Topography-guided treatments of irregular astigmatism with WaveLight ALLEGRETTO WAVE

Mirko R. Jankov II, MD PhD [1]

Aleksandar Stojanović, MD [2]

[1] Milos Eye Hospital, Medical Academy – US Medical School, Belgrade, Serbia
[2] SynsLaser, Tromso/Oslo, Norway

Corresponding author:

Mirko R. Jankov II

Milos Eye Hospital, Medical Academy – US Medical School

11000 Belgrade, Serbia

www.milosklinika.com

+381 11 245 5759

e-mail: visioncare@mac.com

Introduction

Excimer laser surgery provides an accurate tool to reshape the cornea in order to correct refractive errors. Although in most of the cases very successful and precise, an amount of problems has been described originating from two main reasons: flap-related and ablation-related problems. Most common of the ablation-related ones are residual refractive error and over correction, which can be quite easily and successfully treated by different enhancement techniques [1].

Treatment of the irregular astigmatism, however, has been posing a challenge before the refractive surgeons such as small optical zones (OZ), decentered OZ and irregular ablation, which produce irregular corneas poorly correctable with standard photo-ablative treatments. Highly irregular corneas can also originate from corneal scars deriving from injuries, inflammation or surgical procedures, such as penetrating keratoplasty, radial keratotomy or arcuate cuts.

The alternatives for correction of irregular astigmatism were few, expectations were limited and consequences were unpredictable anatomically and functionally [2]. In the recent years, however, advancements in the laser technology offered us better tools for facing the irregular astigmatism [3]-[15]. After the encouraging pre-clinical results with ALLEGRETTO WAVE excimer laser (WaveLight, Erlangen, Germany) [Jankov M. et al. Topography-guided treatments and corneal asphericity – first clinical results with Allegretto WaveLight laser, International Society of Refractive Surgery Fall Refractive and Cataract Symposium, 2001 New Orleans, EUA] and Topolyzer software, clinical data showed good outcome in symptomatic eyes with high irregular astigmatism by topography-guided photo-ablation with the and T-CAT software (topography-guided customized ablation treatment) [16].

The ALLEGRO TOPOLYZER (WaveLight Laser Technologie, AG, Erlangen, Germany), which is almost identical in the terms of hardware to Keratograph (Oculus Wetzlar, Germany), features a built-in keratometer and a high resolution Placido-ring corneal topographer detecting 22 000 points of measurement from 22 ring edges, with an interactive elevation map that allows individual selection of reference body, radius, and asphericity. The measurements are aligned to the line of sight that passes through the pupil centre and all the raw data of the corneal topography are exported relative to the pupil centre. To ensure this, the patients were instructed to maintain fixation on the target light, while the TOPOLYZER software automatically released the measurements only when the corneal apex was correctly focused in x, y and z axis.

Corneal topographer OCULYZER, which is almost identical in the terms of hardware to Pentacam (Oculus Wetzlar, Germany), is also being tested for clinical use as the source of elevation raw data of the cornea. The system is linked to specialized T-CAT software to capture and transfer treatment data to the ALLEGRETTO WAVE excimer laser.

T-CAT software is based on the principle of fitting the best-fit asphere and removing the excess tissue in order to turn the irregular cornea into a rotationally symmetric aspheric cornea. At the same time, one can adjust the aim asphericity (Q-value) of the cornea within a range 0 to -0.6, as well as the desired refraction in the terms of sphere and cylinder.

Eight repeatable and highly reproducible topography maps can be averaged in the software [Figure 1]. In the upper left corner one can observe the K values, lower left corner the average of eight maps, upper right corner the aim asphericity of -0.34, while the lower right shows a list of main topographic features of each of the maps. One can observe that the last column shows percentage of the data contained in the chosen optical zone (in this case 6.5 mm), and the software automatically eliminates the map that has less then 90 % of data (in this example map number 8 that is marked red).

Having chosen the good quality maps and defined the optical zone and the aim asphericity, the software leads us to the next screen showing us the ablation profile. One can adjust the actually modified refraction based on the clinical and the topolyzer refractions, while there is also an option to turn the tilt on or off. Tilt off is a recommended treatment mode, where the software tries to restore the morphologic axis while using the minimal amount of tissue possible. These were the actual preparation screens for the case 1 reported below.

