASIK and concluded significantly inferior outcomes in eyes wherein the discrepancy between manifest and topolyzer-based cylindrical axis was greater than 21°.[16]

In a study conducted by Stulting *et al*. on 249 eyes using laser delivery by the Allegretto Wave Eye-Q excimer laser system, it was found that the topo-guided treatment significantly reduced the refractive spherical equivalent and astigmatism which showed stability up to 1 year, with a significant improvement in visual symptoms. Additionally, they reported an improvement in 1 or more lines in postoperative uncorrected distance visual acuity (UDVA) vis-à-vis preoperative CDVA in 30% of the eyes.[13] Similar results by demonstrated by Waring and coworkers in 131 eyes treated with topography-guided LASIK using the Nidek CX II custom aspheric treatment zone (CATz) algorithm.[12]

El Awady *et al*. compared topography-guided and wavefront-optimized ablation in a contralateral-eye study with the Allegretto Wave excimer laser and reported that 19% of eyes in the topography-guided group versus 12% of eyes in the wavefront-optimized group had a 1 or more-line gain in UDVA.[7]

Though superior results using the topography guided ablation profile were demonstrated in the earlier studies, subsequent cohorts failed to establish any clinically significant superiority. Kim and co-workers demonstrated no significant difference in the visual outcomes following WFO and topo-guided LASIK using the Contoura software (Wavelight EX500 excimer laser) in a contralateral eye study of 43 patients. Additionally, there was no significant difference in the postoperative residual cylinder between the two groups.[17]

Similar results were demonstrated by Jain *et al*. comparing WFO and topo-guided ablation using the Mel 80 Excimer laser in 35 patients.[14] Shetty *et al*. in a contralateral study demonstrated no statistically significant difference in visual outcomes between WFO and topo-guided ablation using the Wavelight EX500.[18]

The newer Phorcides Analytic Engine software introduced recently provides a topography-guided treatment after taking into consideration the anterior and posterior corneal astigmatism, lenticular astigmatism, and the topographic irregularities that create higher-order aberrations. Lobanoff *et al*. published a retrospective comparative analysis of eyes that underwent topography-guided treatment based on manifest refraction vis-à-vis Phorcides analytic software. They reported significantly better outcomes with the Phorcides software with 62.5% eyes achieving a UDVA of 20/16 or better as against 41.3% in the other group.[19]

Higher Order Aberrations and Contrast Sensitivity

Topography-guided treatment may potentially lead to an unmasking of internal HOAs. Numerous studies have demonstrated an increase in ocular HOAs following both WFO and topo-guided ablation profiles, however, the induced aberrations are lower with the latter. Kim *et al*. demonstrated a significant reduction in trefoil postoperatively with no significant increase in coma and spherical aberrations following topo-guided ablation. A similar reduction of trefoil was not seen following wavefront-optimized ablation.[17] On the contrary, Shetty *et al*. showed no statistically significant difference in the induced corneal HOAs between topography-guided and wavefront-optimized treatment.[18] Jain *et al*. demonstrated lower levels of an induced coma and spherical aberration following topo-guided treatment in comparison with the wavefront-optimized approach.[14] Similar results were reported by Stulting *et al*. where they showed a lower induction of total HOAs in the topo-guided treatment group.[13] On comparing standard clinical refraction-based treatment and TMR, in the study conducted by Kanellopoulos *et al*., the TMR group was found to show better results in terms of total HOAs, coma, and contrast sensitivity.[6]

Topography-Guided Treatment for Ectatic and Irregular Corneas

Numerous publications have described the application of topography-guided ablation in irregular corneas including keratectasia, both idiopathic and iatrogenic, post keratoplasty, small or decentered optic zones, and flap interface complications.[20-26]

Kymionis and coworkers described a cohort of eleven eyes with decentered ablation profiles and subsequent loss of corrected distance visual acuity. Significant improvement in corrected and uncorrected visual acuity following enhancement with topography-guided customized ablation was observed. They concluded better visual outcomes in eyes with larger decentration and greater HOAs.[24]

