International Medical Case Reports Journal

Dovepress
Taylor & Francis Group

Open Access Full Text Article

CASE REPORT

Application of Surgical Protocols for the Treatment of Highly Irregular Astigmatism with Topographic Guided Ablation in a Case of Post-LASIK Ectasia

Manoj Motwani[1], Emmanuel Agu[2], Albert Xu[2], Madeline Yung[2]

[1]Motwani Lasik Institute/Cornea Revolution, San Diego, CA, USA; [2]Department of Ophthalmology, University of California San Francisco, San Francisco, CA, USA

Correspondence: Madeline Yung, Email madeline.yung@ucsf.edu

Purpose: To compare the outcomes of two different surgical planning strategies for topography-guided repair of post-LASIK ectasia.

Methods: This is a case report of a patient presenting with post-LASIK ectasia. A retrospective chart review was used to collect details of the ophthalmic exam, as well as ocular imaging such as anterior segment optical coherence tomography and Scheimpflug corneal tomography. Treatment planning was performed initially with the Phorcides analytical engine, and then an enhancement was performed with the LYRA/San Diego Protocol. Epithelium-off corneal cross-linking was performed at 3.0 mW/cm for 30 minutes.

Results: The patient initially presented with a remote history of LASIK and progressive left eye blurring. His uncorrected distance visual acuity (UDVA) was 20/40, with a corrected distance visual acuity (CDVA) of 20/25 with a manifest refraction of −1.25 +1.75 × 180. His central corneal thickness was 529 µm, and corneal topography/tomography demonstrated inferior steepening of the left eye consistent with post-LASIK ectasia. He underwent simultaneous PRK and epithelium-off corneal cross-linking with a treatment plan by Phorcides of –0.14 −0.87 × 001. His vision stabilized at post-operative month 7 to a UDVA 20/40, CDVA 20/20, and manifest refraction of −2.75 +3.50 × 005. He underwent PRK enhancement with a treatment plan by the San Diego Protocol of +0.00 –1.15 × 094, with an outcome of UDVA 20/20, CDVA 20/20, and manifest refraction of −1.00 +0.75 × 174.

Conclusion: The LYRA/San Diego Protocol outperformed Phorcides in a case of corneal ectasia. With appropriate planning, patients with irregular corneas can achieve excellent refractive outcomes.

Keywords: corneal cross-linking, post-LASIK ectasia, Phorcides, San Diego Protocol, topography-guided ablation

Introduction

Corneal ectasia is a progressive degeneration that entails corneal protrusion, irregular astigmatism, and corneal thinning.[1] Laser-assisted in situ keratomileusis (LASIK) induced ectasia occurs when loss of supportive tissue from flap creation and laser ablation results in a residual stromal thickness that can no longer maintain structural integrity. The positive pressure of fluid within the globe pushes the weakened cornea forward, creating an irregular, ectatic shape.[2]

Alpins et al established the importance of incorporating topographic with refractive parameters by employing Vector Planning for photorefractive keratectomy in patients with keratoconus.[3] The combination of topography-guided ablation and corneal cross-linking has emerged as an effective treatment for corneal ectasia.[4,5] This has been shown to significantly decrease corneal irregularity and increase the quality and quantity of vision.[5] In LASIK-induced ectasia, the ablated tissue consists of stromal tissue from the original LASIK flap, which does not contribute to the structural integrity of the cornea, and it becomes free tissue that can be utilized to reshape the cornea.

Accurate treatment of astigmatism with topography-guided ablation can be complex and challenging. Astigmatism arises from optical aberrations, which are disturbances in the visual system that scatter light and cause visual blur.

Received: 11 September 2024
Accepted: 17 December 2024
Published: 15 January 2025

Aberrations include corneal lower-order aberrations (LOA) and corneal higher-order aberrations (HOA). LOAs refer to disturbances that can be mathematically described by lower-order polynomials; for the purposes of this case, LOA refers to the degree of refractive error denoted by sphere and cylinder. HOAs refer to disturbances described by higher-order polynomials and generally refers to more complex or irregular aberrations in the optical system.

