Topography-guided Treatment of Irregular Astigmatism With the WaveLight Excimer Laser

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ABSTRACT

PURPOSE: To evaluate the feasibility, safety, and predictability of correcting high irregular astigmatism in symptomatic eyes with the use of topography-guided photoablation.

METHODS: In a prospective, non-comparative case series, 16 consecutive symptomatic eyes of 11 patients with small hyperopic and myopic excimer laser optical zones, decentered and irregular ablation after corneal graft, and corneal scars were operated. Uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), manifest and cycloplegic refraction, and corneal topography, with asphericity and regularity, were analyzed. LASIK (n=10) and photorefractive keratectomy (n=6) were performed using the ALLEGRETTO WAVE excimer laser and T-CAT software (Topography-guided Customized Ablation Treatment; WaveLight Laser Technologie AG, Erlangen, Germany).

RESULTS: In the LASIK group, UCVA improved from 0.81±0.68 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. In the PRK group, mean 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. Best spectacle-corrected visual acuity did not change significantly in either group. One PRK patient lost one line of BSCVA. Refractive cylinder for the LASIK group improved from −2.53±1.71 diopters (D) (range: −0.75 to −5.75 D) to −1.28±0.99 D (range: 0 to −2.50 D) at 6 months. Refractive cylinder in the PRK group improved from −2.21±2.11 D (range: −0.25 to −5.50 D) to −1.10±0.42 D (range: −0.50 to −1.50 D). Index of surface irregularity showed a decrease from 60±12 (range: 46 to 89) to 50±9 (range: 32 to 63) at 6 months in the LASIK group whereas no significant change was noted in the PRK group. Subjective symptoms, such as glare, halos, ghost images, starbursts, and monocular diplopia, were not present postoperatively.

CONCLUSIONS: Topography-guided LASIK and PRK resulted in a significant reduction of refractive cylinder and increase of UCVA, without a significant loss of BSCVA. [*J Refract Surg*. 2006;22:335-344.]

Excimer laser surgery provides an accurate tool to reshape the cornea to correct refractive errors. Although most cases have successful and precise outcomes, some problems occur, and these are somehow related to the corneal flap and ablation. The most common problems that result due to ablation are residual refractive error and overcorrection, which can be easily and successfully treated using different enhancement techniques.[1]

Other more challenging ablation-related problems are small optical zones, decentered optical zone, and irregular ablation, which produce irregular corneas that are difficult to correct with standard photoablative 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.

In the past, the options for correcting irregular astigmatism were few, expectations were limited, and outcomes, anatomical and functional, were unpredictable.[2] In recent years, however, advancements in laser technology have offered better tools for dealing with irregular astigmatism.[3-15] After the encouraging pre-clinical results with the ALLEGRETTO WAVE excimer laser (WaveLight Technologie AG, Erlangen, Germany) and Topolyzer software (Jankov M et al. Topography-guided treatments and corneal asphericity—first clinical results with ALLEGRETTO WaveLight laser. Presented at: International Society of Refractive Surgery Fall Refractive and Cataract Symposium; November 8-10, 2001; New Orleans, La) our objective was to present the 6-month postoperative outcomes in symptomatic eyes with high irregular astigmatism treated with topography-guided photoablation and T-CAT software

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The authors have no proprietary interest in the materials presented herein.

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(topography-guided customized ablation treatment) to evaluate its safety and predictability.

PATIENTS AND METHODS

In a prospective, non-comparative case series, 16 consecutive eyes (7 right and 9 left) of 11 patients (9 males and 2 females) underwent LASIK or PRK between February and December 2004. Mean patient age was 32±9 years (range: 17 to 43 years). Patients were sent from several centers in Greece and the Middle East.

Inclusion criteria were irregular corneal astigmatism caused by trauma or previous corneal surgery: eight eyes had small optical zones (four hyperopic and four myopic), three eyes had irregular ablation, two eyes underwent corneal grafts, two eyes had corneal scars, and one eye had a decentered myopic ablation. All patients were contact lens-intolerant and had subjective complaints of ghosting, starbursts, halos, or monocular double vision when specifically asked during the preoperative assessment.

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 a residual corneal thickness <250 µm after treatment, interval <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 informed as to the experimental nature of the study, and written consent was obtained before surgery. The study received institutional review board approval.

