European Journal of Ophthalmology / Vol. 17 no. 4, 2007 / pp. 507-514

Changes in higher order aberrations after wavefront-guided PRK for correction of low to moderate myopia and myopic astigmatism: Two-year follow-up

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PURPOSE. *To assess efficacy, safety, and changes in higher order aberrations after wavefront-guided photorefractive keratectomy (PRK) in comparison with conventional PRK for low to moderate myopia with myopic astigmatism using a WASCA Workstation with the MEL 70 G-Scan excimer laser.*

METHODS. *A total of 126 myopic or myopic-astigmatic eyes of 112 patients were included in this retrospective study. Patients were divided into two groups: Group 1, the study group; and Group 2, the control group. Group 1 consisted of 78 eyes treated with wavefront-guided PRK. Group 2 consisted of 48 eyes treated with spherocylindrical conventional PRK.*

RESULTS. *Two years postoperatively, in Group 1, 5% of eyes achieved an uncorrected visual acuity (UCVA) of 0.05; 69% achieved a UCVA of 0.00; 18% of eyes experienced enhanced visual acuity of -0.18 and 8% of -0.30. In Group 2, 8% of eyes achieved a UCVA of 0.1; 25% achieved a UCVA of 0.05; and 67% achieved a UCVA of 0.00 according to logMAR calculation method. Total higher-order root-mean square increased by a factor 1.18 for Group 1 and 1.6 for Group 2. There was a significant increase of coma by a factor 1.74 in Group 2 and spherical aberration by a factor 2.09 in Group 1 and 3.56 in Group 2.*

CONCLUSIONS. *The data support the safety and effectiveness of the wavefront-guided PRK using a WASCA Workstation for correction of low to moderate refractive errors. This method reduced the number of higher order aberrations induced by excimer laser surgery and improved uncorrected and spectacle-corrected visual acuity when compared to conventional PRK. (Eur J Ophthalmol 2007; 17: 507-14)*

KEY WORDS. *Higher order aberrations, Myopia, Myopic astigmatism, Wavefront-guided PRK*

Accepted: January 3, 2007

INTRODUCTION

Wavefront-guided corneal ablation is designed to correct the traditional sphere and cylindrical error of the eye and reduce the eye's higher order optical aberration. Ablative corrections that reduce the optical aberrations of the eye will increase retinal image resolution and contrast, which in turn should allow patients to see with higher contrast and finer details. Several groups report a large increase in higher order optical aberrations after traditional corneal laser surgery that is correlated with a significant decrease in quality of vision, especially under night conditions (1-6). Reports of cases treated with wavefront-based algorithms reaching a visual acuity of 20/20 (0.00 logMAR) and better raised the hope of further improving the visual outcome of refractive corneal laser surgery (7-12). Only a few studies addressing the outcome of wavefront-guided photorefractive keratectomy (PRK) with a reasonable follow-up and investigating the changes in ocular higher order aberrations have been published in the peer-reviewed literature

1120-6721/507-08$15.00/0

(13, 14). We present the data of a retrospective clinical trial in which eligible eyes with low to moderate myopia with astigmatism were treated using either conventional PRK or wavefront-guided PRK using a WASCA Workstation to demonstrate its safety, effectiveness, and changes in higher order aberrations in laser ablation.

PATIENTS AND METHODS

A total of 126 myopic or myopic-astigmatic eyes of 112 patients with a mean age of 27.2 years (range, 20–47) who were interested in reducing their dependence on glasses and contact lenses were included in this retrospective study between December 2001 and December 2004. For this study we included patients who achieved maximum visual acuity with best spectacle correction 0.00 according to logMAR calculation method (Snellen 20/20) preoperatively. There were 76 women (82 eyes) and 36 men (44 eyes). Patients with a history of eye diseases, pupil diameter wider than 6 mm, ocular surgery, systemic diseases, morphologic eye abnormalities, or autoimmune diseases were excluded. Patients were divided into two groups: Group 1, the study group; and Group 2, the control group. Group 1 consisted of 78 eyes of 72 patients treated with wavefront-guided PRK. Group 2 consisted of 48 eyes of 40 patients treated with spherocylindrical conventional PRK. The mean sphere in Group 1 was –2.90±0.47 diopters (D) (range, –0.25 D to –5.75 D), the mean cylinder was –0.99±0.24 D (range, –0.25 D to –2.75 D), and spherical equivalent (SE) was –3.39±0.46 D. The mean sphere in Group 2 was –2.99±0.87 D (range, –0.25 D to –6.00 D), the mean cylinder was –1.50±0.46 D (range, 0.00 D to –3.75 D), and spherical equivalent was –3.74±0.78 D. Patients were informed about the surgical and study procedures and gave consent. The research was in accordance with the Declaration of Helsinki. All studies were approved by the Ethics Committee of the Silesian University of Medicine.