Manifest astigmatism reflects the sum of all lower and higher order aberrations in the optical system, which result from anterior corneal astigmatism and posterior ocular astigmatism. Topographic software can quantify anterior corneal aberrations. Meanwhile, posterior ocular astigmatism (POA), which cannot be directly measured, encompasses posterior corneal curvature, lens-related aberrations, and any additional posterior aberrations. What has been debated in the literature is the extent to which POA is significant. The WaveLight Contoura System performs topography-guided ablation by creating a laser ablation pattern to treat the measured HOA in the anterior cornea. The surgeon must input the LOA treatment consisting of the sphere and second order astigmatism with axis. Combining HOA and LOA creates a unique laser ablation pattern for that eye.

Several strategies have been proposed to determine the target astigmatism for topography-guided ablations.[6] First, the LYRA/San Diego/CREATE Protocol, as proposed by Motwani, and topography-modified refraction, as proposed by Kanellopoulos, utilize the Contoura-measured lower-order astigmatism and axis.[7–10] LYRA Protocol (Layer Yolked Reduction of Astigmatism) postulates that the interaction between HOA and LOA impacts the astigmatism magnitude and axis.[7–9] The LYRA Protocol papers demonstrated how utilizing the Contoura measured astigmatism and axis leads to the creation of a more uniform cornea in primary laser vision correction procedures.[7–9] This can be utilized for highly aberrated eyes, such as in eyes with keratoconus or post-LASIK ectasia, to reduce corneal irregularity and make a more uniform cornea.[11] Topography-guided ablation of corneal HOAs will inherently impact residual astigmatism, and the programmed lower-order astigmatism must be adjusted accordingly. San Diego Protocol was the repair version of LYRA and includes the C4/C12 compensation for the sphere component.[11] CREATE Protocol (Corneal Repair Epithelium and Topography Enhanced) builds on San Diego Protocol by quantifying and treating the epithelial compensation of HOA and the topography-guided correction.[12] This method assumes minimal contribution of the posterior cornea and lens to the manifest astigmatism, with studies showing the proportion of eyes with significant posterior corneal astigmatism to be less than 1%.[13]

Second, the Phorcides Analytic Engine (Phorcides LLC) is a planning software for topography-guided ablation that uses a proprietary algorithm to modify the Contoura measured lower-order astigmatism and axis numbers with factors that include astigmatism sources posterior to the anterior cornea (POA).[8,14] Third, Wallerstein et al advocate simply using the manifest astigmatism as the target astigmatism.[15] Additional strategies, such as Zhang-Zheng vector compensated refraction and mutual comparative analysis, have been proposed in small studies.[16,17] To the authors' knowledge, the accuracy of Phorcides, manifest protocol, and other listed methods have primarily been evaluated in normal eyes, and there is a lack of data regarding outcomes for ectatic eyes.

The optimal strategy for the management of astigmatism with topography-guided ablation is under debate even for healthy, non-ectatic eyes, much less for cases of corneal ectasia.[15,18,19] In this study, we examine the manifest outcomes of a patient with post-LASIK ectasia who underwent topography-guided ablation first with Phorcides, then enhanced with LYRA/San Diego.

Materials and Methods

This is a case report of a patient with LASIK-induced ectasia treated at the University of California, San Francisco, Department of Ophthalmology. This study was approved by the local Institutional Review Board (IRB #23-39858) and adheres to the tenets of the Declaration of Helsinki. Written consent was obtained from the patient to participate in this study. Clinical data was obtained via retrospective chart review. LOA and HOA were measured using the WaveLight Topolyzer Vario Diagnostic Device (Alcon, Fort Worth, USA). Scheimpflug tomography was obtained using Pentacam (Oculus, Wetzlar, Germany) and epithelial thickness mapping was obtained by anterior segment optical coherence tomography (AS-OCT) using the Avanti (Optovue/VisioniX, Fremont, USA).

Treatment Planning

Phorcides Analytic Engine was used for treatment planning of the initial ablation, while the LYRA/San Diego Protocol was used to plan the enhancement ablation. Phorcides Analytic Engine and LYRA/San Diego Protocol are competing protocols described for topography-guided ablations. The LYRA/San Diego Protocol was first described by one of the investigators (M.M).

Treatment planning for the first surface ablation was completed using the Phorcides Analytic Engine. A planned optical zone diameter of 6.0 millimeters (mm) with a maximum depth of ablation of 31 micrometers (μm) was selected. Data from the Contoura system and Pentacam imaging were uploaded into Phorcides. Treatment planning was determined in consultation with Phorcides system support, and the support team recommended using Phorcides as the treatment planning software for this irregular cornea by treating the cone as a talus. Talus identification was manually reviewed and adjusted for accuracy. The calculated treatment was inputted directly for surface ablation.

