Topographically-guided Laser In Situ Keratomileusis to Treat Corneal Irregularities

Michael C. Knorz, MD, Bettina Jendritza, MD

Objective: To evaluate the predictability and safety of topographically guided laser in situ keratomileusis (LASIK) to treat corneal irregularities.

Design: Prospective, noncomparative interventional case series.

Participants: Twenty-seven patients (29 eyes) with postsurgical corneal irregularities, divided into four subgroups (postkeratoplasty, 6 eyes; posttrauma, 6 eyes; postphotorefractive keratectomy (PRK)/LASIK with decentered or small ablations, 11 eyes; post-PRK/LASIK with central islands, 6 eyes).

Intervention: LASIK was performed using the Automatic Corneal Shaper and the Keracor 117 C spot-scanning excimer laser (Bausch & Lomb Surgical Technolas, Munich, Germany). Individual ablation patterns were calculated on the basis of axial radii of curvature data obtained with the Corneal Analysis System (EyeSys Premier, Irvine, CA).

Main Outcome Measures: Change of corneal topography pattern, patient satisfaction, manifest spectacle refraction, and visual acuity at 12 months after surgery.

Results: Corneal topography showed improved corneal regularity in 66% of eyes in the postkeratoplasty group, whereas 34% remained irregular. In the posttrauma group, 83% improved and 17% remained irregular. In the decentered/small optical zone group, 91% improved and 9% remained irregular. In the central islands group, 50% improved and 50% remained irregular. Refractive cylinder decreased from 5.83 $\pm$ 1.25 diopters (D) to 2.96 $\pm$ 1.23 D in the postkeratoplasty group ($P = 0.01$), from 2.21 $\pm$ 1.35 D to 0.50 $\pm$ 0.84 D in the posttrauma group ($P = 0.001$), from 0.73 $\pm$ 0.71 D to 0.36 $\pm$ 1.05 D in the decentered/small optical zone group (NS), and from 1.42 $\pm$ 1.13 D to 0.50 $\pm$ 0.84 D in the central island group ($P = 0.01$). Uncorrected visual acuity improved from 20/200 $\pm$ 0.07 to 20/50 $\pm$ 0.17 in the postkeratoplasty group ($P = 0.01$), from 20/83 $\pm$ 0.12 to 20/50 $\pm$ 0.28 in the posttrauma group ($P = 0.01$), from 20/60 $\pm$ 0.16 to 20/50 $\pm$ 0.29 in the decentered/small optical zone group (NS), and from 20/71 $\pm$ 0.12 to 20/60 $\pm$ 0.24 in the central island group (NS).

Conclusions: The topographically-guided LASIK method used in this study resulted in a significant reduction of refractive cylinder, a significant increase of uncorrected visual acuity, and improved corneal regularity in a large percentage of patients with severe corneal irregularities such as decentered/small optical zones after LASIK or irregular astigmatism after keratoplasty or trauma. With small irregularities such as central islands, results were sufficiently poor to advise against the use of our technique in these patients. *Ophthalmology 2000; 107:1138–1143 © 2000 by the American Academy of Ophthalmology.*

Excimer laser surgery provides an accurate tool to reshape the cornea to correct refractive errors.[1] The widespread use of refractive surgery has also resulted in a large number of corneal irregularities caused by central islands, too small an optical zone, and decentrations.[2,3] To date, these complications cannot be satisfactorily treated surgically, despite attempts to mask part of the cornea during ablation[4–7] or to combine several treatments.[8] Current ablation algorithms are either spherical, some with peripheral transition zones to correct spherical errors, or elliptical to correct astigmatic errors.[3] They do not allow for customized treatments of corneal irregularities such as irregular astigmatism. The recent introduction of spot-scanning excimer lasers provides the technologic platform to perform ablations of any shape.[9] Corneal topography enables us to measure the shape of the individual cornea and possibly to calculate an individualized ablation profile. Could we combine corneal topography and scanning lasers to create topographically-guided, customized ablations? Experimental results demonstrated the feasibility of this concept,[10] and early clinical data from our group indicated that the concept works clinically, too.[11] We therefore analyzed the predictability and safety of topographically-guided laser in situ keratomileusis (LASIK) in the treatment of corneal irregularities.

Originally received: November 9, 1998.
Accepted: March 1, 2000. Manuscript no. 98566.

From the Department of Ophthalmology, Klinikum Mannheim, Mannheim, Germany.

Presented in part at the annual meeting of the American Academy of Ophthalmology, New Orleans, Louisiana, November 1998.