Preoperative measurements included uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), manifest and cycloplegic refraction, slit-lamp examination with fundus evaluation, corneal topography (Topolyzer; Oculus, Wetzlar, Germany), ultrasonic pachymetry (Pac Scan 300P; Sonomed, Lake Success, NY), infrared pupillometry (Colvard pupillometer; Oasis, Glendora, Calif), and corneal diameter (white-to-white distance, Canon Autorefractometer Medical Systems, Irvine, Calif).

Eight repeatable and highly reproducible topography maps were obtained, aligning the measurement to the line of sight that passes through the pupil center. To ensure this, the patients were instructed to maintain fixation on the target light while the TOPOLYZER software automatically released the measurements when the corneal apex was correctly focused in the 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 eyes was set to Q=−0.46, which is believed to be the theoretical optimum for the eye's physiology according to Manns et al.[16]

Ten eyes had LASIK enhancement with a new cut or flap lift, whereas six eyes, due to the limitations in the corneal thickness, underwent PRK. LASIK procedures were performed in a standardized manner. One drop of proparacaine 0.5% (Alcaine; Alcon, Couvreur NV, Belgium) was instilled in each eye 5 minutes prior to and just before the procedure. This was followed by a povidone-iodine 10% (Betadine, Lavipharm, Paenia, 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 for maximum flap diameter. The M2 110 single-use head (Moria, Antony, France) was used for a desired cut depth of 130 µm and a superior hinge. After the microkeratome pass, the flap was lifted and folded onto itself. In cases in which the original flap was lifted, 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 onto 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 the flap thickness (subtraction pachymetry).

The ablations were made using the ALLEGRETTO WAVE excimer laser (WaveLight Laser Technologie AG). The machine uses 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 eyetracker. 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 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, Jacksonville, Fla). After central subtraction pachymetry, photoablation was performed and a soft bandage contact lens was placed.

In both surgical techniques, dexamethasone 0.1%, tobramycin 0.3% (Tobradex, Alcon) and apraclonidine

TABLE 1

Clinical Data for Eyes With Irregular Astigmatism Treated by Topography-guided LASIK*

	Preoperative	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)
UCVA (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)‡
BSCVA (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)
ISV	60±12 (46 to 89)	58±15 (42 to 81)	57±14 (45 to 82)	50±9 (32 to 63)†

SEQ = spherical equivalent refraction, UCVA = uncorrected visual acuity, BSCVA = best spectacle-corrected visual acuity, ISV = index of surface variance
**Represented as mean±standard deviation (range).*
†$P<.05$
‡$P<.01$

0.125% (Iopidine, Alcon) were instilled. The patients rested for 15 minutes with their eyes closed, and then the flap or bandage contact lens was re-checked and the patient dismissed. Patients used hard transparent polymethylmethacrylate eye shields overnight for 3 nights after LASIK or until removal of the bandage contact lens after PRK.

Postoperatively, LASIK patients used sodium flurbiprofen 0.03% (Ocuflur; Allergan, Westport, Ireland) drops 4 times a day for 2 days, Tobradex drops 4 times a day for 2 weeks, and sodium hyaluronate 0.18% (Vismed, TRB Chemedica, Greece) drops initially every hour and then when needed for 1 month thereafter. The PRK patients used Ocuflur drops 4 times a day for 2 days, Tobradex drops 4 times a day until removal of the bandage contact lens, with a progressive tapering over the following 4 months. Vismed drops were used every hour initially and then when needed for 1 month thereafter.

After the initial early evaluation at 24 hours, the scheduled follow-up intervals were at 1 week and 1, 3, and 6 months. Slit-lamp examinations were performed to assess the LASIK flap status for flap-related complications, and primary outcome measures were UCVA, BSCVA, manifest refraction, asphericity, and index of surface variance (ISV). Wilcoxon signed ranks and Student *t* test were used for statistical analysis.

RESULTS

Improvements in mean UCVA, BSCVA, corneal asphericity, and corneal irregularity occurred in the LASIK and PRK groups at every follow-up interval (Tables 1 and 2).