Lin *et al*. in a retrospective analysis described acceptable safety of topography-guided treatment profile in 67 and 48 eyes with decentered and small optic zones post LASIK respectively.[21]

Topography-Guided Treatment for Keratoconus

The efficacy of corneal cross-linking (CXL) for arresting disease progression in keratectasia, both idiopathic and iatrogenic is well established.[27] While cross-linking achieves disease stability, corneal surface irregularities and aberrations remain untreated requiring rigid gas permeable contact lens (RGP) postoperatively. RGP also brings with it unique challenges including reduced patient comfort, poor fit in case of increased flattening, or haze caused by cross-linking.[28]

The advent of topography-guided excimer laser ablation with concomitant CXL allows the reduction of corneal anterior surface irregularities along with disease stability.

Kanellopoulos and Binder first described the novel application of topography-guided ablation in a cross-linked eye to improve visual acuity.[28] Following this, a report of two cases exhibiting stability for over a period of 30 months was published.[29] The same author then subsequently went on to describe the stability and anterior surface normalization in a larger cohort of 232 eyes.[30] These results were then replicated by other groups as well demonstrating the safety and efficacy of the treatment over a 2-year follow-up period.[31,32]

The subsequent discussion entails a comprehensive overview of the preoperative requisites, treatment parameters, and visual outcomes of this technique.

Simultaneous versus sequential cross-linking with topography-guided ablation

Despite numerous publications on topography-guided treatment in keratoconus, there still exists a debate between whether the procedures of cross-linking and topography-guided ablation should be carried out sequentially or simultaneously. Proposed advantages of simultaneous cross-linking with ablation include reduced patient time away from work and possible reduction of haze formation as cross-linking induces keratocyte apoptosis in the anterior corneal stroma reducing the number of migrating fibroblasts.[33] Additionally, sequential treatment ablates a significant proportion of the anterior cross-linked stroma thereby reducing treatment efficacy.[33] Moreover, the ablation rate of tissue would be predictable in virgin eyes vis-à-vis cross-linked corneas, allowing more predictable results with simultaneous treatment. The removal of the Bowmans membrane post-ablation additionally enhances riboflavin penetration into the corneal stroma.[33,34]

The above advantages notwithstanding, sequential treatment may have a benefit in select few patients who may have an exaggerated response to CXL with greater haze and flattening. Performing topography-guided treatment following corneal curvature and refractive error stabilization would be ideal. Additional candidates for nonsimultaneous treatment would include a limited cohort wherein disease progression continues despite corneal collagen cross-linking.[34] However, since progression and incidence of haze formation cannot be predicted beforehand, simultaneous ablation with cross-linking has gained greater worldwide acceptance.

Treatment requisites and parameters

Concomitant cross-linking and topography-guided corneal regularization is ideally suited for mild to moderate grades of keratoconus, with a minimum corneal thickness of 450 μ.

Additionally, a postoperative corneal thickness of 400 μ and an intraoperative residual stromal bed of 350 μ post-ablation is suggested.[31,33,35]

Although the maximum tissue ablation is usually limited to 50 μ, ablations up to 80 μ have been performed safely in eyes with greater preoperative corneal pachymetry in excess of 450 μ.[31] Any additional ablation planned beyond 50 μ is carried out ensuring the minimum safety limit of 350 μ residual stromal bed after epithelial removal and at the end of ablation.[33,34] Since the treatment is aimed at corneal surface regularization as against refractive error reduction, an optic zone of 5.5 mm can be utilized as a tissue saving measure.[35,36]

It is important that pre-operative images obtained are repeatable and are of appropriate quality as this is key to the subsequent planning stages. After obtaining a minimum of six repeatable scans, [Fig. 1] the treatment is initially planned with zero refractive error correction [Fig. 2]. This allows the generation of an ablation profile to treat the corneal irregularities with a combination of myopic and hyperopic ablation. Myopic ablation overlying the apex of the cone allows flattening and an arcuate hyperopic mid-peripheral treatment steepens the cornea anterior to it, providing a more regular anterior corneal contour [Figs. 3 and 4]. Subsequently, refractive error debulking can be planned based on the remaining corneal tissue that can be safely ablated [Fig. 5]. An under correction of the refractive error by 30% is recommended to account for the flattening effect and subsequent myopic shift secondary to cross-linking.[34]