Dr. Knorz is a consultant to Bausch & Lomb Surgical.

Reprint requests to Michael C. Knorz, MD, Klinikum Mannheim, Mannheim 68135, Germany.

ISSN 0161-6420/00/$–see front matter
PII S0161-6420(00)00094-4

Table 1. Refraction, Visual Acuity, Corneal Topography, and Patient Satisfaction 12 Months after Topographically-guided LASIK

	Group 1 Postkeratoplasty	Group 2 Posttrauma	Group 3 Decentered/Small	Group 4 Central Islands
No. of eyes	n = 6	n = 6	n = 11	n = 6
SE preoperatively	−2.83 ± 2.71 D (−5.50–1.50 D)	0.81 ± 1.81 D (−2.00–3.50 D)	−1.00 ± 2.24 D (−3.63–3.50 D)	−0.46 ± 2.02 D (−3.50–1.25 D)
SE at 12 mos	−0.15 ± 1.23 D (−2.25–1.25 D)	0.17 ± 1.21 D (−1.00–2.50 D)	0.20 ± 2.41 D (−4.00–3.70 D)	0.63 ± 2.15 D (−3.25–3.00)
Cylinder preoperatively	5.83 ± 1.25 D (4.00–8.00 D)	2.21 ± 1.35 D (1.00–5.00 D)	0.73 ± 0.71 D (0–2.00 D)	1.42 ± 1.13 D (0–3.50 D)
Cylinder at 12 mos	2.96 ± 1.23 D* (1.50–4.50 D)	0.50 ± 0.84 D† (0–2.5 D)	0.36 ± 1.05 D (0–3.5 D)	0.50 ± 0.84 D* (0–2.00 D)
UCVA preop	20/200 ± 0.07 (20/400–20/100)	20/83 ± 0.12 (20/200–20/50)	20/60 ± 0.16 (20/400–20/30)	20/71 ± 0.12 (20/200–20/50)
UCVA at 12 mos	20/50 ± 0.17* (20/100–20/30)	20/50 ± 0.28* (20/125–20/25)	20/50 ± 0.29 (20/400–20/20)	20/60 ± 0.24 (20/400–20/30)
UCVA improved 2 or more lines	83%	83%	55%	50%
UCVA ± 1 line	17%	17%	36%	17%
UCVA lost 2 or more lines	0%	0%	9%	33%
SCVA preop	20/30 ± 0.11 (20/40–20/25)	20/34 ± 0.29 (20/100–20/20)	20/35 ± 0.30 (20/200–20/20)	20/36 ± 0.14 (20/50–20/25)
SCVA at 12 mos	20/31 ± 0.22 (20/50–20/20)	20/31 ± 0.34 (20/60–20/15)	20/37 ± 0.30 (20/125–20/15)	20/40 ± 0.16 (20/50–20/25)
SCVA improved 2 or more lines	33% (n = 2)	33% (n = 2)	9% (n = 1)	17% (n = 1)
SCVA ± 1 line	50% (n = 3)	50% (n = 3)	82% (n = 9)	83% (n = 5)
SCVA lost 2 or more lines	17% (n = 1)	17% (n = 1)	9% (n = 1)	0%
Topo as planned	0%	17% (n = 1)	27% (n = 3)	17% (n = 1)
Topo improved	66% (n = 4)	66% (n = 4)	64% (n = 7)	34% (n = 2)
Topo refractive change only	34% (n = 2)	17% (n = 1)	9% (n = 1)	50% (n = 3)
Topo unchanged	0%	0%	0%	0%
Success rate (Topo as planned or improved)	66% (n = 4)	83% (n = 5)	91% (n = 10)	50% (n = 3)
Patient response: "very satisfied"	66% (n = 4)	66% (n = 4)	18% (n = 2)	34% (n = 2)
Patient response: "moderately satisfied"	17% (n = 1)	0%	46% (n = 5)	0%
Patient response: "not satisfied"	17% (n = 1)	34% (n = 2)	36% (n = 4)	66% (n = 4)
Reoperation rate	50% (n = 3)	50% (n = 3)	36% (n = 4)	50% (n = 3)

SE = spherical equivalent of manifest refraction; SCVA = spectacle-corrected visual acuity; Topo = corneal topographic map at 12 months as compared to the preoperatige map; UCVA = uncorrected visual acuity.

* $P = 0.01$.

† $P = 0.001$.

