Q-factor customized ablation profile for the correction of myopic astigmatism

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PURPOSE: To compare the results of the Q-factor customized aspheric ablation profile with the wavefront-guided customized ablation pattern for the correction of myopic astigmatism.

SETTING: Institute for Refractive and Ophthalmic Surgery, Zurich, Switzerland.

METHODS: Thirty-five patients were enrolled in a controlled study in which the nondominant eye was treated with the Q-factor customized profile (custom-Q study group) and the dominant eye was treated with wavefront-guided customized ablation (control group). Preoperative and 1-month postoperative high-contrast visual acuity, low-contrast visual acuity, and glare visual acuity, as well as aberrometry and asphericity of the cornea, were compared between the 2 groups. All eyes received laser in situ keratomileusis surgery, and the laser treatment was accomplished with the Wavelight Eye-Q 400 Hz excimer laser.

RESULTS: For corrections up to −9 diopters (D) of myopia, there were no statistically significant differences between the 2 groups regarding any visual or optical parameter except coma-like aberrations (3rd Zernike order), where the wavefront-guided group was significantly better 1 month after surgery ($P = .002$). For corrections up to −5 D (spherical equivalent), the Q-factor optimized treated eyes had a significantly smaller shift toward oblate cornea: $\Delta Q_{15} = 0.25$ in Q-factor customized versus $\Delta Q_{15} = 0.38$ in wavefront-guided treatment ($P = .04$).

CONCLUSIONS: Regarding safety and refractive efficacy, custom-Q ablation profiles were clinically equivalent to wavefront-guided profiles in corrections of myopia up to −9 D and astigmatism up to 2.5 D. Corneal asphericity was less impaired by the custom-Q treatment up to −5 D of myopia.

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Corneal refractive surgery is based on the change in corneal curvature to compensate for refractive errors of the eye. After many mechanical approaches, such as radial keratotomy, keratomileusis, and astigmatic keratotomies, ablative procedures using the excimer laser have become the most successful technique. It was mainly the submicron precision and the high repeatability of the ablation of the cornea accompanied by minimal side effects that guaranteed this success.

Standard ablation profiles for the correction of myopic astigmatism were based on the removal of convex–concave tissue lenticules with spherocylindrical surfaces.[1] Although these algorithms proved to be effective to compensate for refractive error, the quality of vision deteriorated significantly, especially under mesopic and low-contrast conditions.[2–5] As a logical consequence, research was directed toward aspheric ablation profiles, wavefront analysis of the eyes operated on, and the optical aberrations induced by the operations.[6–8] The results of a preoperative wavefront analysis were used to create individualized ablation patterns to also compensate for preexisting aberrations[9,10]; however, this analysis is time consuming and appears not to be necessary in the majority of the cases. Therefore, new aspheric nonindividualized algorithms were designed to compensate for the spherical aberration induced,[11] which led to an improved visual outcome.[12] On the other hand, it has been known for many years that any refractive treatment of the cornea must respect the preoperative and postoperative asphericity of the cornea.[13–15]

The outer surface of the human cornea is physiologically not spherical but rather like a conoid.[16] On average, the central part of the cornea has a stronger curvature than the periphery or, in other words, the refractive power of the outer corneal surface decreases from central toward peripheral. For this form, the term *prolate cornea* has been coined, and the opposite form is called *oblate cornea*. The physiologic asphericity of the cornea shows a significant individual variation ranging from mild oblate to moderate prolate.[16] Therefore, it was necessary to introduce a shape factor to characterize the amount of asphericity of the cornea numerically, the so-called Q-factor. Gatinel et al.[17] and Manns et al.[18] emphasized that the preoperative and postoperative Q-factors have significant influence on the ablation depth and profile to be used, and Manns et al.[18] concluded that a minimum of spherical aberration would be obtained at a target Q-factor of approximately −0.4. These calculations were based on an aspheric eye model, and the approximate target value of −0.4 to −0.5 holds for the whole range of myopic corrections up to −10 diopters (D).

In this study, we present refractive, optical, and visual results of an aspheric ablation algorithm that takes the preoperative and attempted postoperative Q-factor of the cornea to be operated on into account. The nondominant eye of patients with myopic astigmatism was corrected using this algorithm, and the outcome at 1 month was compared with that in the dominant fellow eye that was treated by wavefront-guided ablation. Our interest was focused on the quality of vision and the induced wavefront aberrations.