Case report 1

One of our first patients we treated in the clinical protocol in 2003 was a 54-year-old male that had undergone RK in 1985 for Sph: -6.0 D. He presented himself with UVA OD: 20/60 and OS: 20/50, BSCVA OD: 20/30 with Sph: +1.75 Cyl: -2.25 @ 20º and OS: 20/30 with Sph: +1.0 Cyl: -1.75 @ 40º. Central ultrasound pachymetry was OD: 590 μm and OS: 588 μm, while scotopic pupil size was OD: 6.0 and OS: 5.5 mm. His main complaints were halos, glare, visual fluctuation, that prevented him from driving safely. Three months post-op T-CAT OS his UVA improved to 20/30, BSCVA 20/20 with Sph:+0.50 Cyl: -2.00 @ 25º. There were no cuts open in the slitlamp examination [Figure 2].

Case report 2

A 39-year-old male was seen 2 years after bilateral LASIK for myopic compound astigmatism (OD: Sph: -1.00 D Cyl: -3.00 D @ 180 and OS: -1.00 D Cyl: -2.50 D @ 175) that resulted in a small optical zone and severe glare, halos, and ghost images. His UVA was 20/25, and his BSCVA was 20/20 with Sph: plano Cyl: -0.75 @ 175. The Q-value was +0.16 and the ISV was 24. Post-operatively his UVA actually worsened to 20/30, BSCVA maintained at 20/20 with Sph: -1.25 D Cyl: -0.25 D @ 65, while Q-value improved to -0.29 and his index of surface variance to 20 [Figure 3]. None of the subjective symptoms were present post-operatively [Figure 3] and [Figure 4].

Case report 3

Another patient was a 32-year-old female that had PRK in 1989 for OD: Sph -5.25 D and OS: Sph -5.50 D. She reported to our clinic with UVA 20/25 bilaterally (non correctable with spectacles) and pinhole improved her vision to 20/20 reducing her halos, glare and star bursts. Her central ultrasound pachymetry was OD: 490 μm and OS: 488 μm, while here scotopic pupil size was 6.0 mm in both eyes. After 3 months, her post-operative UVA was 20/20 and BSCVA 20/20+ Sph: -0.25 without any symptoms [Figure 5].

Methods

In a prospective, non-comparative case series, we operated 16 consecutive (7 right and 9 left) eyes of 11 patients (9 males and 2 females) with the mean age of 32 +/- 9 (range, 7 to 43) between February and December 2004 in Vardinoyiannion Eye Institute of Crete, University of Crete, Greece. As there were no other equally or less invasive treatment options, we did not perform a randomized trial. Patients were sent from several centers in Greece and Middle East.

Inclusion criteria were irregular corneal astigmatism caused by trauma or previous corneal surgery: there were eight eyes with small optical zone (four hyperopic and four myopic), three eyes with irregular ablation, two eyes after corneal graft, two eyes with corneal scar and one eye with decentered myopic ablation. All patients had subjective complaints of ghosting, star-bursts, halos or monocular double vision when specifically asked during the pre-operative assessment, and were contact lens intolerant.

Exclusion criteria were central corneal scars or central haze interfering with visual acuity, ectasia at corneal graft margins, irregular astigmatism caused by corneal ectasia or keratoconus, ablations leaving less than a residual corneal thickness of 250 µm after treatment, a minimum interval of 2 years (post-keratoplasty group) or 1 year (all other groups) after last surgery, and inability to complete the 6-month follow-up. All patients were fully informed as to the experimental nature of our study, and written consent was obtained before surgery. Our institutional review board approved the study.

Pre-operative measurements included UCVA, BSCVA, manifest and cycloplegic refraction, slit lamp examination with fundus evaluation, corneal topography (Topolyzer, Oculus, Wetzlar, Germany) ultrasonic pachymetry (Pac Scan 300P by Sonomed, USA), infra-red pupilometry (Colvard pupilometer, Oasis, Giendora, CA, USA) and corneal diameter (‘white to white’ in Canon autorefractometer Medical Systems 15955, Alton Parkway, CA, USA).

Eight repeatable and highly reproducible topography maps were obtained aligning the measurement to the line of sight that passes through the pupil centre. To ensure this, the patients were instructed to maintain fixation on the target light, while the TOPOLYZER software automatically released the measurements only when the corneal apex was correctly focused in x, y and z axis. Only topographies with at least 75% of the corneal surface mapped were included as data for the treatment. The topography height maps, together with the pupil size and position, were exported to the T-CAT software. The target asphericity for all the patients was set to Q=-0.46, which is believed to be the theoretically optimum for the eye's physiology according to Manns et al [17].