Patients and Methods

Patient Population

In a prospective, noncomparative case series, we operated on 32 consecutive eyes of 30 patients between July 1996 and July 1997. Because there were no other equally or less invasive treatment options, we did not perform a randomized trial. Patients were sent from several centers in Germany. Inclusion criteria were irregular corneal astigmatism caused by trauma or previous corneal surgery. All patients had to be contact lens intolerant. We considered topographically-guided LASIK as their last option before performing a corneal graft. Exclusion criteria were corneal scars or 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 360 μm after treatment (see calculation of ablation), a minimum interval of 2 years (postkeratoplasty group) or 1 year (all other groups) after last surgery, and inability to complete the 1-year follow-up. All patients were fully informed as to the experimental nature of our study, and written consent was obtained before surgery. The study was approved by our institutional review board. Three eyes (three patients) were excluded, as explained in detail in the "Results" section. The remaining 29 eyes (27 patients) were divided into four groups.

Group 1 (postkeratoplasty group) consisted of six eyes (five patients) with irregular corneal astigmatism after penetrating keratoplasty. In three eyes, the steep half-meridians were 140 degrees apart and merged peripherally, whereas the flat meridians were asymmetric with more than 4.00 diopters (D) difference in refractive power. In two eyes the steep half-meridians showed more than 4.00 D difference in steepness, whereas the flat meridians were symmetric. The topographic map of one of these eyes is shown in Figure 1. In one eye the steep half-meridians were 160 degrees apart with an asymmetric shape, one half-meridian being twice as large as the other. Average age was 42 years (range, 26–61). All grafts were performed more than 2 years ago. Visual acuity, corrective cylinder used, and spherical equivalent of refraction are given in Table 1.

Group 2 (posttrauma group) consisted of six eyes (six patients) with irregular corneal astigmatism after corneal trauma. Average age was 42 years (range, 8–60). The trauma dated back more than 2 years in all eyes. Visual acuity, corrective cylinder used, and spherical equivalent of refraction are given in Table 1. A typical example is shown in Figure 2.

Group 3 (decentered/small optical zone group) consisted of 11

eyes (10 patients) with decentered or small optical zones. All patients complained about halos and image distortion even during the day. Four eyes had had LASIK for hyperopia with 2.5 to 3 mm optical zones, two of them centered and two decentered 1.5 mm. Three had had LASIK for myopia with resulting optical zones of 3.5 mm. An example is shown in Figure 3. Three eyes had had LASIK and one eye had photorefractive keratectomy (PRK) for myopia, with the optical zones decentered 1.5 to 2.5 mm. An example is shown in Figure 4. Average age was 41 years (range, 32–57). All previous surgery was at least 1 year ago. Visual acuity, corrective cylinder used, and spherical equivalent of refraction are given in Table 1.

Group 4 (central islands group) consisted of six eyes (six patients) with irregular astigmatism after PRK (two eyes) or LASIK (four eyes) caused by central islands or keyhole patterns. A typical example is shown in Figure 5. All patients complained about blurred vision or image distortion even during the day. Average age was 42 years (range, 35–50). All previous surgery was at least 1 year ago. Visual acuity, corrective cylinder used, and spherical equivalent of refraction are given in Table 1.

Surgical Technique

Surgery was performed by one surgeon (MCK) using topical anesthesia (oxybuprocaine 0.4%). The Automatic Corneal Shaper (Bausch & Lomb Surgical, St. Louis, MO) was used to cut an 8.5 mm hinged flap. The 160 μm thickness plate was used in all eyes. After the cut, suction was released, but the suction ring was left on the eye to aid in centering the ablation. The corneal flap was then carefully displaced nasally with a blunt spatula. The coaxial helium-neon-laser of the Keracor 117 C excimer laser (Bausch & Lomb Technolas, Munich, Germany) was centered over the middle of the entrance pupil.[12] The oblique lights of the laser were adjusted to maintain a pupil size of approximately 3 to 4 mm to facilitate centration control. The ablation was centered on the entrance pupil by the surgeon throughout the procedure with the suction ring. The stromal bed was neither irrigated nor dried to avoid changes in hydration, but fluid accumulating at the hinge during the ablation was removed with a Merocel sponge (Merocel Inc., Mystic, CT). After the ablation, the back of the flap and the stromal bed were irrigated, and the flap was replaced. Once the flap was aligned, we waited for 2 minutes to ensure proper adhesion. After surgery, gentamicin (3 mg/1 ml) and dexamethasone (1 mg/ml) eyedrops were administered and the eye was covered with a hard shield for the first night. Topical treatment with gentamicin and dexamethasone eyedrops (one drop three times daily) was continued for 5 days and then discontinued.