In the LASIK group, mean UCVA improved from 0.81±0.68 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, whereas mean 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, a statistically significant increase was noted in UCVA at 1, 3, and 6 months compared to the preoperative UCVA (P=.008, P=.01, and P=.008, respectively), whereas the difference in BSCVA was not statistically different. No patient lost any lines of BSCVA; two patients gained one line and all other patients maintained their BSCVA (Fig 1). The mean gain at 6 months was 5.4 lines of UCVA and 0.2 lines of BSCVA.

In the PRK group, mean 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, and mean 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. A statistically significant increase was noted in UCVA at 6 months compared to the preoperative UCVA (P=.04, Wilcoxon signed rank test), whereas the difference in BSCVA was not statistically different (Table 2). No patient lost two or more lines of BSCVA, one patient lost one line, two maintained their BSCVA, and three patients gained one, two, and four lines of BSCVA, respectively

TABLE 2

Clinical Data for Eyes With Irregular Astigmatism Treated by Topography-guided PRK*

	Preoperative	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)
UCVA (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)
BSCVA (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)
ISV	44±21 (24 to 67)	43±25 (22 to 87)	44±26 (20 to 85)	48±29 (20 to 78)

SEQ = spherical equivalent refraction, UCVA = uncorrected visual acuity, BSCVA = best spectacle-corrected visual acuity, ISV = index of surface variance
**Represented as mean±standard deviation (range).*
†P<.05
‡P<.01

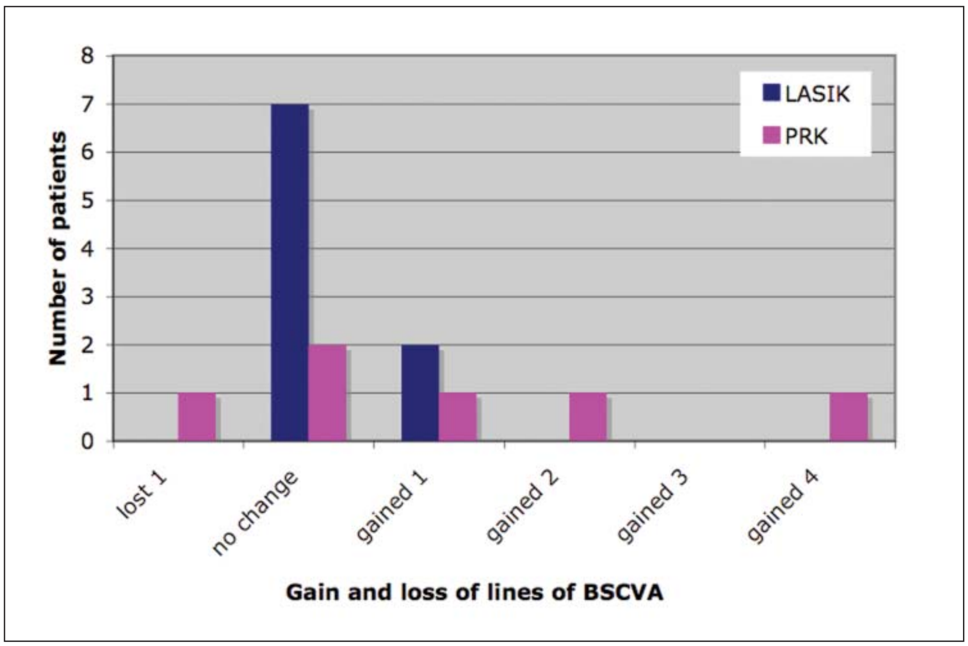


Figure 1. Gain and loss of lines of BSCVA at 6 months after topography-guided LASIK and PRK.

(see Fig 1). The mean gain at 6 months was 5 lines of UCVA and 1.1 line of BSCVA.

Refractive error for the LASIK group improved from sphere −0.90±2.55 diopters (D) (range: +2.75 to −5.00 D) to −0.33±1.06 D (range: +0.75 to −2.25 D) (not significant), and from cylinder −2.53±1.71 D (range: −0.75 to −5.75 D) preoperatively to cylinder −1.28±0.99 D (range: 0 to −2.50 D) postoperatively at 6 months, with a significant difference for 1, 3, and 6 months (*P*=.02, *P*=.03, and *P*=.04, respectively, paired Student *t* test) (Table 1) (Figs 2 and 3). The axis between pre- and postoperative cylinder was within ±10°.