Ten patients had LASIK enhancement with new cut or with flap lift, while in six patients, due to the limitations in the corneal thickness, PRK was performed. LASIK procedures performed in a standardized manner: a drop of proparacaine 0.5% (Alcaine, Alcon, Couvreur NV, Belgium) was instilled in each eye 5 minutes and just before the procedure. This was followed by a povidon-iodine 10 % (Betadine, Lavipharm, Greece) preparation of the lids. Eyelashes were isolated by a drape and a speculum with suction was placed into the operative eye. The cornea was marked with a corneal marker using gentian violet staining.

If the flap was re-cut, the microkeratome settings (suction ring, flap stop) were chosen according to the steepest K (manufacturer's nomogram), aiming the maximum flap diameter. The M2 110 single-use head (Moria, Antony, France) was used for a desired cut depth of 130μm and a superior hinge. After the microkeratome pass, the flap was lifted and folded unto itself. In the cases of lifting the original flap, the flap edge from the previous surgery was traced using a Sinskey hook, the edges were lightly teased and the separation between the flap and the corneal bed was extended using a blunt iris spatula. The flap was then fully lifted and folded unto itself. A central ultrasound pachymetry of the residual stromal bed was performed by taking three measurements and subtracting their mean value from the preoperative corneal thickness. This difference was considered as the flap thickness (subtraction pachymetry).

The ablations were made using the ALLEGRETTO WAVE excimer laser (WaveLight Laser Technologie AG, Erlangen, Germany). The machine utilizes a flying spot laser of 0.95 mm in diameter with a Gaussian energy profile, 200 Hz repetition rate and an active video-based 250 Hz eye-tracker. After performing the laser ablation, the flap was floated back into position, and the stromal bed was irrigated with balanced salt solution (BSS). Flap alignment was checked using gentian violet pre-markings on the cornea and a striae test was performed to ensure proper flap adherence.

For the PRK patients, epithelium was removed with a hockey-knife 30 seconds after the application of 20 % ethyl-alcohol, the stroma copiously irrigated by 10 mL of chilled BSS, and then dried with Merocel eye spears (Medtronic solan). After the central subtraction pachymetry was performed, the photo-ablation has been performed, and finally a soft bandage contact lens (CL) was placed.

In either surgical technique, a drop of dexamethasone 0.1% + tobramycin 0.3% (Tobradex, Alcon, Couvreur NV, Belgium) and apraclonidine 0.125% (Iopidine, Alcon – Couvreur NV, Belgium) has been instilled, the patients oriented to wait with eyes mildly closed for a 15-minute interval, by the end of which the flap after LASIK, or the presence of the CL after PRK, was re-checked and the patients dismissed. The patients were using the hard transparent

PMMA eye shields overnight for three nights after LASIK or until the removal of the CL after PRK.

The LASIK patients were using postoperatively sodium flurbiprofen 0.03% (Ocuflur, Allergan, Westport, Ireland) drops 4 times a day for two days, Tobradex drops 4 times a day for two weeks and sodium hyaluronate 0.18% (Vismed, TRB Chemedica, Greece) drops initially hourly and then upon patients' needs for a month thereafter. The PRK patients were using Ocuflur drops 4 times a day for two days; Tobradex drops four times a day until the removal of the CL, with a progressive tapering over the following 4 months. Vismed drops were used initially hourly and then upon patients' needs for a month thereafter.

After the initial early evaluation at 24h, the scheduled follow-up intervals were at one week, one, three and six months. Slit lamp examinations were performed to assess the LASIK flap status for any flap related complications, and primary outcome measures were UCVA and BSCVA, manifest refraction, asphericity, and index of surface variance. Wilcoxon signed ranks and Student t-test were used for the statistical analysis.

Results

An improvement in the mean uncorrected visual acuity, best corrected visual acuity, corneal asphericity and corneal irregularity was noted in both LASIK and PRK group for all follow-ups [Table 1] and [Table 2].