Treatment planning for the repeat surface ablation was completed using the LYRA/San Diego Protocol. The optical zone diameter was set to 6.00 mm with a maximum ablation depth of 20 μm. Calculation of the planned astigmatism treatment was conducted as previously described:

1. "Enter the manifest/cycloplegic refraction into Contoura during presurgical planning
2. Zero out the astigmatism and sphere to see ablation pattern for the aberration correction layer
3. Enter the Contoura measured astigmatism and axis for the final correction. The ablation map at this point should be similar to the Pentacam anterior elevation map. This will assist understanding the ablation when there is a significant discrepancy between manifest versus measured astigmatic power and axis.
4. The sphere is now entered after adjustment for the spherical equivalent of the change in astigmatism."[8]

The manifest sphere, C4/C12 compensation, and second-order astigmatic spherical equivalent were incorporated and considered to make the final plan of a plano spherical treatment with a refractive target of −0.60 diopters (D). In this protocol, sphere is not generally treated as treatment of large corneal irregularity will significantly change the spherical component of the manifest refraction as the multifocal nature of the cornea is reduced.

Surgical procedures

Surface ablations were carried out using the Contoura Vision System of the WaveLight EX500 excimer laser (Alcon, Inc). 20% ethanol was applied to the central corneal epithelium for 20 seconds, then mechanically debrided before laser ablation. 0.02% mitomycin C was applied with a corneal sponge for 45 seconds after the first ablation and for 30 seconds after the second ablation. A bandage contact lens was left in place for 1 week and removed after resolution of the epithelial defect. Post-operative medications included moxifloxacin 0.5% four times daily for one week and fluorometholone 0.1% four times daily on a slow taper.

Corneal cross-linking (CXL) was performed immediately following the first surface ablation. After an initial pachymetry of 450 μm, the cornea was saturated with Photrexa dextran-free hypotonic riboflavin solution every 2 minutes for a total of 30 minutes, with a final pachymetry of 420 μm. Ultraviolet-A light was then applied using the CXL machine (Glaukos, In) at an irradiance of 3.0 milliwatts/centimeters^2 (mW/cm^2) for 30 minutes, and Photrexa viscous dextran 20% riboflavin solution was applied every 2 minutes during this time.

Results

A 52-year-old male with a history of myopic LASIK in both eyes (OU) 20 years prior presented to the ophthalmology clinic with several months of slow progressive vision loss in the left eye (OS). On examination, his uncorrected distance visual acuity (UDVA) was 20/20 OD and 20/40 pinhole 20/25 OS. His corrected distance visual acuity (CDVA) OS was 20/25 with a manifest refraction of −1.25 +1.75 × 180. His intraocular pressures were 11 mmHg OD and 10 mmHg OS. Scheimpflug tomography showed in the right eye regular central flattening with a mean keratometry (Km) of 42.9 D, maximum keratometry (Kmax) of 46.6 D, and a central corneal thickness of 550 μm OD, which remained stable over the course of follow-up. Meanwhile, the left eye demonstrated inferior steepening and thinning with an anterior central astigmatism of 0.4 D at 040, Km of 43.3 D, Kmax of 49.2 D, and a central corneal thickness (CCT) of 529 μm OS (Figure 1A). The posterior astigmatism was minimal at 0.3 D. Anterior segment optical coherence tomography (AS-OCT) demonstrated a uniform epithelial thickness of 56 um centrally and a measured flap thickness of 194 um.

The patient was diagnosed with LASIK-induced ectasia OS. The diagnosis of post-LASIK ectasia was made based on the classic topographic appearance of inferior steepening, apical corneal thinning, and progressive against-the-rule astigmatism with the history of LASIK. Keratoconus was considered less likely due to the patient's age. Pellucid marginal degeneration was considered less likely due to the lack of classic topographic signs and lack of greatest thinning inferior to the corneal apex. Regardless of the diagnosis, the patient presented with progressive corneal ectasia requiring treatment for stabilization.