Calculation of Ablation

The ablation was based on the preoperative corneal topographic map. Once the topography was taken, the data of the true curvature map (axial radii of curvature) were copied and sent to Bausch & Lomb Surgical Technolas, Munich, Germany. The axial radii of curvature were converted into true corneal height values using a special software program and algorithm developed by Technolas. We had to provide the desired postoperative corneal refractive power (target K-value, given in diopters), the maximum ablation depth, and the manifest refraction. The target K-value was determined as follows: the K-values of the steepest and the flattest corneal meridian within the central 4 mm zone were taken and the mean value of these two was calculated. Because we were aiming for emmetropia in all eyes, the spherical equivalent of the manifest refraction was then added to the mean K-value. The maximum ablation depth and therefore the maximum ablation zone diameter were calculated on the basis of preoperative pachymetry values. Measurements were taken of the central cornea and a point each 2 mm temporal, nasal, superior, and inferior to the central cornea (System Corneo-Gage II, Sonogage Co., Cleveland, OH). To prevent ectasia, the maximum ablation was calculated as the difference of actual central thickness minus 360 μm (160 μm for the flap and 200 μm for the stromal bed). On the basis of the maximum ablation, Technolas calculated the diameter of the fully corrected optical zone. The average diameter was 5.3 $\pm$ 0.34 mm (range, 4.9–6 mm).

The basic principles of the software were as follows: the TopoLink software (Bausch & Lomb Surgical Technolas, Munich, Germany) compares the shape of the target sphere with the corneal shape actually measured. Simplified, the target shape is fitted from beneath to the actual cornea for a given planned optical zone size. The difference between the two shapes is then ablated. Any "overlap" between target and actual shape must thus be outside the planned optical zone because tissue cannot be "added" but ablated only. The TopoLink software therefore represents a new and different approach that is not based on Munnerlyn′s formula rather, it calculates a certain "lenticule" of corneal tissue to be removed, and the scanning laser used provides the means to remove this tissue even if its shape is asymmetric or irregular. The diameter of the overlap between target and actual map was varied to achieve the maximum optical zone size possible for the given maximum amount of tissue that could be ablated.

On the basis of the preceding data, Technolas calculated a treatment file that basically contained information for the scanning laser on which ablation pattern to perform. The session file was transferred to us by E-mail and loaded into the Keracor 117 C excimer laser just before treatment. We also received a pictorial, depicting the preoperative corneal topographic map (scale in diopters), the calculated ablation (as a color-coded map, scale in micrometers), and the predicted postoperative corneal topography map (scale in diopters) (see Fig 5).

We used the Keracor 117 C excimer laser which uses a 2-mm beam that is scanned across the cornea at a shot frequency of 50 Hz. It was modified by including an aperture that allows the use of both a 1-mm beam and a 2-mm beam. We used the "TopoLink" mentioned, which is not commercially available yet. This software splits the total ablation into several (four to eight) cycles. During the first two to four cycles, a 1-mm scanning spot is used; during the remaining two to four cycles, a 2-mm scanning spot is used. After loading the individual session file, we performed one treatment on a polymethyl methacrylate plate covered with a thin aluminum foil (so-called fluence test plates, available from Bausch & Lomb Surgical Technolas, Munich, Germany). During this test treatment, the ablation pattern was compared with the pattern shown in the pictorial supplied by Technolas. After the test, the treatment file was loaded again and the actual surgery was started.

Manifest Refraction and Visual Acuity

All patients were examined preoperatively, and at 1 day, 1 month (range, 4–8 weeks), 6 months (range, 4–6 months), and 12 months (range, 12–14 months) postoperatively by one observer (BJ). Patients were called immediately in case they missed one scheduled visit to ensure examination within the respective follow-up periods. We measured subjective spectacle refraction. Because the number of reoperations was high in most groups, no data on refractive change between any of the scheduled follow-up visits are given, and data at 12 months are reported only.