Preoperative examination

The preoperative examination included general, medical, and ophthalmic histories and concomitant medications. All eyes were examined for distance visual acuity including uncorrected (UCVA) and best spectacle-corrected visual acuity (BSCVA) using high-contrast optotypes according to logMAR calculation method, manifest and cycloplegic refraction, pupil size, corneal topography, applanation tonometry, biomicroscopy of the anterior and posterior segment, wavefront measurements, and ultrasonic pachymetry. All patients filled out a satisfaction questionnaire pertaining to the quality of their vision. Study inclusion criteria included a minimum age of 20 years and a visual acuity correctable to 0.00. Wavefront measurements were carried out in a dimly light room with a Hartmann-Shack wavefront sensor (WASCA Workstation Asclepion-Meditec, Germany). For the best determination of higher order aberrations the measurements were performed consecutively seven times with a dilated pupil using 1% tropicamide drops (Polfa-Warszawa). The aberration calculation and the treatment plan were based on the central 6.0 mm diameter of the cornea. WASCA-guided PRK treatments were performed with the Asclepion-Meditec MEL 70 G-Scan flying spot excimer laser. The laser, which has an active eye tracker, operates with 200 mJ/cm^2 fluence at a repetition frequency of 35 Hz, with a 1.8 mm diameter flying spot beam.

Surgical procedure and postoperative treatment

Corneas were anesthetized with 0.5% proxymetacaine eyedrops (Alcain, Alcon). The corneal epithelium was removed with a hockey knife, and then the optical center of the eye was identified using the laser eye tracker, which recognized the geometric center of the metal ring. Treatment data for the higher order aberrations were transported via a zip disc to the computer control panel of the excimer laser. First the lower order aberrations were treated in an ablation diameter depending on pupil diameter and then, after again identifying the pupillary center, the higher order aberrations were treated during the same session with a 6.0 mm diameter zone. A soft bandage lens was applied for the first 4–5 postoperative days. Postoperative standard medication in both groups consisted of 0.3% amikacin sulfate eyedrops (0.3% Biodacyna, Bioton) five times a day for 5 days, diclofenac sodium eyedrops (Naclof, Novartis) three times a day for 5 days, and dexpanthenol (Corneregel, Mann Pharma) three times a day for 2 weeks, followed by dexamethasone eyedrops (0.1% dexamethasone, Polfa-Warszawa) three times a day in a gradually tapering dose for 3 months. Additionally, artificial tears were prescribed and applied five times a day for 6 or more weeks. All eyes were targeted for emmetropia.

Postoperative follow-up

Postoperatively, patients were followed at 1 day, 1 week, and 1, 6, and 24 months.

Data analysis and statistics

Statistical analysis was performed with Statistics for Windows software. Paired-sample and independent-sample Student *t*-test was used for the comparison of variables within and between groups. Friedman's test was used for the data which were not normally distributed. For independent variables we used the *t*-test and Mann-Whitney *U* or Wald-Wolfowitz test. We considered a p value < 0.05 as statistically significant.

RESULTS

Efficacy

Before excimer laser surgery in both treated groups UCVA and BSCVA were not statistically significant and achieved 1.00 and 0.00 acuity, respectively. None of the treated patients achieved BSCVA better than 0.00 preoperatively. In Group 1, 100% of the eyes (78 eyes) and in Group 2, 96% of the eyes (46 eyes) had BSCVA equal to 0.00 preoperatively. In the follow-up period the visual acuity in the group who had WASCA-guided PRK was statistically better. One month after surgery, this group's UCVA was 23.2% better than in the control group, then at 6 and 24 months of observation UCVA was 18.4% better. BSCVA in Group 1 was better than in Group 2 by 17.4% at month 1, by 17.9% at month 6, and by 15.0% after 24 months (Tab. I).