Of note, he was also found to have floppy eyelids and endorsed preferring to sleep on his left side. He subsequently underwent simultaneous topography-guided photorefractive keratectomy (PRK) and CXL OS as detailed above. Table 1 summarizes the patient's manifest, Contoura-measured, and planned treatments. The laser ablation was planned using Phorcides, with a Contoura measured refraction of −0.68 −0.44 × 167 and a final recommended treatment plan of −0.14 −0.87 × 001. Phorcides system support was consulted during treatment planning for this first ablation with the endorsement that Phorcides may be used for irregular corneas. The max ablation depth was measured to be 35.4 μm (Figure 1B). Post-operatively, his UDVA OS fluctuated between 20/50 and 20/70, before stabilizing at 20/40 at post-operative month (POM) 3. His manifest refraction stabilized at POM 7 to −2.75 +3.50 × 005, with a CDVA of 20/20. AS-OCT showed an even and smooth epithelial thickness map. Scheimpflug tomography showed resolution of inferior steepening within the optical zone and development of 2.0 D of central bowtie astigmatism at 004, with a Km of 41.8 D, Kmax of 51.0 D, and CCT of 481 μm (Figure 1C). His post-operative course was otherwise notable for mild transient subepithelial haze without loss of BCVA at POM 1.5 that was managed with a slow steroid taper and improved by POM 7. The post-procedure corneal densitometry OS shows a total measurement of 22.1 standardized gray units (GSU) compared to 19.7 GSU OD.

Due to high residual astigmatism, the patient underwent repeat topography-guided PRK. Treatment planning was conducted using the LYRA/San Diego protocol, with a Contoura measured refraction of +0.08 –1.15 × 094 and a final planned treatment of +0.00 −1.15 × 094. At POM 7, his UDVA improved to 20/20-3, with a manifest refraction of −1.00 +0.75 × 174 and a CDVA of 20/20+2. The max ablation depth was measured to be 25.1 μm (Figure 1D). Scheimpflug tomography demonstrated a spherical optical zone with a residual anterior astigmatism of 0.5 D at 061, a Km of 41.9 D, a Kmax of 51.6 D, and a CCT of 464 μm (Figure 1E).

Discussion

In this report, a patient with LASIK-induced ectasia underwent topography-guided PRK and cross-linking planned with the Phorcides Analytic Engine, and then topography-guided enhancement with the LYRA/San Diego Protocol.

Even with the less predictable outcomes for treating corneal irregularity and flattening from cross-linking, combination topography-guided ablation and cross-linking have been shown to significantly improve manifest refraction for ectasia patients.[4,5] Residual refractive error can be further treated with topography-guided enhancement or wavefront-optimized enhancement, which has been demonstrated to be safe and effective for patients desiring further refractive correction.[5] Epithelium-off cross-linking maximizes the depth of stromal cross-linking (over 200 μm) compared to epithelium-on protocols.[20] In comparison, treatment of residual error removes a minimal amount of cross-linked tissue (ideally about 20 μm), having a negligible effect on corneal integrity.[21,22] In cases of post-LASIK ectasia, ablations are confined to the LASIK flap, which contributes negligibly to stromal integrity.

Previous studies of topography-guided ablation for corneal ectasia generally agree on several methodological parameters: to decrease the optical zone to 5.0–5.5 mm (which cannot be utilized in the United States as the smallest optical zone allowed is 6.0 mm), to limit the stromal ablation depth to less than 50–60 μm, to leave a residual stromal bed greater than 350 and to perform simultaneous rather than sequential cross-linking.[21,22] These guidelines were followed in the treatment of this patient. However, strategies for astigmatism treatment vary, with several studies treating up to 80% of astigmatism (limited by the 50 μm threshold for ablation depth), others not attempting refractive correction at all, and