Uncorrected and spectacle-corrected visual acuity were tested using projection charts (Rodamat, Rodenstock, Munich, Germany). Visual loss was calculated as the difference in line number on a logarithmic scale. For each group, the percentages of eyes gaining two or more lines, losing two or more lines, and within $\pm$

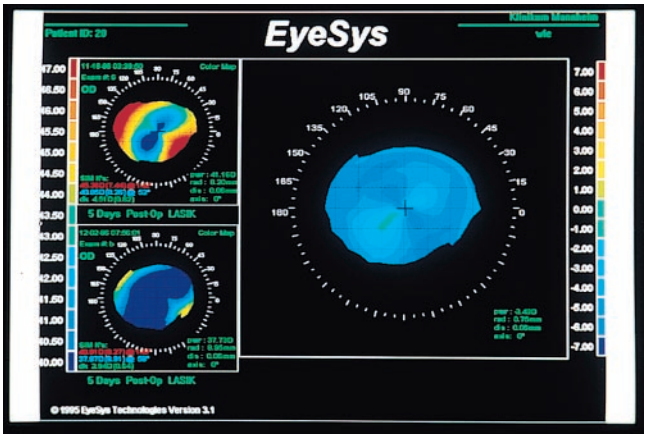

Figure 1. Difference map of a postkeratoplasty eye (group 1). The preoperative map, upper left, shows asymmetric astigmatism. After topographically-guided LASIK, lower left, a large regular central optical zone is visible. The difference map, right, shows the change in astigmatism.

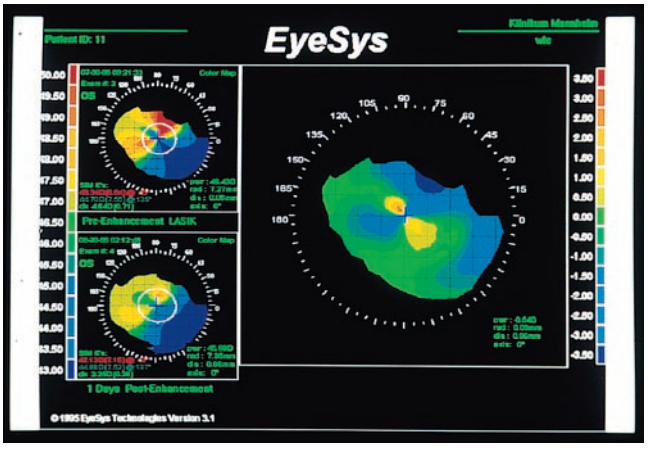

Figure 2. Difference map of an eye with irregular astigmatism after trauma (group 2). The preoperative map, upper left, shows asymmetric steepening in the upper left and excessive flattening in the lower right of the cornea. After topographically-guided LASIK, lower left, there is much less steepening, but still significant irregular astigmatism, which demonstrates undercorrection. The difference map, right, shows the change in astigmatism.

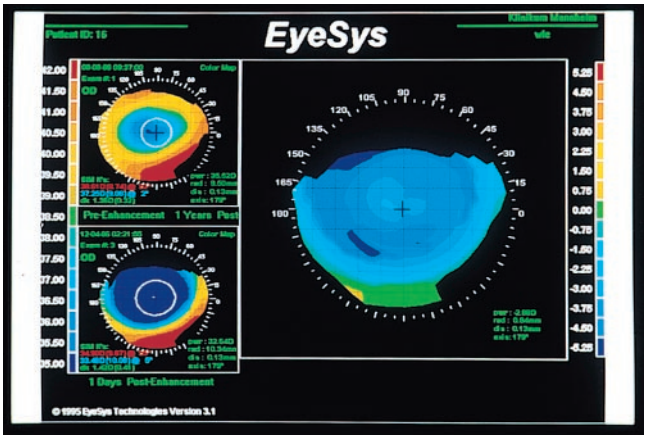

Figure 3. Difference map of an eye with a small optical zone after LASIK for myopia (group 3). The preoperative map, upper left, shows a small ablation zone. After topographically-guided LASIK, lower left, a much larger ablation zone is visible. The differential map is shown on the right.

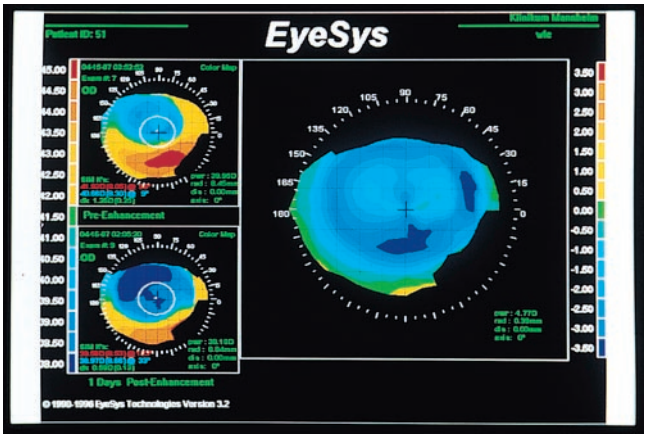

Figure 4. Difference map of an eye with a decentered and small ablation after LASIK for myopia (group 3). The preoperative map, upper left, shows a small ablation zone, decentered upward. After topographically-guided LASIK, lower left, a much larger ablation zone, which is only slightly decentered upwards, is visible. The differential map is shown on the right.