In the PRK group, refractive error improved from sphere −0.88±2.50 D (range: +1.50 to −5.25 D) to −0.85±0.68 D (range: 0 to −1.75 D) at 6 months (not significant, paired Student *t* test), and from cylinder −2.21±2.11 D (range: −0.25 to −5.50 D) preoperatively to −1.10±0.42 D (range: −0.50 to −1.50 D),

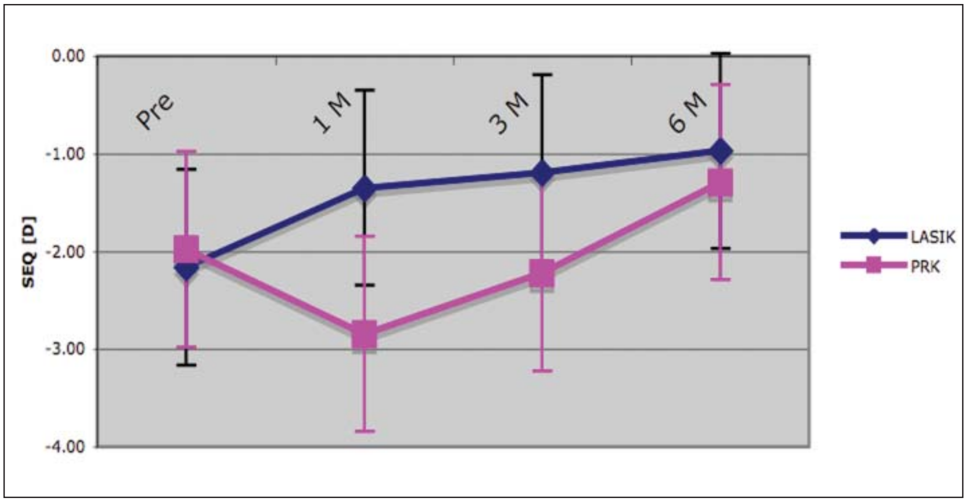


Figure 2. Stability of spherical equivalent refraction (SEQ) over time after topography-guided LASIK and PRK.

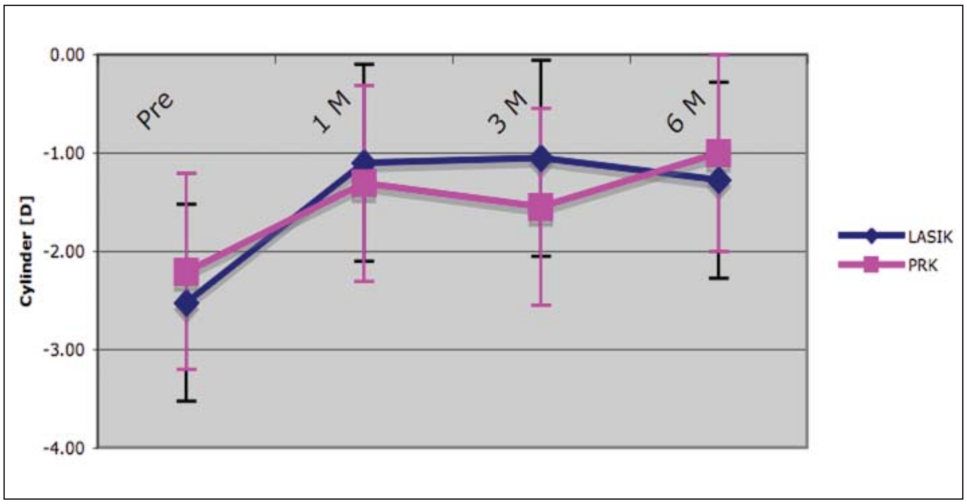


Figure 3. Stability of refractive cylinder over time after topography-guided LASIK and PRK.

reaching significance only at 6 months postoperatively (P=.04, paired Student t test) (Table 2) (see Figs 2 and 3). The axis between pre- and postoperative cylinder was within ±10°. Attempted versus achieved spherical equivalent (SEQ) refraction for both LASIK (R^2=0.89) and PRK (R^2=0.93) groups can be seen in Figure 4.

In the 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 variance showed a decrease from 60±12 (range: 46 to 89) to 50±9 (range: 32 to 63) at 6 months, with a statistically significant difference (P=.04, paired Student t test) (Table 1).