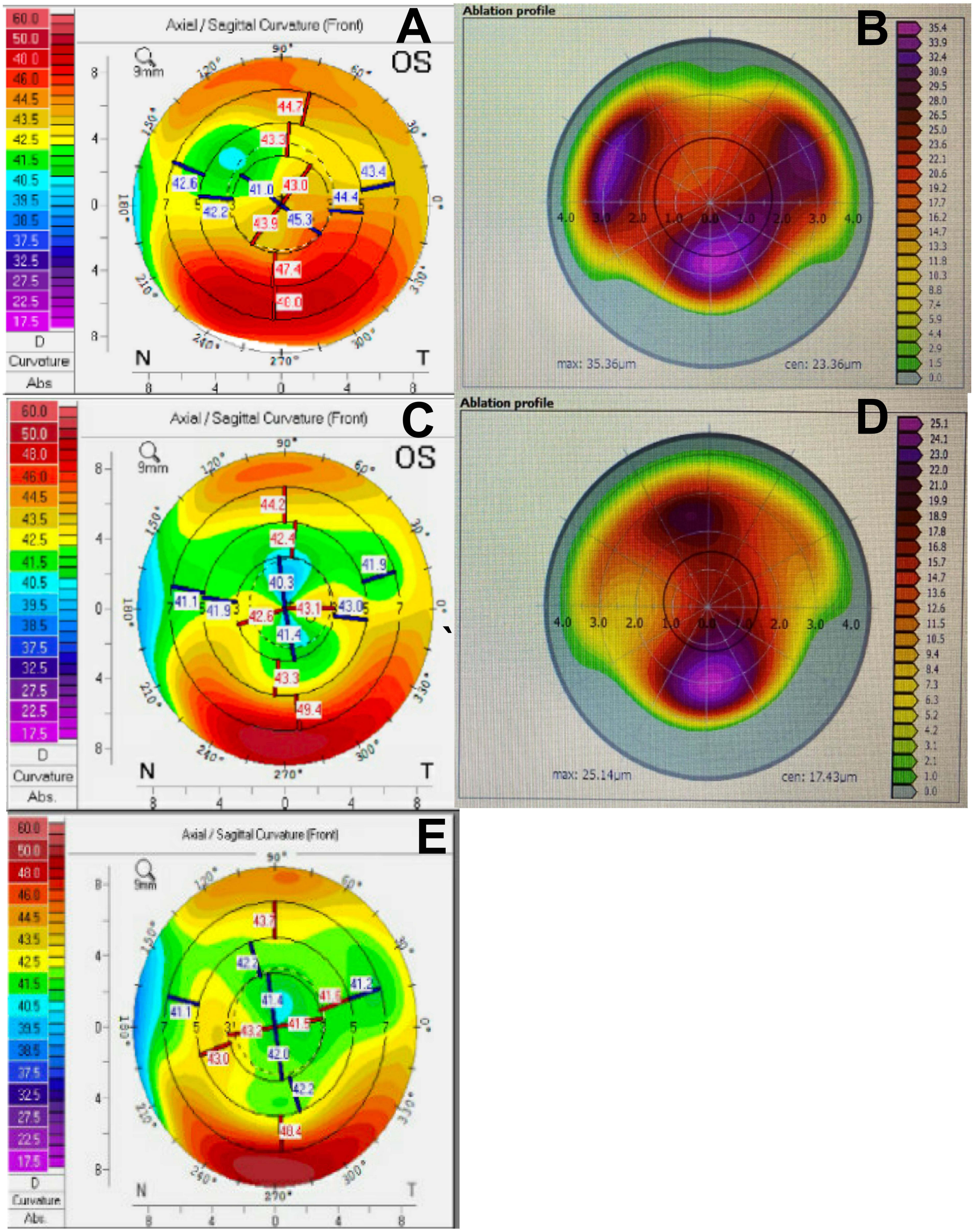

Figure 1 Progression of Axial Curvature Maps and corresponding ablation profiles in a case of post-LASIK ectasia. (**A**) Map at initial presentation showing anterior steepening consistent with corneal ectasia (**B**) Ablation profile map from initial PRK + CXL planned with Phorcides Analytic Engine (**C**) Pentacam Axial Curvature Map 7 months after initial PRK + CXL planned with Phorcides Analytic Engine (**D**) Ablation profile map from topography-guided PRK enhancement planned with LYRA/San Diego protocol. (**E**) (Pentacam Axial Curvature Map 7 months after topography-guided PRK enhancement planned with LYRA/San Diego protocol.

https://doi.org/10.2147/IMCRJ.S476407

Table 1 Table of Patient Characteristics

	Pre-operative	Post-Phorcides (POM 7)	Post-Lyra (POM 7)
Manifest refraction	+0.50 –1.75 x 090	+0.75 −3.50 x 095	−0.25 −0.75 x 084
Contoura-measured refraction	−0.68 –0.44 x 167	+0.08 –1.15 x 094	
Proposed Phorcides treatment	**−0.14–0.87 × 001 (used)**	−0.74 –0.77 x 001	
Proposed LYRA/San Diego treatment	−0.15 –0.44 x 167	**0.00 –1.15 × 094 (used)**	
UDVA	20/40	20/40	20/20 −3
CDVA	20/25 + 3	20/20 −2	20/20 +2
HOA (RMS)	1.642	1.083	0.920