In LASIK group, mean uncorrected visual acuity (UCVA) improved from 0.81+/- 0.68 logarithm of the minimum angle of resolution (logMAR) (20/130) (range 0.2 to 2.0) to 0.29

+/- 0.21 logMAR (20/39) (range 0.1 to 0.7) at 6 months, while mean best spectacle corrected visual acuity (BSCVA) improved from 0.07 +/- 0.07 logMAR (20/24) (range 0.1 to 0.7) to 0.05 +/- 0.08 logMAR (20/22) (range -0.1 to 0.7) at 6 months [Table 1]. Using a Wilcoxon signed rank test, there was a statistically highly significant increase in UCVA at one, three and six months compared to the pre-operative UCVA (*p=0.008, p=0.01 and p=0.008,* respectively), while the difference in BSCVA was not statistically different. None of the patients lost any lines of BSCVA, two patients gained one line and all other patients maintained their BSCVA [Graph 1]. The mean gain at 6 months was 5.4 lines of UCVA and 0.2 lines of BSCVA.

In PRK group, mean uncorrected visual acuity (UCVA) improved from 0.89 +/- 0.87 logMAR (20/157) (range 0.1 to 2.0) to 0.42 +/- 0.35 logMAR (20/53) (range 0.1 to 1.0) at 6 months, while mean best spectacle corrected visual acuity (BSCVA) improved from 0.24 +/- 0.24 logMAR (20/35) (range 0 to 0.7) to 0.14 +/- 0.15 logMAR (20/28) (range 0 to 0.3) at 6 months. There was a statistically significant increase in UCVA at six months compared to the pre-operative UCVA (*p=0.04*, Wilcoxon signed rank test), while the difference in BSCVA was not statistically different [Table 2]. None of the patients lost two or more lines of BSCVA, one patient lost one line, two maintained their BSCVA, while one patient gained one, two and four lines of BSCVA each [Graph 1]. The mean gain at 6 months was 5 lines of UCVA and 1.1 lines of BSCVA.

Refractive error for the LASIK group improved from Sph: -0.90 +/- 2.55 (range +2.75 to -5.00) D to -0.33 +/- 1.06 (range +0.75 to -2.25) D (not significant), and from Cyl: -2.53 +/- 1.71 (range -0.75 to -5.75) D preoperatively to Cyl: -1.28 +/- 0.99 (range 0 to -2.50) D postoperatively at 6 months, with a significant difference for one, three and six months (*p=0.02, p=0.03 and p=0.04*, respectively, paired Student t-test) [Table 1], [Graph 2] and [Graph 3]. The axis between pre- and post-operative cylinder was within +/- 10 degrees. In the PRK group refractive error improved from Sph: -0.88 +/- 2.50 (range +1.50 to -5.25) D to Sph: -0.85 +/- 0.68 (range 0 to -1.75) D at 6 months (not significant, paired Student t-test), and from Cyl: -2.21 +/- 2.11 (range -0.25 to -5.50) D preoperatively to Cyl: -1.10 +/- 0.42 (range -0.50 to -1.50) D, reaching significance only at 6 months postoperatively (*p=0.04*, paired Student t-test) [Table 2], [Graph 2] and [Graph 3]. The axis between pre- and post-operative cylinder was within +/- 10 degrees. Attempted vs. achieved spherical equivalent (SEQ) for both LASIK (R^2=0.89) and PRK (R^2=0.93) groups can be seen in Graph 4.

In LASIK group, corneal asphericity, as measured by the Q value, improved slightly from +0.08 +/- 1.03 (range -1.72 to +1.21) to +0.04 +/- 1.05 (range -1.37 to +1.46) at 6 months, without reaching statistical significance (paired Student-t test). Index of surface irregularity showed a decrease from 60 +/- 12 (range 46 to 89) to 50 +/- 9 (range 32 to 63) at six months, with a statistically significant difference (*p=0.04,* paired Student-t test) [Table 1].

In PRK group, corneal asphericity changed from +0.30 +/- 0.43 (range -0.02 to +1.12) preoperatively to -0.06 +/- 0.10 (range -0.18 to +0.05) post-operatively, reaching statistical significance at 1 and 3 months, but not six months (*p=0.008, p=0.03* respectively, paired Student-t test). Index of surface irregularity showed a change from 44 +/- 21 (range 24 to 67) to 48 +/- 29 (range 20 to 78), without reaching a statistically significant difference (paired Student-t test) [Table 2].

Subjective symptoms, such as glare, halos, ghost images, starbursts and monocular diplopia, although present in all cases preoperatively, were reported post-operatively when specifically asked in the post-operative assessment.