In the 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) postoperatively, reaching statistical significance at 1 and 3 months, but not 6 months (P=.008 and P=.03, respectively, paired Student t test). Index of surface variance 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 only reported postoperatively when specifically asked in the postoperative assessment.

CASE REPORT

A 39-year-old man was seen 2 years after bilateral LASIK for myopic compound astigmatism (right eye: −1.00 −3.00 @ 180 and left eye −1.00 −2.50 @ 175), which resulted in a small optical zone and severe glare, halos, and ghost images. Uncorrected visual acuity was 0.1 logMAR (20/25), and BSCVA was 0 logMAR (20/20) with plano −0.75 @ 175. The Q-value was +0.16 and ISV was 24. Postoperatively, UCVA actually worsened to 0.2 logMAR (20/30), BSCVA maintained 0 logMAR (20/20) with −1.25 −0.25 @ 65, while Q-value improved to −0.29

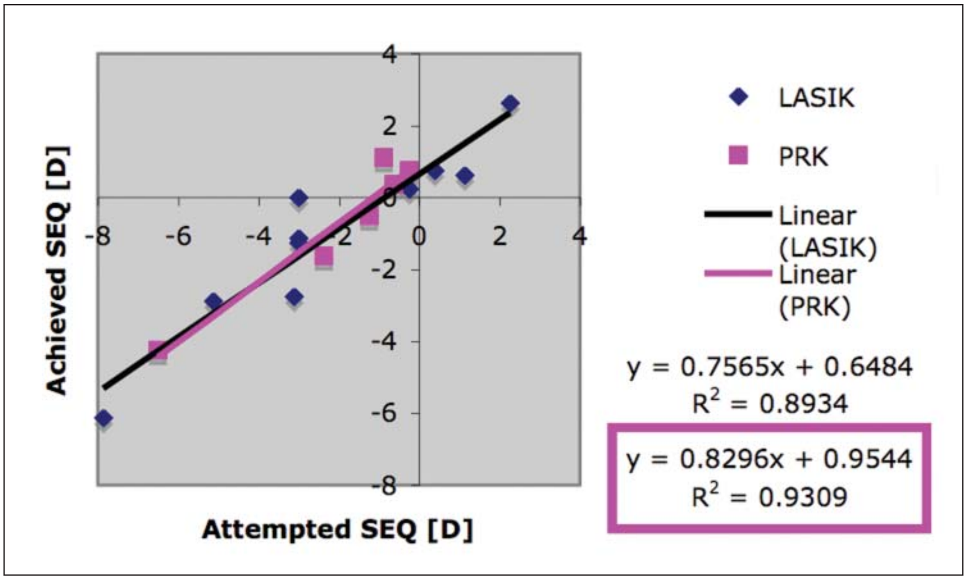


Figure 4. Correlation between attempted and achieved spherical equivalent refraction (SEQ) at 6 months after topography-guided LASIK and PRK.