Two years postoperatively, in Group 1, 4 eyes (5%) had UCVA of 0.05; 54 eyes (69%) had 0.00; 14 eyes (18%) achieved enhanced visual acuity of –0.18; and 6 eyes (8%) achieved –0.30. In Group 2, 4 eyes (8%) had UCVA of 0.10; 12 eyes (25%) had 0.05; and 32 eyes (67%) had 0.00. None of the eyes achieved enhanced visual acuity. The efficacy index (ratio of postoperative UCVA and preoperative BSCVA) was 1.17 for Group 1 and 0.98 for Group 2.

Safety

One month after surgery, in Group 1, 26% of the treated eyes gained one line of Snellen BSCVA; 15% gained two lines. Six months after wavefront-guided PRK 23% of the eyes gained one line; 13% gained two lines. After 2 years 22% gained one line and 11% gained two lines of Snellen BSCVA. None of the eyes lost any Snellen line (Fig. 1).

One month after surgery in Group 2, 17% of the treated eyes gained one line of Snellen BSCVA. Six and 24 months after conventional PRK 12% of the eyes gained one line. None of the eyes gained two lines, but 4% of the eyes lost one Snellen line because of coma aberration increasing which influenced patient visual quality considerably (Fig. 2).

TABLE I - MEASUREMENT OF UCVA AND BSCVA BEFORE AND 1, 6, AND 24 MONTHS AFTER TREATMENT WITH WAVEFRONT-GUIDED AND SPHEROCYLINDRICAL CONVENTIONAL PRK ACCORDING TO LOGMAR CALCULATION METHOD

	Preop		1 mo postop		6 mo postop		24 mo postop	
	Mean value	**p value**	**Mean value**	**p value**	**Mean value**	**p value**	**Mean value**	**p value**
UCVA								
Group 1	1.00±0.47		–0.06±0.10		–0.05±0.10		–0.05±0.10	
Group 2	0.98±0.44	0.8418	0.02±0.05	0.0000*	0.01±0.02	0.0000*	0.01±0.03	0.0000*
BSCVA								
Group 1	0.00±0.00		–0.09±0.12		–0.08±0.11		–0.08±0.11	
Group 2	0.00±0.01	0.0701	–0.03±0.07	0.0021*	–0.02±0.06	0.0013*	–0.02±0.06	0.0033*

Data are mean ± SD
*Significant difference compared to preoperative value
UCVA = Uncorrected visual acuity; BSCVA = Best spectacle-corrected visual acuity; PRK = Photorefractive keratectomy

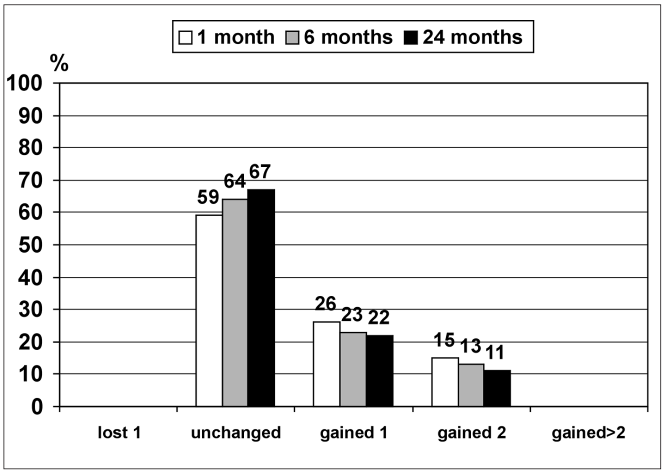

Fig. 1 - *Changes in best spectacle-corrected visual acuity 1, 6, and 24 months after wavefront-guided photorefractive keratectomy in 78 eyes.*

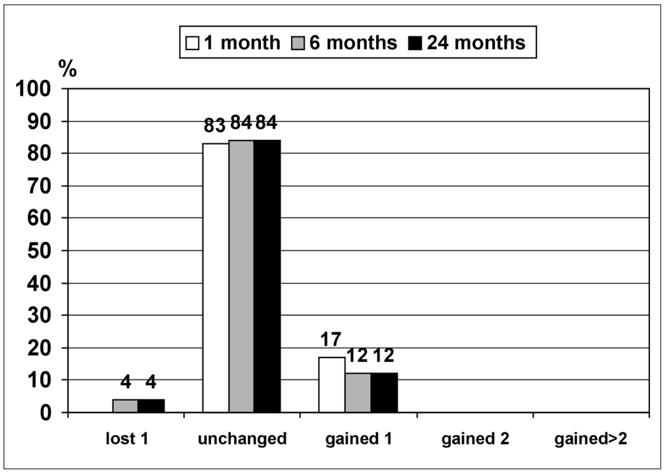

Fig. 2 - *Changes in best spectacle-corrected visual acuity 1, 6, and 24 months after conventional photorefractive keratectomy in 48 eyes.*