Discussion

Irregular corneal astigmatism has posed a challenge to the refractive surgeons for a long time, having led to different techniques of solving them. Ultimately, technological advances led us to two most promising customized approaches: based on wavefront measurements [4]-[10] and based on corneal topography [11]-[15].

There are several differences between wavefront- and topography-guided approaches. The underlying assumption of wavefront-guided laser surgery is that most, and potentially all, the aberrations of the eye can be corrected by reshaping the cornea. This assumption relies on the fact that in normal eyes, the aberrations of the lens and of the cornea are of the same order of magnitude [18].

Hence, in theory, the post-operative anterior corneal surface can be calculated to compensate for all the internal aberrations, leading to a zero sum of aberrations. In practice, however, many factors are described to frustrate such attempts including the limited precision and predictability of the ablation [19],[20], epithelial hyperplasia and stromal remodeling [21], new aberrations created with the flap [22], changes in the thickness and the distribution of the tear film [23], biomechanical properties and variations in ocular aberrations with age [24], and accommodation [25].

Moreover, calculations for the ideal anterior corneal surface based on the wavefront measurements assume that the aberrations in the posterior corneal surface and the lens remain unchanged after surgery, based on the fact that these are untouched. However, in an optical system such a the eye, the contribution of each optical surface to the aberration of the whole system is dependent not only on the shape and refractive index of each surface and surrounding media, but also on the height and incident angle of the light rays or, on the distance from the object of the surface. Since the corneal reshaping alters the path of rays propagating in the eye, Manns et al [17] expected that even thought the shape of the posterior corneal surface and lens surfaces are unchanged after surgery, their contribution to the ocular aberration will be different from preoperatively.

Despite the theoretical limitations, several authors have performed wavefront-guided treatments in non-virgin eyes in limited case series showing a statistically significant increase of UVA and a modest decrease in Higher order monochromatic aberrations (HOA) in the terms of root mean square (RMS), together with a rare loss of BSCVA [4]-[10]. Alió et al [13] were disappointed with their results after topography-guided LASIK for irregular astigmatism and suggested wavefront-guided treatments should be the treatment of choice in post refractive surgery cases with irregular astigmatism.

In the case of non-virgin eyes showing high irregularities or sharp changes in corneal contour, such as severely decentered, very small optical zone after previous refractive surgery or corneal scars, it is reasonable to believe that the optical path distal to the anterior corneal surface will be significantly changed once the anterior surface be turned regular. Consequently, besides a frequent inability to obtain repeatable and consistent pre-operative aberration maps, as reported by Mrochen et al [6], a rather important question emerges: what is the advantage of trying to correct the anterior corneal surface using the ablation profile based on the whole eye aberrations in case of clear preponderance of the anterior corneal surface aberrations? Wouldn't it make sense in these cases to determine the ideal anterior corneal contour without taking into consideration the influence of the internal structures?

Topography-guided treatments do not take into consideration any assumption regarding internal structures of the eye and use solely corneal front surface information originating from topographic height maps as a baseline. An ablation profile can thus be calculated by fitting an ideal rotationally symmetrical shape (preferably a prolate asphere with negative Q-value) under the present corneal height map and by adjusting it with the present refractive sphero-cylindrical error.

The advantages of topography guided treatments over wavefront-guided treatments would be: since it is based on the corneal surface, it is theoretically possible to try to restore the natural aspheric shape of the cornea; by disregarding the aberrations that originate from the intra-ocular structures that change with age or accommodation, it concentrates on correcting the non-physiological irregularities; it can be used in patients with corneal scars, where media opacities are present, as its measurement is based solely on the surface reflection; it can also be used in highly irregular corneas which are beyond the limits of wavefront measuring devices, as the cornea contributes with two thirds to the total dioptric power of a normal eye; and topography maps are relatively easy and intuitive to interpret, and most of the refractive surgeons are more familiarized then with the wavefront maps.

The major disadvantage of topography-guided ablation comes from the same fact that it ignores the rest of the intra-ocular structures, decreasing thus the predictability of the refractive outcomes. The topography alone can serve for calculating the best-fit ideal anterior corneal contour to reduce the corneal irregularities, but the newly achieved curvature may not be adequate for the particular eye, when the remainder of the intraocular structures exert their effect on refraction.