The location of the cone additionally has an effect on the final visual outcomes. While improvement in topographic and keratometric parameters has been demonstrated in both centered and decentered cones, the topography-guided treatment provided superior visual outcomes in centered cones with significantly better postoperative UDVA.[37]

Haze formation following combined treatment has been one of the minor shortcomings. The use of intraoperative Mitomycin C (MMC) to reduce the incidence of postoperative haze has been controversial. Certain studies recommend the intraoperative administration of 0.02% MMC for 20–40 s. However, Kymonis *et al*. demonstrated favorable outcomes without the adjunctive application of MMC in their cohort. The depopulation of keratocytes in the anterior corneal stroma following CXL was attributed to a reduced propensity for haze development.[28,38-40]

Conventional wavefront-based treatment as an alternative for topography-guided treatment has also been tried to debulk refractive error in keratoconic eyes along with cross-linking. The challenge in these irregular corneas is obtaining a repeatable wavefront which is a dynamic measurement in comparison to corneal topography which is a static measurement and is more repeatable. Therefore, when available, topography-guided treatment should be preferred over wavefront-guided treatment in irregular corneas.[41]

Epithelial removal

The original Athens protocol entails the removal of corneal epithelium using manual debridement prior to topography-guided excimer ablation. However, the topographic corneal surface is obtained preoperatively with an intact corneal epithelium. Anterior segment Optical Coherence Tomography (AS-OCT) has established variable epithelial thickness in keratoconic eyes, with reduced thickness over the conical apex and greater thickness around the base as a masking agent.[42,43] Thus, manual epithelial removal allows debridement

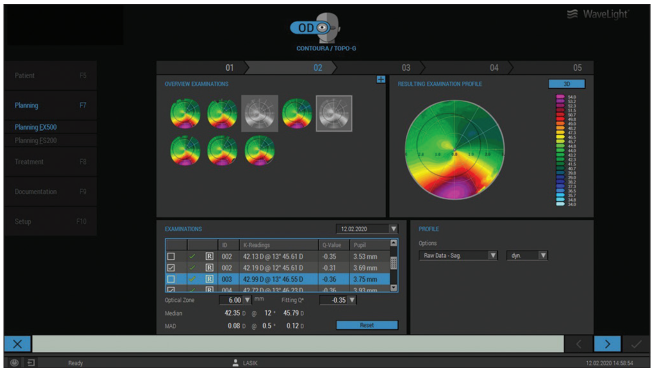

Figure 1: Repeatable preoperative scans which are an essential prerequisite for subsequent treatment planning. The outliers are deselected from analysis

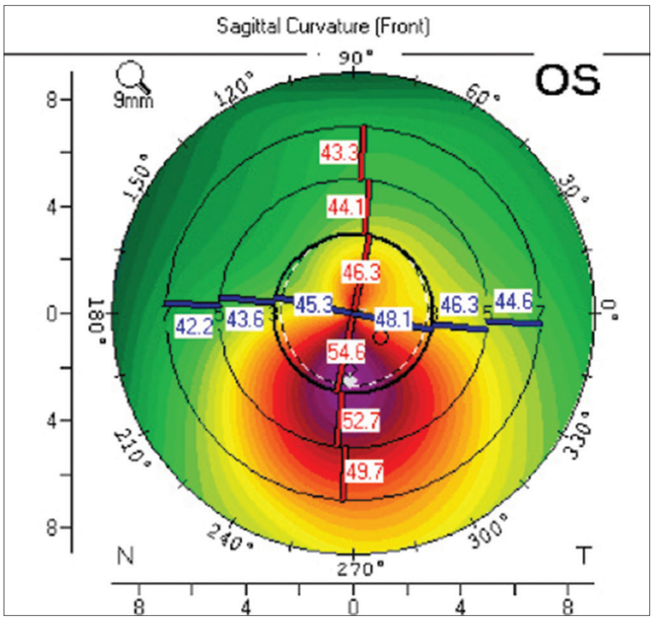

Figure 3: Preoperative sagittal curvature of a patient undergoing combined topography-guided treatment with cross-linking