Stability

The change of mean SE in Group 1 between the 1 month and 6 month examinations was –0.22 D and 0.26 D between 6 month and 2 year results. In Group 2 the change of mean SE between the 1 month and 6 month examinations was –0.24 D and 0.24 D between 6 month and 2 year results. The overall regression from 1 month to 24 months was –0.04 D in Group 1 and 0.00 D in Group 2.

Patient satisfaction questionnaire

Patient satisfaction questionnaires were obtained preoperatively and at months 1, 6, and 24. Patients were asked about night vision, glare, and halo. Twenty-four months after wavefront-guided PRK glare manifested 1.3% (1 eye), halo 1.3% (1 eye) of treated eyes in Group 1. In the same observation period in the control group 8.3% (4 eyes) manifested glare and 10.4% (5 eyes) manifested halo.

Higher order wavefront aberrations

In order to estimate changes in optical aberrations before and after PRK in the wavefront-guided and the conventional group the following parameters were measured and analyzed: RMS OPD HO - root mean square value of optical path difference (OPD) for higher order aberrations; PV OPD HO - peak-to-valley optical path difference for higher order aberrations; third order aberrations (trefoil, coma); fourth order aberrations (quatrefoil, secondary astigmatism, spherical aberration). The preoperative values of all parameters in the wavefront-guided and the conventional group were comparable. Coefficient RMS OPD HO and coefficient PV OPD HO increased statistically significantly in both groups after surgery. In Group 1 coefficient RMS OPD HO increased by a factor 1.35 in the first month, by 1.29 in the sixth month, and by 1.18 in the 24th month after surgery. In Group 2, RMS OPD HO increased accordingly by a factor 1.88, 2.00, and 1.56 in the first, sixth, and 24th month of observation. Coefficient PV OPD HO increased by 31.0% in the first, by 23.0% in the sixth, and by 17.0% in the 24th month in Group 1, and in Group 2 accordingly by 84.4%, 93.8%, and 51.0% in the first, sixth, and 24th month of observation in comparison to coefficient values before surgery. Increased values of both coefficients in the group of patients who had conventional PRK was statistically significantly higher in comparison to the group of patients treated with wavefront-guided procedure (WASCA) (Tab. II).
Comparison of third order aberrations between Groups 1 and 2 in the whole follow-up period displayed statistically significant higher trefoil and coma aberrations in patients treated with conventional PRK. It is important to note the evidence of the increase of coma aberration (by 74.1%) in Group 2 24 months after surgery in comparison to the value before surgery. In Group 1 the wavefront-guided pro-

TABLE II - COMPARISON OF RMS OPD HO AND PV OPD HO BEFORE AND 1, 6, AND 24 MONTHS AFTER TREATMENT WITH WAVEFRONT-GUIDED AND SPHEROCYLINDRICAL CONVENTIONAL PRK

	Preop		1 mo postop		6 mo postop		24 mo postop	
	Mean value	**p value**	**Mean value**	**p value**	**Mean value**	**p value**	**Mean value**	**p value**
RMS OPD HO								
Group 1	0.17±0.02		0.23±0.02		0.22±0.02		0.20±0.02	
Group 2	0.16±0.03	0.8926	0.30±0.05	0.0028*	0.32±0.04	0.0000*	0.25±0.04	0.0172*
PV OPD HO								
Group 1	1.00±0.13		1.31±0.15		1.23±0.11		1.17±0.14	
Group 2	0.96±0.17	0.6907	1.77±0.30	0.0024*	1.86±0.25	0.0000*	1.45±0.20	0.0146*

Data are mean ± SD
*Significant difference compared to preoperative value.
RMS OPD HO = Root mean square value of optical path difference for higher order aberrations; PV OPD HO = Peak-to-valley optical path difference for higher order aberrations; PRK = Photorefractive keratectomy

cedure not only changed coma type aberration but trefoil type aberration decreased statistically significantly (by 34.8%) in the 24th month of observation.