Several topography-guided customized ablations, both using LASIK and PRK refractive techniques, have been performed for the treatment of the corneal irregularities with variable results. Knorz et al [11] found a significant improvement of UVA, a significant reduction of corrective cylinder, and a more regular corneal topography in most of the patients after topography-guided LASIK, with the exception of those with central island after previous photo-ablative refractive treatment. Kymionis et al [12] reported a general increase in UVA and BSCVA, better re-centration of previously decentered ablations, without a significant change in spherical equivalent Alió et al [13] showed good results with TOPOLINK LASIK in the patients with a recognizable topographic pattern while the superficial surface quality, as well as BSCVA, actually worsened in the group with irregular astigmatism. Our results of topography-guided LASIK in patients with irregular astigmatism showed also a significant improvement of UVA, a significant reduction of corrective cylinder, and a more regular corneal topography in most of the patients, without losing lines of BSCVA.

Alessio et al [14],[15] performed topography-guided PRK in patients with decentered myopic ablation and irregular astigmatism after penetrating keratoplasty and showed a significant decrease in sphere and cylinder and a gain in BSCVA in all patients with irregular astigmatism, and 50% of the patients with decentered ablation. In our series a significant decrease in UVA was achieved, and only one patient lost one line of BSCVA after 6 months. However, although we found a decrease both in sphere and cylinder, it was not statistically significant showing a generalized under-correction, probably due to more irregular and biomechanically altered corneas (scars from penetrating corneal wounds, arcuate cuts etc) in our study series.

Among the encountered problems Knorz et al [11] and Alió et al [13] pointed out the difficulty of centration of the treatment, as there was no direct link between the topography and the excimer laser centration. Alessio et al [14],[15] also argued about long acquisition time of Orbscan to decrease the precision of the elevation maps used for the calculation of the ablation profiles. In our system however both the topographer and the excimer laser's centration are based on the pupil center, which is stable, as the measurement (under photopic conditions, as no pharmacological dilation is needed) and the treatment are both being performed under photopic conditions, thus rendering a similar pupil size. Moreover, the acquisition time on a placido ring based topographer is significantly shorter than of a scanning Orbscan device.

Other problem described by Knorz et al [11] and Alió et al [13] was a generalized under-correction of the sphere and astigmatism in most of the cases. Several reasons may have been responsible for that: the ablation algorithm of the particular laser used may not be compensating for the possible lesser effect in human tissue compared with experimental ablations. Other reasons may be a fact that a sphere rather than asphere was used for building the ablation profiles. Moreover, as described by Hull et al [26], the topography system itself may underestimate the actual irregularity of the cornea at the first place. Finally, as previously discussed, when calculating the ablation profile for topography-guided treatments, the contribution of the internal structures of the eye is not taken into equation, therefore the refractive inaccuracies are expected. We also encountered refractive changes that were not consistent with the planned treatment showing an under-correction of less than -0.75 D in LASIK patients and about -1.00 D in PRK patients [Graph 3].

Perhaps the best example of this myopic shift in spherical refraction would be in the treatment to widen the optical zone of previously myopic patients, as described in Case report and Figure 1. The treatment for the enlargement of the optical zone, as well as adjustment to a rotationally symmetric asphere of Q = -0,46 would require the laser to remove tissue peripherally in order to flatten the peripheral cornea and 'push' the limit of the optical zone more towards periphery [Figure 2a]. Therefore, this ablation pattern that resembles a hyperopic treatment, will consequently turn the untreated center of the cornea relatively steeper when compared to the 'new' periphery, and thus will cause a certain amount of myopic shift, as seen in difference topographic map on Figure 1b. The actual ablation profile used in this patient is shown on Figure 2b. Some of these patients may later require an enhancement procedure with a "standard" treatment to correct for the remaining spherical refractive error. We made adjustments to the refractive corrections accordingly (i.e. putting in a myopic component in the ablation pattern) to our later cases in order to compensate for this expected shift in refraction towards myopia. This patient in particular was one of the first in series, where the ablation profile as shown on Figure 2c, which compensates for the induction of central steepness, would have yielded better UVA and refractive outcome. Perhaps an ablation profile built by combining the information of topography and wavefront would give us a definite solution for treating eyes with highly irregular astigmatism.