Figure 5: Final treatment plan with the regularization and debulking of the cylindrical error with the extent of ablation around 50 μ

of variable epithelial thickness with a resultant underlying contour that varies from the preoperative epithelium-on measurements. Therefore, utilization of phototherapeutic keratectomy (PTK) mode would ensure a uniform tissue removal

Figure 2: During the treatment, it's advisable to first keep the power at zero and check if the ablation profile matches with the sagittal curvature

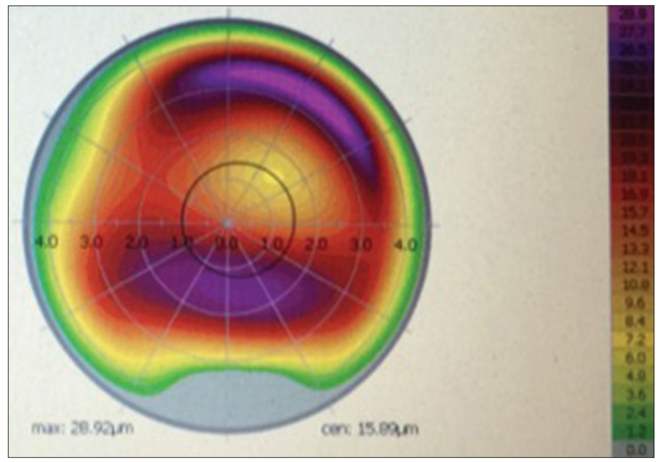

Figure 4: Ablation profile for the corresponding topography in Fig. 3, showing a myopic ablation over the area of the cone, and a broader mid-peripheral hyperopic ablation which will steepen the area anterior to it, thereby performing a regularization of the anterior cornea

along the entire surface and thereby the underlying contour may better mimic the one measured by preoperative topography.[32,34]

Stability of Outcomes

Several authors have reported improvement in uncorrected and best-corrected distance visual acuity along with corresponding topographic improvement of the anterior corneal surface. Additionally, long term stability of the refractive outcomes has also been established. Recently 10-year outcomes of this combined procedure have been published demonstrating the stability of keratometric and visual outcomes with only 3.5% of eyes showing progressive flattening leading to overcorrection or hyperopic shift.[44]

More recently the advent of customized cross-linking has added an extra dimension to further enhance outcomes in ectatic corneas. Initial reports of combining customized cross-linking with topography-guided treatment also show promising results and the combination could augur for maximizing outcomes.[45,46]

Topography-guided treatment for highly irregular corneas/ post surgical irregular corneas

Apart from keratoconus, topography-guided ablation in combination with cross-linking has also been successfully applied in post LASIK ectasia as well as pellucid marginal degeneration. In both instances stability of disease progression and improvement in topographic and refractive outcomes has been demonstrated.[47,48]

A retrospective analysis done by Lin *et al*. showed that topography-guided treatment using the custom topographical neutralization technique (TNT) along with CXL resulted in safe, effective, and predictable outcomes in highly aberrated corneas including post-refractive surgery decentered ablations or ectasia, asymmetrical astigmatism, post-radial keratotomy, and post-keratoplasty.[35]

Motwani *et al*. published the results of topography-guided treatment with Wavelight Contoura in four eyes with highly irregular corneas resulting from either trauma or previous surgery. Using the San Diego protocol, which essentially incorporated Contoura measured astigmatism and axis into the treatment protocol, they reported an improvement in CDVA and topographic uniformity.[49]

Conclusion

Over the past decade, topography-guided treatment has revolutionized the field of refractive surgery allowing improved outcomes with keratorefractive procedures, correction of corneal HOAs, treatment of high astigmatic errors, and anterior surface regularization for ectatic corneas. Further refinements in topography-guided ablation profiles along with superior imaging of the posterior cornea and measurements of the internal aberrations of the eye would help in enhancing outcomes in the years to come.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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