PATIENTS AND METHODS

Study Group

Thirty-five patients seeking laser correction at the Institut für Refraktive und Ophthalmochirurgie (IROC) were enrolled in this study. The age of the patients ranged from 23 to 53 years (mean 35.37 years ± 8.64 [SD]). The refractive and demographic data are listed in Table 1. All patients had LASIK in both eyes, the nondominant eye (study group) being operated on first and the dominant eye (control group) 1 day later. On average, best spectacle-corrected visual acuity (BSCVA) was significantly better in the dominant eye (1.127 ± 0.182 versus 1.040 ± 0.247, P = .049). The target refraction was emmetropia in 59 eyes and slight myopia between −0.50 D and −1.25 D in 11 eyes because of intended monovision. After a complete ophthalmic examination and a thorough discussion of the risks and benefits of the surgery, the patients gave written informed consent. Exclusion criteria were any pathology of the eyes, age under 20 years, asymmetric astigmatism detected in corneal topography, central corneal thickness less than 500 μm and residual stromal thickness of less than 270 μm, and high-order wavefront error (rmsh) of more than 0.35 μm in the nondominant eye (pupil size 7 mm). The study protocol was approved by the review board of the IROC.

Examinations

The complete preoperative ophthalmic examination consisted of autorefractometry and autokeratometry (Humphrey Model 599, Zeiss), corneal topography (Keratograph C, Oculus, equipped with Topolyzer software, Wavelight), manifest refraction using the fogging technique, uncorrected visual acuity (UCVA) and BSCVA, glare visual acuity and low-contrast visual acuity (Humphrey Model 599), wavefront analysis with pupils dilated to at least 7 mm in diameter (Wavefront Analyzer, Wavelight), applanation tonometry, central ultrasound pachymetry (SP-2000, Tomey), and slitlamp inspection of the anterior and posterior segments of the eyes. All root-mean-square (RMS) values are reported at a pupil size of 7 mm. The determinable glare visual acuity and low-contrast acuity values range on a decimal scale from 0 to 0.8 (equivalent to 20/25), whereas for UCVA and BSCVA, the maximum was 2.0 (equivalent to 20/10).

The patients were seen on postoperative days 1 and 3 (if necessary) and 1 month after surgery. On postoperative days 1 and 3, UCVA was measured and a slitlamp inspection was performed. At the 1-month follow-up, the examination was identical to preoperatively.

Q-Factor Analysis and Asphericity Treatment

Preoperative and postoperative Q-factor analysis was performed by means of the corneal topographer. Only automatically taken topographies were accepted. The Q-factor was calculated by the topography software in all 4 main hemimeridians at radial distances 10, 15, 20, 25, and 30 degrees from the apex of the cornea, and for treatment, the average of 2 opposite hemimeridians was used as the Q-factor in the main axes. The preoperative and postoperative Q-factors for numeric evaluation are the averages of all 4 hemimeridians. Since the aim was a postoperative prolate cornea, the target Q-factor was −0.4 within a diameter of 6.5 mm in all cases. A typical ablation pattern attempting an asphericity change of ΔQ = −0.6 within an optical zone of 6.5 mm in diameter is shown in Figure 1.

Surgical Technique

All operations were performed as LASIK procedures. The microkeratome used was the M2 (Moria), with appropriate suction rings selected according to the specifications of the manufacturer. The laser treatment was performed by means of the Eye-Q excimer laser with the custom-Q software (Wavelight). This device works at a repetition rate of 400 Hz and produces a spot size of 0.68 mm (FWHM) with a truncated Gaussian energy profile. Eye tracking is accomplished with a latency of 6 ms. The optical zone of full treatment had a diameter of 6.5 mm with a transition zone of 1.25 mm in both groups.

After the flap was repositioned, the patient was given a bandage lens that was soaked with preservative-free ofloxacin 0.3% (Floxal SDU) eyedrops for 20 minutes. The bandage lens was removed the next morning. The surgery in the fellow eye was done on 2 consecutive days. The postoperative medication consisted of fluorometholone 0.1% (FML) twice a day for 1 week and artificial tears (Hylo-Comod) at the patient's discretion.