Considering the expected imprecision regarding the refraction, it is important to evaluate the gain and loss of lines of BSCVA. Indeed, all the studies showed a moderate gain, while Kymionis et al [12] and Alessio et al [15] described again of up to 5 lines after LASIK and up to 8 lines of after PRK respectively. One should be aware thought that the gain of lines of BSCVA depends on the pre-operative BSCVA, so that the real benefit may be overestimated if the pre-operative BSCVA is worse, as a higher gain in BSCVA is expected. In our series, there was a gain of up to four lines of BSCVA (PRK group), most of the patients maintained their BSCVA, while only one eye lost one line of BSCVA (PRK group). The BSCVA in PRK group increased from 0.24 logMAR (20/35) to 0.24 logMAR (20/28) at six months, compared with an increase from 0.07 logMAR (20/24) to 0.05 logMAR (20/22) in LASIK group at six months, confirming thus the expectation that a higher gain of lines of BSCVA be expected in the former group.

The Q value for normal eyes was described to be between -0.15 by Guillon et al. [27] and -0.3 Kiely et al. [28], while theoretical values of -0.46 to -0.61 have been suggested by Manns et al. [17] and by Días et al. [29] respectively. As theoretically described by Gatinel et al. [30] enlargement of the optical zone diameter and an intentional increase in negative asphericity on an initially oblate corneal surface, result in deeper central ablations; for an optical zone of 6.5 mm and a central curvature of 7.8 mm, every -0.1 in Q-value adjustment would add about 3 microns more to the central ablation. In our series the ideal endpoint of -0.46 was targeted in all the cases, as suggested by Manns et al. [17]. Although the desired Q value was not exactly met in most of the cases, we did note a shift of the Q values in the direction of the targeted direction (i.e. more negative Q-values providing a more prolate cornea) [Table 1] and [Table 2].

Explanations for such poor predictability concerning the adjustment of Q-value may lay in the fact that a common mistake in the theoretical calculations of the ablation profiles is that they are based on a static-shape subtraction model. Accordingly, the post-operative corneal shape is determined only by the difference between the preoperative shape and the ablation profile. However, biological effects of healing, as well as the variations in the fluence of the laser beams applied at different points of cornea, may be held responsible for the discrepancy between the clinical findings and the theoretical predictions in final corneal shape, including corneal asphericity. Epithelial hyperplasia is also a predominant factor after PRK, while flap-induced changes, together with biomechanical reaction of the cornea, may be altering the results in LASIK patients. This could explain the refractive inaccuracy, as well as asphericity adjustment imprecision of the topography-guided treatments, despite a notable improvement of the corneal surface regularity.

Surface regularity, as described by index of surface variance (ISV), improved notably after LASIK from 60 +/- 12 (46 to 89) to 50 +/- 9 (32 to 63), confirming a similar observation of regularization of the anterior corneal contour after topography-guided treatments by Alió et al [13]. The PRK group however did not show such a change, probably due to healing process and epithelial remodeling more present after PRK then LASIK procedure, as postulated before.

In conclusion, the topography-guided LASIK and PRK used in this study resulted in a significant reduction of refractive cylinder and increase of uncorrected visual acuity, without a significant loss of BSCVA in patients with severe corneal irregularities. Without the possibility of incorporating information both from corneal topography and the internal structures of the eye into a single ablation profile, it is reasonable to expect topography-guided treatments to be a two-step procedure, should we aim at eliminating both corneal irregularities and refractive error.

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Tables and figures

Table 1– Pre and post-operative clinical data for LASIK patients

	LASIK Group			
	Pre-operative	1 month	3 months	6 months
No. of eyes	10	10	9	9
Sphere [D]	-0.90 +/- 2.55 (+2.75 to -5.00)	-0.80 +/- 0.61 (0 to -1.75)	-0.67 +/- 0.83 (+0.50 to -2.00)	-0.33 +/- 1.06 (+0.75 to -2.25)
Cylinder [D]	-2.53 +/- 1.71 (-0.75 to -5.75)	-1.10 +/- 1.10 (0 to -3.25) †	-1.06 +/- 0.90 (0 to -2.75) †	-1.28 +/- 0.99 (0 to -2.50) †
SEQ [D]	-2.16 +/- 3.07 (+2.25 to -7.88)	-1.35 +/- 0.95 (-0.25 to -2.63)	-1.19 +/- 1.11 (+0.50 to -3.13)	-0.97 +/- 0.94 (+0.50 to -2.25)
UVA [LogMAR]	0.81 +/- 0.68 (0.2 to 2.0)	0.20 +/- 0.18 (0 to 0.5) *	0.27 +/- 0.27 (0 to 0.7) *	0.29 +/- 0.21 (0.1 to 0.7) *
BCVA [LogMAR]	0.07 +/- 0.07 (0 to 0.2)	0.04 +/- 0.08 (-0.1 to 0.2)	0.05 +/- 0.15 (-0.1 to 0.4)	0.05 +/- 0.08 (-0.1 to 0.2)
Asphericity (Q-value)	+0.08 +/- 1.03 (-1.72 to +1.21)	+0.08 +/- 0.93 (-1.35 to +1.43)	+0.06 +/- 1.12 (-1.56 to +1.48)	+0.04 +/- 1.05 (-1.37 to +1.46)
Index of surface variance (ISV)	60 +/- 12 (46 to 89)	58 +/- 15 (42 to 81)	57 +/- 14 (45 to 82)	50 +/- 9 (32 to 63) †