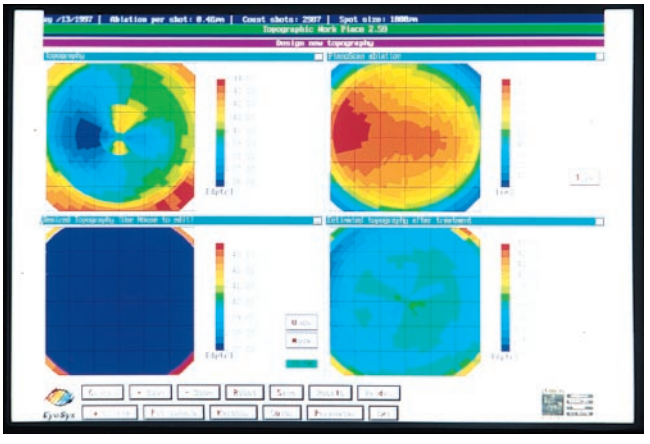

Figure 5. Pictorial depicting the preoperative corneal topography map of a bow-tie–shaped central island (group 4), upper left, the calculated ablation, upper right; an editing window, lower left; and the predicted postoperative topographic map, lower right, after topographically-guided LASIK.

one line were calculated. All data were recorded on prospectively completed data forms. Statistical analysis was performed using the paired *t* test.

Corneal Topography

Topography was performed by one observer (BJ) using the Corneal Analysis System (EyeSys System 2000, Software Version 3.10 and 3.20, EyeSys Premier, Irvine, CA), and all maps were graded by the same observer. The topographic changes from the preoperative examination to the postoperative examination at 12 months were subjectively graded as follows: planned correction fully achieved (irregularity less than 1 D and optical zone size as predicted); attempted correction partially achieved (decrease of irregularity of more than 1 D on the differential map and/or increase of optical zone size by at least 1 mm); flattening or steepening of the corneal contour level only, no change of irregularity (change 1 D or less on differential map); no change at all. For each of the groups, percentages of eyes at each grade are given.

Patient Satisfaction

A short questionnaire was completed 12 months after surgery by all patients. Patients were asked to rate their satisfaction with the result of the surgery (high, moderate, not satisfied).

Reoperations

Reoperations were performed in cases of undercorrection or regression of effect. If undercorrection was present at 1 month and the patient was unhappy, reoperation was scheduled 2 months later. If the topographic maps taken at 1 and 3 months did not show a change, retreatment was performed as scheduled, which means 3 months after the first topographically-guided LASIK. In case regression of effect became visible at any of the follow-up visits and the patient was unhappy, we also scheduled retreatment 2 months later and proceeded accordingly. In all eyes, the flap was lifted with a blunt spatula instead of recutting.

Results at 12 Months

Drop-out Analysis. Three eyes (three patients) were excluded from evaluation. The first, a 33-year-old man, had had LASIK in his right eye in 1995 with a broad-beam laser and the Draeger lamellar microkeratome (formerly manufactured by Storz Instrument Co., Heidelberg, Germany). Treatment was performed because of a persistent central island. We recut using the technique described previously, and ended up with a flap and an additional irregular lamella of tissue on the stromal bed. We removed the irregular lamella and performed the treatment. The cornea was even more irregular after treatment, and a corneal transplant was performed 3 months after surgery. Six months after grafting, spectacle-corrected visual acuity was 20/100 compared with 20/40 preoperatively. The second case, a 66-year-old woman, had had a corneal transplant in her right eye with irregular astigmatism. She had bacterial keratitis develop 3 days after LASIK, and despite topical and systemic antibiotics, the flap melted and had to be removed. The cornea healed and developed haze grade 2, and spectacle-corrected visual acuity was 20/100 at last follow-up compared with 20/80 before surgery. The third case, a 32-year-old man, had had LASIK in his right eye in 1995 with a broad-beam laser and was treated because of a persistent central island. He unexpectedly returned to his home country immediately after surgery and was lost to follow-up.