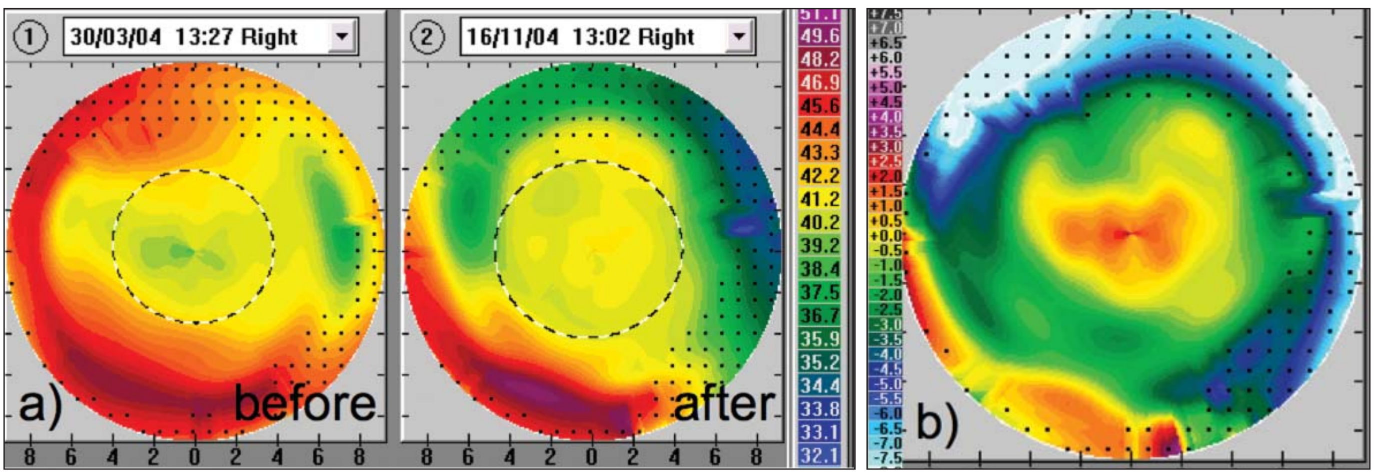


Figure 5. Enlargement of a small optical zone after myopic ablation. **a)** Pre- and postoperative corneal topography (tangential map). **b)** Difference map between pre- and postoperative corneal topography.

and ISV to 20 (Fig 5). None of the subjective symptoms were present postoperatively.

DISCUSSION

Irregular corneal astigmatism has posed a challenge to refractive surgeons for a long time. Ultimately, technological advances have led to two promising customized approaches: wavefront measurements[4-10] and 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, of 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 cornea are of the same order of magnitude.[17]

Hence, in theory, the postoperative anterior corneal surface can be calculated to compensate for all of 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,[18,19] epithelial hyperplasia and stromal remodeling,[20] new aberrations created with the flap,[21] changes in the thickness and the distribution of the tear film,[22] biomechanical properties and variations in ocular aberrations with age,[23] and accommodation.[24]

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 as 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. Because the corneal reshaping alters the path of rays propagating in the eye, Manns et al[16] expected that even though 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 UCVA and a modest decrease in higher order monochromatic aberrations in the terms of root-mean-square 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 treatment be the treatment of choice in post refractive surgery cases with irregular astigmatism.

In non-virgin eyes with 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 changes significantly once the anterior surface becomes regular. Consequently, aside from a frequent inability to obtain repeatable and consistent preoperative 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 when anterior corneal surface aberrations are clearly preponderant? Shouldn't the ideal anterior corneal contour be determined without taking into consideration the influence of the internal structures?

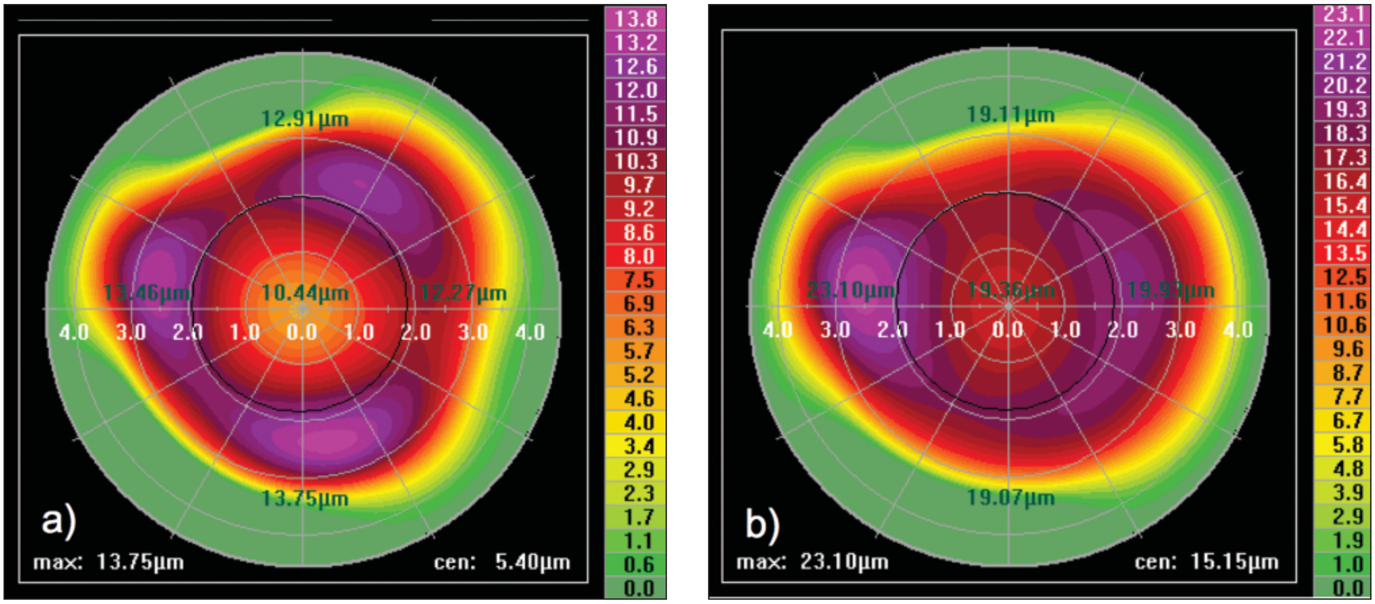
Topography-guided treatments do not take into consideration any assumption regarding internal structures of the eye and use solely corneal front surface information originating from topographic height maps as a baseline. An ablation profile can thus be calculated by fitting an ideal rotationally symmetrical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