* *p<0.01* † *p<0.05*

Table 2– Pre and post-operative clinical data for PRK patients

	PRK Group			
	Pre-operative	1 month	3 months	6 months
No. of eyes	6	4	5	6
Sphere [D]	-0.88 +/- 2.50 (+1.50 to -5.25)	-2.19 +/- 1.42 (-1.25 to -4.25)	-1.45 +/- 0.51 (-1.00 to -2.25)	-0.79 +/- 0.62 (0 to -1.75)
Cylinder [D]	-2.21 +/- 2.11 (-0.25 to -5.50)	-1.31 +/- 2.29 (0 to -4.75)	-1.55 +/- 1.12 (-0.75 to -3.50)	-1.00 +/- 0.45 (-0.50 to -1.50) †
SEQ [D]	-1.98 +/- 2.33 (-0.25 to -6.50)	-2.84 +/- 2.54 (-1.38 to -6.63)	-2.23 +/- 1.02 (-1.38 to -4.00)	-1.40 +/- 0.68 (-0.74 to -2.25)
UVA [LogMAR]	0.89 +/- 0.87 (0.1 to 2.0)	0.37 +/- 0.17 (0.2 to 0.5)	0.43 +/- 0.36 (0.1 to 1.0)	0.39 +/- 0.32 (0.1 to 1.0)
BCVA [LogMAR]	0.24 +/- 0.26 (0 to 0.7)	0.13 +/- 0.15 (0 to 0.3)	0.12 +/- 0.16 (0 to 0.4)	0.13 +/- 0.14 (0 to 0.3)
Asphericity (Q-value)	+0.30 +/- 0.43 (-0.02 to +1.12)	-0.39 +/- 0.58 (-1.37 to +0.16) *	-0.18 +/- 0.15 (-0.36 to -0.01) †	-0.06 +/- 0.10 (-0.18 to +0.05)
Index of surface variance (ISV)	44 +/- 21 (24 to 67)	43 +/- 25 (22 to 87)	44 +/- 26 (20 to 85)	48 +/- 29 (20 to 78)

* *p<0.01* † *p<0.05*

Legends

Figure 1 – T-CAT software screenshots: a) Raw data validation, map selection, optical zone (OZ) definition and aim Q-value assignment; b) ablation profile build, tilt definition, refraction selection and OZ confirmation.

Figure 2 – Regularization and enlargement of small effective optical zone after RK: Ablation profiles for enlargement of a small myopic optical zone: a) Pre- and b) post-operative corneal topography (tangential map).

Figure 3 – Enlargement of irregular astigmatism and small optical zone and after myopic LASIK: a) Pre- and b) post-operative corneal topography (tangential map); c) Difference map between pre- and post-operative corneal topography.

Figure 4 – Ablation profiles for enlargement of a small myopic optical zone: a) aims at correcting the anterior corneal contour only to a rotationally symmetrical asphere of Q = -0.46; b) adds the correction of a pre-operative refraction (Cyl: -0.75 @ 175); c) incorporates the compensation for the induced myopic shift (Sph: -1.25 Cyl: -0.75 @ 175).

Figure 5 – Enlargement of small optical zone after myopic PRK: a) Pre- and b) post-operative corneal topography (tangential map).

Graph 1 – Gain and loss of lines of BSCVA at six months after topography-guided LASIK and PRK.

Graph 2 – Stability of spherical equivalent (SEQ) over time after topography-guided LASIK and PRK.

Graph 3 – Refractive stability of cylinder over time after topography-guided LASIK and PRK.

Graph 4 – Correlation between attempted and achieved SEQ at 6 months after topography-guided LASIK and PRK.