Note: The proposed ablation plans using either the Contoura measured refraction or Phorcides Analytic Engine for each round of treatment is listed. The treatment plan actually utilized has been bolded.
Abbreviations: POM, post operative month; UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity; HOA, higher order aberrations; RMS, root mean square.

yet others that treat the maximum amount of Contoura measured astigmatism possible.[12,23,24] In most studies, it is not specified if the strategy for addressing astigmatism is based on manifest refraction, topography-modified refraction, Phorcides Analytic Engine, or other calculations, and the refractive outcomes for patients with corneal ectasia are far more variable compared to those for healthy eyes. This report investigates different strategies to increase the accuracy of astigmatic correction in corneal ectasia.

In this case, the initial treatment proposed by Phorcides Analytic Engine increased both corneal and manifest astigmatism. This outcome may be explained by the fact that the inferior corneal steepening resulted in Contoura-measured astigmatism at an axis of 001 (negative cylinder, with the rule) but manifest astigmatism at 095 (negative cylinder, against the rule). Ablation of the inferior HOA caused flattening of the cornea just below the horizontal midline, resulting in increased residual against the rule astigmatism. It is unclear why Phorcides suggested a higher with-the-rule correction than the Contoura-measured astigmatism, as the algorithm is proprietary. In this case, Phorcides recommended treatment at an astigmatic axis opposite the manifest refraction and Contoura-measured axis, compared to the LYRA/San Diego Protocol, which recommends using the Contoura-measured axis. Treatment of the incorrect magnitude and axis of the lower-order astigmatism can create new anterior corneal irregularities, as demonstrated by Motwani et al in LYRA Protocol Part 2.[8] Given this outcome, Phorcides appears to inadequately address and may even increase astigmatism in cases of corneal ectasia. Previous publications evaluating the efficacy of Phorcides in normal eyes largely include patients with low levels of discrepancy between manifest and Contoura-measured astigmatism without data regarding the axis of astigmatism.[14,25,26] Analysis of Phorcides in normal eyes has shown overcorrection of astigmatism in eyes with large differences between manifest and corneal astigmatism.[21] Due to the high residual astigmatism and the difficulty with quantifying HOA, LOA, and residual refractive astigmatism, theoretical outcomes for LYRA/San Diego protocol and manifest refraction protocol were not compared for this stage but have been in another publication.[19]

The enhancement ablation was planned with the LYRA/San Diego protocol, resulting in excellent improvement of corneal and manifest astigmatism. As with the primary ablation, there was a significant discrepancy in the magnitude of the manifest (3.50 D × 095) and Contoura-measured (1.15 D × 094) astigmatism, although this time the axis differed by only 1 degree. The Phorcides recommended astigmatism at this stage was −0.77 × 001. As the enhancement achieved excellent astigmatic correction, a qualitative comparison was performed with other planning strategies using the LYRA/San Diego protocol as a reference. Inputting the recommended astigmatism by Phorcides would likely have again increased the against-the-rule astigmatism, resulting in an even poorer outcome with further increased manifest astigmatism. Meanwhile, inputting the full manifest astigmatism as recommended by the manifest protocol could have led to a large overcorrection. Especially in highly aberrated corneas, when HOAs may account for a significant portion of the manifest astigmatism, the manifest protocol may overtreat astigmatism.

Conclusions

Our preliminary results suggest that topography-modified treatment of astigmatism, such as with the LYRA/San Diego protocol, may outperform Phorcides Analytic Engine and the manifest refraction protocol in eyes with corneal ectasia. The refractive error generated by corneal ectasia appears to primarily result from anterior corneal HOAs and LOAs. Accurate management of corneal astigmatism combined with cross-linking can restore uncorrected vision and quality of life, marking a revolutionary paradigm shift for treating corneal ectasia, and other causes of corneal irregularity. Further investigation is needed to confirm the optimal strategy for astigmatic treatment planning and refine the accuracy and precision of refractive ablations of corneal ectasia.

Abbreviations

AS-OCT, anterior segment optical coherence tomography; CCT, central corneal thickness; cm, centimeters; CXL, Corneal cross-linking; CREATE, Corneal Repair Epithelium and Topography Enhanced; D, diopters; HOA, higher-order aberrations; Km, mean keratometry; Kmax, maximum keratometry; LASIK, laser-assisted in situ keratomileusis; LOA, lower-order aberrations; LYRA, Layer Yolked Reduction of Astigmatism; mm, millimeters; mW, milliwatts; OD, right eye; OS, left eye; OU, both eyes; POA, posterior ocular astigmatism; POM, post-operative month; PRK, photo-refractive keratectomy.