Topography-guided treatment has several advantages over wavefront-guided treatment. First, as it is based on the corneal surface, it is theoretically possible to restore the natural aspheric shape of the cornea. Second, by disregarding the aberrations that originate from the intraocular structures that change with age or accommodation, it concentrates on correcting the non-physiological irregularities. Third, it can be used in patients with corneal scars, where media opacities are present, as its measurement is based solely on the surface reflection. Fourth, it can also be used in highly irregular corneas, which are beyond the limits of wavefront measuring devices, as the cornea contributes two thirds to the total dioptric power of a normal eye. And finally, topography maps are relatively easy and intuitive to interpret, and most refractive surgeons are more familiar with these maps than with wavefront maps.

The major disadvantage of topography-guided ablation comes from the same fact that it ignores the rest of the intraocular structures, thus decreasing 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, using LASIK and PRK refractive techniques, have been performed for the treatment of the corneal irregularities with variable results. Knorz and Jendritza[11] found a significant improvement of UCVA, a significant reduction of corrective cylinder, and a more regular corneal topography in most patients after topography-guided LASIK, with the exception of those with central island after previous photoablative refractive treatment. Kymionis et al[12] reported a general increase in UCVA and BSCVA and better re-centration of previously decentered ablations, without a significant change in spherical equivalent. Alió et al[13] showed good results with TOPOLINK (Technomed C-scan, Baesweiler, Germany) LASIK in 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 also showed significant improvement of UCVA, significant reduction of corrective cylinder, and a more regular corneal topography in most 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 patients with decentered ablation. In our series, a significant decrease in UCVA was achieved, and only one patient lost one line of BSCVA after 6 months. However, although we found a decrease in sphere and cylinder it was not statistically significant, showing a generalized undercorrection, probably due to more irregular and biomechanically altered corneas (scars from penetrating corneal wounds, arcuate cuts, etc) in our study series.



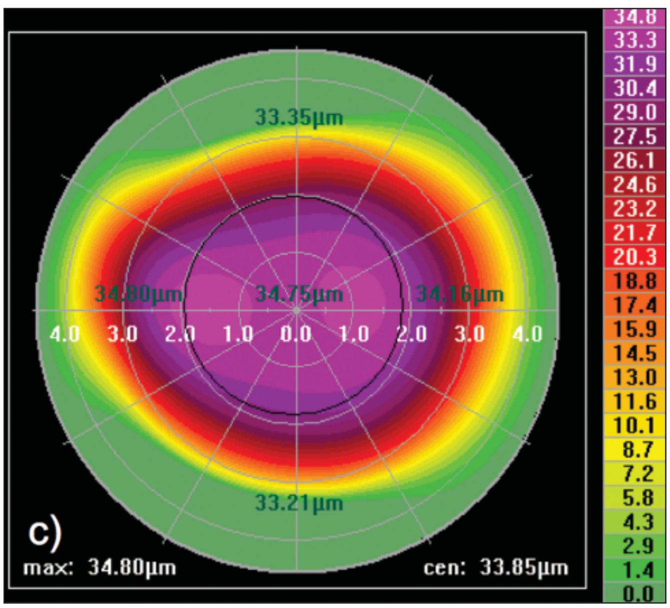


Figure 6. Ablation profiles for enlargement of a small optical zone after myopic ablation—**a)** aims at correcting the anterior corneal contour to a rotationally symmetrical asphere of Q=−0.46; **b)** adds the correction of a preoperative refraction (cylinder: −0.75 @ 175); and **c)** incorporates the compensation for the induced myopic shift (−1.25 −0.75 @ 175).