Manifest Refraction and Visual Acuity. The results of all groups are given in Table 1. In the postkeratoplasty group, corrective cylinder was significantly reduced compared with the preoperative value, and uncorrected visual acuity improved significantly. In the posttrauma group, corrective cylinder was also significantly reduced, and uncorrected visual acuity improved significantly. In the decentered/small optical zone group, both corrective cylinder and spherical equivalent were reduced, and uncorrected visual acuity improved accordingly, but differences were not statistically significant.

In the central islands group, both corrective cylinder and spherical equivalent were reduced, and uncorrected visual acuity improved accordingly, but the difference of corrective cylinders was statistically significant only.

Comparing the groups, uncorrected acuity improved most in the postkeratoplasty and the posttrauma groups. Results were worst in the central-island group, with 33% losing two or more lines of uncorrected visual acuity.

Overall, 3 of the 29 eyes lost two or more lines of spectacle-corrected visual acuity. One eye (postkeratoplasty group) went from 20/25 to 20/50; one eye (posttrauma group) went from 20/25 to 20/40, and one eye (decentered/small optical zone group) went from 20/20 to 20/40. In all eyes, irregular astigmatism was the reason.

Corneal Topography. Overall, the planned result was achieved in 17% of the treated eyes at 1 year after surgery. An additional 58% showed an improved result, bringing the overall success rate to 75%. In 25%, a refractive change was achieved only, and none of the eyes showed no change at all.

Figure 1 shows improved corneal regularity and reduced astigmatism in an eye of the postkeratoplasty group. Figure 2 demonstrates improved corneal regularity in an eye of the posttrauma group. However, significant irregular astigmatism is still present after treatment, which indicates undercorrection. Figure 3 shows the enlarged optical zone and Figure 4 the recentered and somewhat enlarged optical zone; both were patients from the decentered/small optical zone group (group 3). The results of all groups are given in Table 1. Evaluating corneal topography, results were best in the decentered/small optical zone group, with a success rate, defined as the percentage of eye with the planned result plus the percentage of eyes that improved, of 91%, followed by the posttrauma group with a success rate of 83%. The lowest success rate was observed in the central island group, being only 50%.

Patient Satisfaction. The results of all groups are given in Table 1. In all groups, a considerable percentage of patients was not satisfied with the result. Results were worst in the central island group, with 66% of patients dissatisfied.

Reoperations. Overall, 14 of the 29 eyes were reoperated on (48%). In 10 eyes, we performed another topographically-guided LASIK. In 6 of the 10 eyes, undercorrection was the reason for retreatment; in 4 of the 10 eyes, regression of effect had occurred.

In four eyes, the first topographically-guided LASIK had corrected the irregular astigmatism, but ametropia was still present. We used a standard LASIK procedure in these eyes (+5.00 D, one eye; −4.5 D, one eye; astigmatic ablation, two eyes).

The rate of reoperations was lowest in the decentered/small optical zone group, 36%, compared with 50% in all other groups (Table 1).

Discussion

The widespread use of corneal refractive surgery has led to an increasing number of patients with corneal irregularities such as central islands or small and/or decentered optical zones.[1–3] Treatment consisted of masking techniques or additional ablations, but results were generally unsatisfactory.[4–8] In our study, we used the concept of topographically-guided ablations. The feasibility of this concept was proved experimentally[10] and by our initial clinical results.[11] We used LASIK instead of surface ablation to exclude the possible influence of epithelial thickness, which tends to be nonuniform in postsurgical corneas, and to minimize the healing change and the scarring often associated with repeated surface ablations.[13,14] We observed a significant improvement of uncorrected visual acuity, a significant reduction of corrective cylinder, and a more regular corneal topography in all but one of the treatment groups. However, results were poor in one group (central islands group). Our results confirm that topographically-guided LASIK works clinically, but they also demonstrate two basic limitations that have to be overcome before widespread clinical use.

First, no direct link exists between the topographic map and the centration of the ablation. We may therefore not hit exactly the spot we aim for. Accordingly, our results were poor in the central islands group, with a success rate of only 50% based on corneal topography and with 66% dissatisfied patients (Table 1). The missing link between topography and ablation may also explain part of the undercorrection of

the astigmatism (postkeratoplasty group, posttrauma group; see Table 1) because axis misalignment leads to considerable undercorrection.[15]