Statistical Analysis

Preoperative and postoperative parameters in the 2 groups as well as the preoperative versus postoperative changes (paired differences) in each group were compared using the paired 2-sided

Table 1. Demographic and refractive data of the study group (n = 35; side: nondominant 15 right eyes [42.9%] and 20 left eyes [57.1%]).

	Mean ± SD	Range
Age (y)	35.37 ± 8.64	23 to 53
Sphere, dominant eyes (D)	−4.65 ± 2.0	−1.75 to −9.0
Sphere, nondominant eyes (D)	−4.96 ± 2.21	−1.0 to −9.0
Cylinder, dominant eyes (D)	−0.68 ± 0.75	0 to −2.5
Cylinder, nondominant eyes (D)	−0.62 ± 0.61	0 to −2.25
Q-factor 15 degrees, dominant eyes	−0.21 ± 0.12	−0.04 to −0.53
Q-factor 15 degrees, nondominant eyes	−0.20 ± 0.14	−0.03 to −0.58
Rsmh, dominant eyes (μm)	0.242 ± 0.086	0.106 to 0.472
Rsmh, nondominant eyes (μm)	0.237 ± 0.070	0.11 to 0.346

Rsmh = wavefront error of higher orders (including 3rd to 6th Zernike order)

t test. A P value less than 0.05 was considered significant. The vector analysis of astigmatism correction consisted of the calculation of the change in refractive cylinder in the preoperative axis,[19] and its percentage of the preoperative refractive astigmatism served as a measure for the efficiency of astigmatism correction. Similarly, to take the attempted undercorrection in some eyes of the custom Q-group into account, the spherical correction efficiency was calculated as the percentage of the preoperative versus postoperative change in spherical equivalent compared to the target change in spherical equivalent.

RESULTS

The surgery was uneventful in all cases. At postoperative day 1, 2 eyes showed a minor diffuse lamellar keratitis

Figure 1. Ablation pattern for an attempted change in asphericity of ΔQ = −0.6. In the central part, the ablation depth is virtually constant and resembles a phototherapeutic keratectomy. Toward the periphery, a flattening produces the prolate cornea. The central ablation depth is 28.5 μm.

that resolved within 3 days using FML drops 4 times a day. At the 1-month examination, all eyes showed a regular state after LASIK.

The refractive and visual data at the 1-month follow-up are listed in Table 2. Twenty-eight eyes in the custom-Q group (80%) and 30 eyes in the wavefront-guided group (86%) were within ±0.5 D of the target refraction. The preoperative statistically significant difference in BSCVA, better in the dominant eye, remained significant 1 month after surgery ($P = .031$). Regarding safety, both groups showed an identical distribution of lost versus gained lines of BSCVA (Table 3). The eyes that lost 2 lines (1 in each group) belonged to 1 patient suffering from severely dry eyes.

Low-contrast visual acuity and glare visual acuity were preoperatively and postoperatively not statistically different in the 2 groups (Table 2). Also, the preoperative versus postoperative changes did not demonstrate statistical significance in glare acuity ($P = .724$) or low-contrast acuity ($P = .418$).

Regarding the asphericity of the cornea, all eyes demonstrated a tendency toward an oblate cornea after surgery (Table 2). The preoperative Q-factor as a function of the radial distance from the apex is shown in Figure 2. The increase in asphericity $\Delta Q = Q_{post} - Q_{pre}$ was approximately 4% higher for the custom-Q group. For all radial distances, the difference in ΔQ between the groups was not statistically significant. For corrections of −5 D (spherical equivalent) and less, however, the results were different (Figure 3), showing a significantly smaller shift toward oblate in the Q-factor customized group.