Ethics Approval and Informed Consent

This research adheres to the principles of research ethics, ensuring the protection of participants' rights, confidentiality, and integrity of data. All procedures involving human subjects were approved by the Institutional Review Board (IRB #23-39858). Informed consent was obtained from all participants, and their anonymity and privacy were maintained throughout the study. All participants were fully informed prior to providing their consent for the publication of their case details. Institutional approval is not necessary for the publication of case details.

Funding

This research was supported, in part, by the UCSF Vision Core shared resource of NIH/NEI P30 EY002162 and the Research to Prevent Blindness Unrestricted Grant.

Disclosure

Dr Yung has consulted for Iota Biosciences, Inc and Carl Zeiss Meditec. Dr Motwani has 2 patents- one for the creation of a uniform cornea with topography-guided ablation, and the other for treatment of epithelial compensation with excimer laser to decrease higher-order aberrations in conjunction with topography-guided ablation. Dr Motwani's LYRA/ San Diego/CREATE Protocol could also be construed as a competitor to the Phorcides system in surgical planning with WaveLight Contoura. Dr Motwani also has pending systems patents for devices that provide an ideal treatment map for excimer laser ablation. Dr Motwani has no financial relationships with Alcon or Phorcides, or any other companies that would be seen as a conflict. The authors report no other conflicts of interest in this work.

References

1. Sorkin N, Varssano D. Corneal collagen crosslinking: a systematic review. *Ophthalmologica*. 2014;232(1):10–27. doi:10.1159/000357979
2. Ambekar R, Toussaint KC, Wagoner Johnson A. The effect of keratoconus on the structural, mechanical, and optical properties of the cornea. *J Mech Behav Biomed Mater*. 2011;4(3):223–236. doi:10.1016/j.jmbbm.2010.09.014
3. Alpins N, Stamatelatos G. Customized photoastigmatic refractive keratectomy using combined topographic and refractive data for myopia and astigmatism in eyes with forme fruste and mild keratoconus. *J Cataract Refract Surg*. 2007;33(4):591–602. doi:10.1016/j.jcrs.2006.12.014
4. Wan Q, Wang D, Ye H, Tang J, Han Y. A review and meta-analysis of corneal cross-linking for post-laser vision correction ectasia. *J Current Oph*. 2017;29(3):145–153. doi:10.1016/j.joco.2017.02.008
5. Ramamurthy S, Soundarya B, Sachdev GS. Topography-guided treatment in regular and irregular corneas. *Indian J Ophthalmol*. 2020;68 (12):2699–2704. doi:10.4103/ijo.IJO_2119_20