Among the encountered problems, Knorz and Jendritza[11] and Alió et al[13] pointed out the difficulty of treatment centration, as there was no direct link between the topography and excimer laser centration. Alessio et al[14,15] also commented on the long acquisition time of Orbscan (Bausch & Lomb, Rochester, NY), which decreases 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 that of a scanning Orbscan device.

Another problem described by Knorz and Jendritza[11] and Alió et al[13] was a generalized undercorrection of the sphere and astigmatism in most cases. Several reasons may have been responsible: 1) the ablation algorithm of the particular laser used may not be compensating for the possible lesser effect in human tissue compared with experimental ablations and 2) a sphere rather than asphere was used for building the ablation profiles. Moreover, as described by Hull,[25] the topography system itself may underestimate the actual irregularity of the cornea initially. 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 the equation, therefore refractive inaccuracies are expected. We also encountered refractive changes that were not consistent with the planned treatment, showing an undercorrection of <-0.75 D in LASIK patients and approximately -1.00 D in PRK patients (see Fig 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 the case report and Figure 5A. 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 to flatten the peripheral cornea and "push" the limit of the optical zone more towards periphery (Fig 6A). Therefore, this ablation pattern, which 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 the difference topographic map in Figure 5B. The actual ablation profile used in this patient is shown in Figure 6B. Some of these patients may require an enhancement procedure with a "standard" treatment to correct the remaining spherical refractive error. We made adjustments to the refractive corrections accordingly (ie, a myopic component was included in the ablation pattern) in our later cases to compensate for this expected shift in refraction towards myopia. This patient in particular was one of the first in the series where the ablation profile, as shown in Figure 6C, which compensates for the induction of central steepness, would have yielded better UCVA 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 of the studies showed a moderate gain, whereas Kymionis et al[12] and Alessio et al[15] described a gain of up to five lines after LASIK and up to eight lines after PRK, respectively. One should be aware that the gain of lines of BSCVA depends on the preoperative BSCVA, as the real benefit may be overestimated if the preoperative 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, whereas one eye lost one line of BSCVA (PRK group). The BSCVA in the PRK group increased from 0.24 logMAR (20/35) to 0.14 logMAR (20/28) at 6 months, compared with an increase from 0.07 logMAR (20/24) to 0.05 logMAR (20/22) in the LASIK group at 6 months, thus confirming the expectation of a higher gain of lines of BSCVA in the former group.

The Q value for normal eyes was described to be between -0.15 by Guillon et al[26] and -0.3 Kiely et al,[27] whereas theoretical values of -0.46 to -0.61 have been suggested by Manns et al[16] and Díaz et al,[28] respectively. As theoretically described by Gatinel et al,[29] 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 approximately 3 µm to the central ablation. In our series, the ideal endpoint of -0.46 was targeted in all cases, as suggested by Manns et al.[16] Although the desired Q value was not exactly met in most cases, a shift of the Q value toward the targeted direction was noted (ie, more negative Q-values provided more prolate corneas) (Tables 1 and 2).

Explanations for such poor predictability concerning the adjustment of Q value may be due to a common mistake in the theoretical calculations of the ablation profiles, which is the fact that they are based on a static-shape subtraction model. Accordingly, the postoperative 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 the 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, whereas 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 ISV, improved notably after LASIK from 60 ± 12 (range: 46 to 89) to 50 ± 9 (range: 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 the healing process and epithelial remodeling, which are more prominent after PRK than after LASIK, as postulated previously.

Topography-guided LASIK and PRK used in this study resulted in a significant reduction of refractive cylinder and increase of UCVA, without a significant loss of BSCVA in patients with severe corneal irregularities. Because information from the corneal topography and internal structures of the eye have not been incorporated into a single ablation profile, topography-guided treatment is expected to be a two-step procedure in the elimination of corneal irregularities and refractive error.

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