The total rmsh was preoperatively nearly identical in the 2 groups (0.242 ± 0.086 μm and 0.237 ± 0.070 μm, Table 1) and remained postoperatively similar in both groups (0.442 ± 0.142 μm in the custom-Q and 0.381 ± 0.146 μm in the wavefront-guided group [$P = .113$]). The only statistically significant difference regarding wavefront errors was obtained in the postoperative coma-like aberrations S3 (RMS sum of 3rd-order aberrations) with 0.296 ± 0.115 μm in the custom-Q group versus 0.192 ±
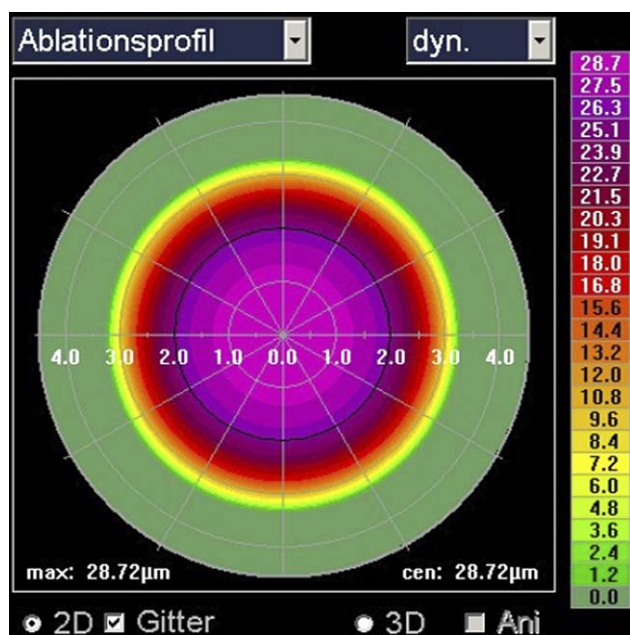
Table 2. Refractive and visual outcomes at 1 month after surgery.

| | Mean ± SD | | |
| | Wavefront-Guided Group Dominant | Custom-Q Group Nondominant | |
Parameter	Eyes	Eyes	P Value
Spherical equivalent (D)			
Preoperative (D)	−4.99 ± 2.05	−5.28 ± 2.25	.289
Postoperative (D)	+0.05 ± 0.44	−0.09 ± 0.58	.072
Efficiency (%)	99.4 ± 4.6	97.7 ± 10.5	.249
Cylinder			
Preoperative (D)	−0.68 ± 0.75	−0.61 ± 0.61	.369
Postoperative (D)	−0.11 ± 0.26	−0.11 ± 0.21	.457
Efficiency (%)	92.6 ± 18	92.2 ± 19	.690
BSCVA			
Preoperative	1.127 ± 0.183	1.040 ± 0.247	.049
Postoperative	1.160 ± 0.201	1.054 ± 0.257	.031
Low-contrast VA			
Preoperative	0.724 ± 0.099	0.725 ± 0.134	.480
Postoperative	0.704 ± 0.132	0.690 ± 0.182	.377
Glare VA			
Preoperative	0.565 ± 0.088	0.553 ± 0.140	.343
Postoperative	0.555 ± 0.133	0.528 ± 0.163	.246
Q-factor Q15			
Preoperative	−0.21 ± 0.12	−0.20 ± 0.14	.335
Postoperative	0.47 ± 0.46	0.50 ± 0.49	.395

BSCVA = best spectacle-corrected visual acuity; VA = visual acuity

0.088 μm in the wavefront-guided group (P = .002). Another important detail is the similar induced spherical aberration (postoperative minus preoperative) in the 2 groups: 0.287 ± 0.219 μm versus 0.295 ± 0.264 μm (P = .457).

DISCUSSION

Wavefront-guided customized ablation appears to be the gold standard for ablative treatment of myopic

Table 3. Safety of wavefront-guided versus custom-Q treatment.

| | Lines Lost | | | Lines Gained | |
VA Type/Group	2 or More	1	Unchanged	1	2 or More
BCVA					
WG	1	5	18	8	3
Custom-Q	1	5	18	8	3
Low contrast VA					
WG	1	4	27	3	0
Custom-Q	2	4	25	4	0
Glare VA					
WG	3	5	19	6	2
Custom-Q	5	4	17	4	5