6. Onishi AC, Lee-Choi C, Marvasti AH. Topography-guided excimer laser ablation. *Curr Opin Ophthalmol*. 2023;34(4):296–302. doi:10.1097/ICU.0000000000000957
7. Motwani M. The use of WaveLight® Contoura to create a uniform cornea: the LYRA Protocol. Part 3: the results of 50 treated eyes. *Clin Ophthalmol*. 2017;11:915–921. doi:10.2147/OPTH.S133841
8. Motwani M. The use of WaveLight® Contoura to create a uniform cornea: the LYRA Protocol. Part 2: the consequences of treating astigmatism on an incorrect axis via excimer laser. *Clin Ophthalmol*. 2017;11:907–913. doi:10.2147/OPTH.S133840
9. Motwani M. The use of WaveLight® Contoura to create a uniform cornea: the LYRA Protocol. Part 1: the effect of higher-order corneal aberrations on refractive astigmatism. *Clin Ophthalmol*. 2017;11:897–905. doi:10.2147/OPTH.S133839
10. Kanellopoulos AJ. Topography-modified refraction (TMR): adjustment of treated cylinder amount and axis to the topography versus standard clinical refraction in myopic topography-guided LASIK. *Clin Ophthalmol*. 2016;10:2213–2221. doi:10.2147/OPTH.S122345
11. Motwani M. A protocol for topographic-guided corneal repair utilizing the US Food and Drug Administration-approved Wavelight Contoura. *Clin Ophthalmol*. 2017;11:573–581. doi:10.2147/OPTH.S127855
12. Motwani M. A Novel Procedure for Keratoconus/Corneal Ectasia Treating Epithelial Compensation of Higher-Order Aberrations, Topographic Guided Ablation, and Corneal Cross Linking - The CREATE+CXL Protocol. *Clin Ophthalmol*. 2023;17:1981–1992. doi:10.2147/OPTH.S411472
13. Motwani M. Analysis and Causation of All Inaccurate Outcomes After WaveLight Contoura LASIK with LYRA Protocol. *Clin Ophthalmol*. 2020;14:3841–3854. doi:10.2147/OPTH.S267091
14. Lobanoff M, Stonecipher K, Tooma T, Wexler S, Potvin R. Clinical outcomes after topography-guided LASIK: comparing results based on a new topography analysis algorithm with those based on manifest refraction. *J Cataract Refract Surg*. 2020;46(6):814–819. doi:10.1097/j.jcrs.0000000000000176
15. Wallerstein A, Gauvin M, Qi SR, Cohen M. Effect of the Vectorial Difference Between Manifest Refractive Astigmatism and Anterior Corneal Astigmatism on Topography-Guided LASIK Outcomes. *J Refract Surg*. 2020;36(7):449–458. doi:10.3928/1081597X-20200609-01
16. Zhang J, Zheng L, Zheng C. A Comparison of Three Cylindrical Treatment Strategies for Topography-Guided LASIK: manifest, Topographic, and ZZ VR Cylinders. *Clin Ophthalmol*. 2023;17:1335–1345. doi:10.2147/OPTH.S408101
17. Cao K, Liu L, Zhang T, Liu T, Bai J. Mutual comparative analysis: a new topography-guided custom ablation protocol referencing subjective refraction to modify corneal topographic data. *Eye and Vision*. 2020;7(1):36. doi:10.1186/s40662-020-00201-7
18. Stulting RD, Durrie DS, Potvin RJ, et al. Topography-Guided Refractive Astigmatism Outcomes: predictions Comparing Three Different Programming Methods. *Clin Ophthalmol*. 2020;14:1091–1100. doi:10.2147/OPTH.S244079
19. Motwani M. Predictions of Residual Astigmatism from Surgical Planning for Topographic-Guided LASIK Based on Anterior Corneal Astigmatism (LYRA Protocol) vs the Phorcides Analytic Engine. *Clin Ophthalmol*. 2020;14:3227–3236. doi:10.2147/OPTH.S272085
20. Salah Y, Omar K, Sherif A, Azzam S. Study of Demarcation Line Depth in Transepithelial versus Epithelium-Off Accelerated Cross-Linking (AXL) in Keratoconus. *J Ophthalmol*. 2019;2019:3904565. doi:10.1155/2019/3904565
21. Al-Mohaimeed MM. Combined corneal CXL and photorefractive keratectomy for treatment of keratoconus: a review. *Int J Ophthalmol*. 2019;12(12):1929–1938. doi:10.18240/ijo.2019.12.16
22. Niazi S, Alio Del Barrio J, Sanginabadi A, et al. Topography versus non-topography-guided photorefractive keratectomy with corneal cross-linking variations in keratoconus. *Int J Ophthalmol*. 2022;15(5):721–727. doi:10.18240/ijo.2022.05.05
23. Kanellopoulos AJ. Ten-Year Outcomes of Progressive Keratoconus Management With the Athens Protocol (Topography-Guided Partial-Refraction PRK Combined With CXL). *J Refract Surg*. 2019;35(8):478–483. doi:10.3928/1081597X-20190627-01
24. Kanellopoulos AJ. Comparison of sequential vs same-day simultaneous collagen cross-linking and topography-guided PRK for treatment of keratoconus. *J Refract Surg*. 2009;25(9):S812–818. doi:10.3928/1081597X-20090813-10
25. Rush SW, Pickett CJ, Wilson BJ, Rush RB. Topography-Guided LASIK: a Prospective Study Evaluating Patient-Reported Outcomes. *Clin Ophthalmol*. 2023;17:2815–2824. doi:10.2147/OPTH.S429991
26. Stulting RD, Lobanoff M, Mann PM, Wexler S, Stonecipher K, Potvin R. Clinical and refractive outcomes after topography-guided refractive surgery planned using Phorcides surgery planning software. *J Cataract Refract Surg*. 2022;48(9):1010–1015. doi:10.1097/j.jcrs.0000000000000910