Second, we observed undercorrection in almost all cases, and the rate of reoperations was very high (Table 1). These findings indicate that either the ablation algorithm must be modified to compensate for the possibly lesser effect in human tissue compared with experimental ablations, or that the topography system itself underestimates the actual irregularity. Experimental studies on aspheres demonstrated the inability of topography systems to accurately measure these aspheres.[16] However, algorithms have improved, and some authors were able to demonstrate that topographically-guided ablation could be used experimentally to achieve the predicted result.[10] Clinically, the situation might be different, and it was reported that neither the TMS-1 (Computed Anatomy Inc., New York, NY) nor the EyeSys system used in our study was able to provide acceptable data on very irregular corneas.[17] The problems are believed to be at least partially related to the proprietary algorithms and their presumed intrinsic assumption that the cornea is spherical. Roberts[16,18] emphasized the limitations of measuring aspherical surface such as the human cornea using spherically biased (axial) computerized reconstructions.

Analyzing our data, we must further consider the small number of eyes in each group and the wide range of irregularities included. On one hand, our study can therefore provide limited conclusions only. On the other hand, considering the grossly irregular corneas treated, our results demonstrate that topographically-guided LASIK works successfully in a large number of eyes even under extreme conditions.

On the basis of the presented technology, topographically-guided LASIK improves results in eyes with decentered or small optical zones after LASIK or PRK and is useful in eyes with irregular astigmatism after keratoplasty or corneal trauma. Results were sufficiently poor in small irregularities such as central islands to advise against the use of our technique in these eyes. After refinement of targeting, ablation algorithms, and corneal topography systems, topographically-guided LASIK may ultimately be a tool to create hard contact lens vision in patients with irregular corneas.

References

1. Hersh PS, Stulting RD, Steinert RF, et al. Results of phase III excimer laser photorefractive keratectomy for myopia. Ophthalmology 1997;104:1535–53.
2. Schwartz-Goldstein BH, Hersh PS. Corneal topography of phase III excimer laser photorefractive keratectomy—optical zone centration analysis. Ophthalmology 1995;102: 951–62.
3. Knorz MC, Wiesinger B, Liermann A, et al. Laser in situ keratomileusis for moderate and high myopia and myopic astigmatism. Ophthalmology 1998;105:932–40.
4. Lim-Bon-Siong R, Williams JM, Steinert R, et al. Retreatment of decentered excimer laser keratectomy ablations. Am J Ophthalmol 1997;123:122–4.
5. Talamo JH, Wagoner MD, Lee SY. Management of ablation decentration following excimer photorefractive keratectomy. Arch Ophthalmol 1995;113:706–7.
6. Alpins NA. Treatment of irregular astigmatism. J Cataract Refract Surg 1998;24:634–46.
7. Buzard KA, Fundingsland BR. Treatment of irregular astigmatism with a broad-beam excimer laser. J Refract Surg 1997;13:624–36.
8. Gibralter R, Trokel S. Correction of irregular astigmatism with the excimer laser. Ophthalmology 1994;101:1310–15.
9. Knorz MC. Broad-beam versus scanning-beam lasers for refractive surgery. Ophthalmic Pract 1997;15:142–5.
10. Seitz B, Langenbucher A, Kus MM, et al. Experimental correction of irregular corneal astigmatism using topography-based flying-spot-mode excimer laser photoablation. Am J Ophthalmol 1998;125:252–6.
11. Wiesinger-Jendritza B, Knorz MC, Hugger P, et al. Laser in situ keratomileusis assisted by corneal topography. J Cataract Refract Surg 1998;24:166–74.
12. Fay AM, Trokel SL, Myers JA. Pupil diameter and the principal ray. J Cataract Refract Surg 1992;18:348–51.
13. Amm M, Wetzel W, Winter M, et al. Histopathological comparison of photorefractive keratectomy and laser in situ keratomileusis in rabbits. J Refract Surg 1996;12:758–66.
14. Knorz MC, Liermann A, Seiberth V, et al. Laser in situ keratomileusis to correct myopia of −6.00 to −29.00 diopters. J Refract Surg 1996;12:575–84.
15. Stevens JD. Astigmatic excimer laser treatment: theoretical effects of axis misalignment. Eur J Implant Refract Surg 1994;6:310–18.
16. Roberts C. Characterization of the inherent error in a spherically-biased corneal topography system in mapping a radially aspheric surface. J Refract Corneal Surg 1994;10: 103–16.
17. Belin MW, Ratliff CD. Evaluating data acquisition and smoothing functions of currently available videokeratoscopes. J Cataract Refract Surg 1996;22:421–6.
18. Roberts C. Analysis of the inherent error of the TMS-1 topographic modeling system in mapping a radially aspheric surface. Cornea 1995;14:258–65.