BCVA = best corrected visual acuity; Custom-Q = Q-factor customized treated eyes; VA = visual acuity; WG = wavefront-guided treated eyes
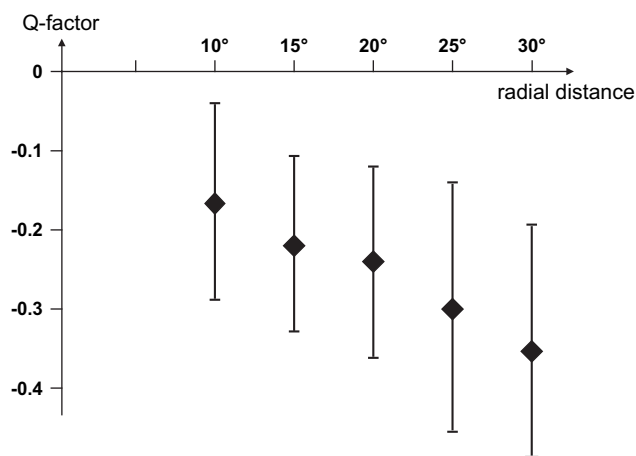

Figure 2. Preoperative asphericity Q as a function of the radial distance from the apex of the cornea. A radial distance of 30 degrees is equivalent to an optical zone diameter of approximately 7.5 mm.

astigmatism regarding the optical performance of the postoperative eye.[20,21] Therefore, it was logical to compare a new algorithm such as the custom-Q profile with this standard. To exclude individual abnormal healing responses, we compared fellow eyes with the dominant eye treated with wavefront-guided ablation and the nondominant eye treated with Q-factor customized. The choice to treat the dominant eyes with wavefront-guided ablation was mainly based on ethical considerations because of the superiority of wavefront-guided algorithms presumed before the study. Regarding refractive and visual outcomes
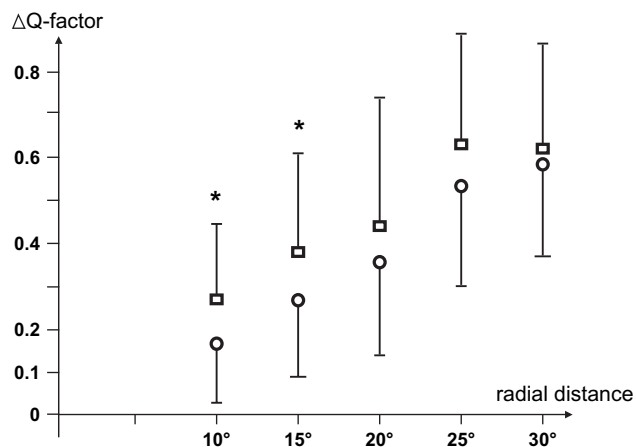

Figure 3. Increase in asphericity $\Delta Q = Q_{post} - Q_{pre}$ in the wavefront-guided (rectangles) and the Q-factor customized treated eyes (circles) in myopic corrections of 5 D and less. A positive value of ΔQ indicates a shift toward an oblate cornea. The bars depict the standard deviation. The difference between the groups is statistically significant for radial distances 10 degrees and 15 degrees from the apex (*).

in the study, however, we could not find any relevant differences (Tables 2 and 3) and conclude that the 2 treatment strategies appear to be clinically equivalent. An important result is the only minor decrease in low-contrast visual acuity in both groups, which is remarkable because after conventional photorefractive keratectomy and LASIK, low-contrast visual acuity shows a significant reduction.[3,22] Although not statistically significant, the better spherical success index (Table 2) in the wavefront-guided group means that the nomogram for spherical custom-Q treatments has to be improved, whereas the efficiency regarding astigmatic treatments was nearly equal in both groups. The small differences reported in this study might have become statistically significant if the group size would have been increased; however, a group of 35 matched pairs is sufficient to detect a clinically meaningful result.

Although the preoperative and postoperative overall optical performance of the eyes treated by the 2 different profiles was very similar in the 2 groups, we found a statistically significant difference regarding the outcome of coma-like 3rd-order aberrations S3. Whereas preoperative versus postoperative S3 increased in the Q-factor customized group from 0.181 ± 0.072 µm preoperatively to 0.296 ± 0.115 µm postoperatively, S3 remained virtually constant in the wavefront-guided group, with 0.182 ± 0.094 µm preoperatively versus 0.192 ± 0.088 µm postoperatively. This result is not surprising because the Q-factor customized approach does not correct coma-like aberrations. On the other hand, the increase in the total wavefront error due to the operation by a factor of 1.83 in the custom-Q group and 1.67 in the wavefront-guided group compares favorably with the increased factors with standard ablation profiles reported in the literature, which range from 1.92[23] to 17.[8] Such an increase in wavefront error during myopia correction is usually due to the inevitably induced spherical aberration, which was identically small in the 2 groups. Chaalita et al.[24] measured higher-order aberrations and correlated them with subjective complaints of patients after LASIK surgery.[24] Whereas the total rmsh and spherical aberration were good quantitative descriptors for starburst and glare, coma was significantly related to double vision. In this study, the postoperative glare visual acuity was on average better compared with the preoperative in both groups, which is consistent with the relatively small increase in spherical aberration and total wavefront error.

So, if the optical performance of the eyes treated by the 2 alternative approaches is similar but coma-like aberrations do better using wavefront-guided ablation, why should the wavefront-guided approach not be preferred in any case? Wavefront-guided ablation requires a time-consuming preoperative wavefront analysis including dilation of the pupil. In a high-volume refractive surgery practice, there is often little time to do such an intensive examination in any case. Not to speak of refractive surgery in third world-countries where for economic reasons such time-consuming analysis is not well accepted. These and other aspects decrease the market penetration of wavefront-guided ablation and create the demand for alternative customized ablation profiles.

We would have expected to find a significant difference in postoperative Q-factors between the groups since we aimed on a postoperative Q-factor of –0.4 in the custom-Q group. Both goals were clearly missed, at least in higher corrections, because there was an underlying strong shift toward an oblate cornea due to the myopic correction that is linearly related with the amount of myopia correction.[25] Thus, on average, a 4% greater shift toward oblate in the custom-Q group is well explained by the 3% higher myopia correction in this group compared with the wavefront-guided group (Table 2). A combination of 2 reasons have recently been considered to be responsible for this shift toward oblate corneal shape[26]: a peripheral undercorrection due to a reduced laser efficacy[27] and the structural response of the cornea that is biomechanically weakened by the LASIK operation itself.[28] Both ablation profiles used in this study include a so-called correction matrix that compensates for the reduced laser ablation in the peripheral cornea.[11] Therefore, we believe that in our cases, the shift was mainly due to a biological response of the cornea.

A totally different picture is drawn when considering myopic corrections of −5 D and less. The corneas of the Q-factor optimized treated eyes were less oblate for all radial distances from the apex (Figure 3); the difference was statistically significant only within the inner 3.5 mm of the cornea (Q_{10} and Q_{15}).

As shown in Figure 1, the Q-factor adjustment consists of a kind of additional correction in the midperiphery of the cornea, resembling a hyperopic correction. To avoid such consecutive hyperopic correction, the central part must be treated by means of a phototherapeutic keratectomy, which enhances the central ablation depth as previously described.[17] An intended change in Q-factor ΔQ of −0.6 within an optical zone of 6.5 mm requires 28.5 µm more central tissue removal (Figure 1). This increased central keratectomy depth may limit the application of Q-factor optimized ablation to corrections of only mild to moderate myopia. A stronger attempted asphericity correction, for example, a target Q of −1.0, might have yielded more prolate postoperative corneas, but, on the other hand, such a strong Q-factor correction would increase the central keratectomy depth by another 30 µm, which we judged not to be appropriate with respect to the already well-preserved low-contrast visual acuity data in this study.

This study is limited regarding the short follow-up of only 1 month. We intended to present early postoperative

data because the corneal optics may be affected by stromal and epithelial healing. Nevertheless, it would be interesting to observe whether corneal optics have some regression. Also, eyes with high preoperative wavefront errors of higher order (at least of the nondominant eye) were excluded from the study. Those eyes, however, should be treated by wavefront-guided customized ablation anyway.

In summary, this study demonstrated that a Q-factor optimized ablation profile yielded visual, optical, and refractive results comparable to those of the wavefront-guided customized technique for corrections of myopia up to −9 D. A significantly better result in corneal optics, however, was obtained only with corrections up to −5 D. The Q-factor optimized ablation represents a customized approach that is much less time consuming than the wavefront-guided technique since it is based on preoperative corneal topography, which is mandatory in any case to detect keratectatic disorders. The Q-factor optimized profile has, therefore, the potential to replace currently used standard profiles for corrections of myopic astigmatism.

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