Only spherical aberrations from the fourth order aberrations were statistically significantly higher after surgery in both groups. However, the comparison of fourth order postsurgical aberrations between Group 1 and Group 2 displayed statistically significantly higher spherical aberrations in patients treated with conventional PRK. After the wavefront-guided procedure spherical aberration increased by a factor 2.64 in the first month, by 2.45 in the sixth month, and by 2.09 in the 24th month of observation. After conventional PRK spherical aberrations increased accordingly by 4.56 in the first month, by 4.44 in the sixth month, and by 3.56 in the 24th month of observation (Tab. III).

DISCUSSION

At the beginning of the 21st century, refractive surgery can be united with customized corneal ablation. Wavefront-guided refractive surgical treatments are based on data taken directly from patients' eyes, rather than on manifest refraction. For the first time, surgeons are not limited to correcting sphere and cylinder only, but we have the means to assess and treat higher order aberrations as well (1, 15, 16). Several studies report an increase in optical wavefront aberrations after refractive surgery with laser-assisted in situ keratomileusis (LASIK) as with PRK (17-21). Oshika et al (19) reported an increase in higher order corneal aberrations after refractive surgery, although they observed a greater induction of spherical-like aberrations after LASIK. Pallikaris et al (22) and other authors (19, 23) suggested that LASIK induces coma aberrations. Marcos and coauthors (3) reported that total and corneal aberrations increased after LASIK and that spherical-like aberrations in the anterior corneal surface were greater than in the entire eye. Some authors suggest that PRK is a more suitable technique than LASIK to treat higher order aberrations, because the LASIK flap cut itself induces significant higher order aberrations (9, 13, 14). Panagopoulou found a 1.3-times increase in RMS value following PRK, and after LASIK, the increase was 1.6 times (14). Mrochen and coauthors (9) reported increase of third order aberrations in 48.4%, and fourth order and higher in 22.5% of cases after wavefront-guided LASIK. Nagy et al (13) reported increase of RMS OPD HO by 31.3% in 6 months after wavefront-guided PRK. Panagopoulou and coauthors (14) had similar results.

Two years postoperatively in our study group we found a 1.18-times increase in RMS OPD HO value following WASCA-guided PRK and 1.6-times increase in the control group. We noticed a significant increase in coma by a factor 1.74 only in the control group and spherical aberration by a factor 2.09 in the study group and 3.56 in the control group. There is clinical evidence that ocular wavefront aberrations of higher order are the main reason for de-

TABLE III - COMPARISON OF THIRD AND FOURTH ORDER ABERRATIONS BEFORE AND 1, 6, AND 24 MONTHS AFTER TREATMENT WITH WAVEFRONT-GUIDED AND SPHEROCYLINDRICAL CONVENTIONAL PRK

	Preop		1 mo postop		6 mo postop		24 mo postop	
	Mean value	**p value**	**Mean value**	**p value**	**Mean value**	**p value**	**Mean value**	**p value**
Trefoil								
Group 1	0.23±0.04		0.24±0.04		0.20±0.03		0.15±0.03	
Group 2	0.30±0.08	0.0964	0.36±0.09	0.0030*	0.38±0.07	0.0000*	0.29±0.09	0.0027*
Coma								
Group 1	0.31±0.06		0.36±0.06		0.37±0.06		0.36±0.06	
Group 2	0.27±0.07	0.4042	0.48±0.12	0.0392*	0.51±0.11	0.0210*	0.47±0.10	0.0362*
Quatrefoil								
Group 1	0.09±0.02		0.13±0.02		0.11±0.01		0.07±0.02	
Group 2	0.09±0.02	0.7283	0.14±0.03	0.6839	0.12±0.03	0.2434	0.10±0.03	0.1678
Spherical aberration								
Group 1	0.11±0.03		0.29±0.06		0.27±0.03		0.23±0.05	
Group 2	0.09±0.03	0.2805	0.41±0.09	0.0262*	0.40±0.07	0.0010*	0.32±0.03	0.0045*
Secondary astigmatism								
Group 1	0.11±0.02		0.19±0.04		0.15±0.02		0.13±0.03	
Group 2	0.10±0.05	0.7833	0.23±0.07	0.3703	0.21±0.06	0.0377*	0.14±0.05	0.4609

Data are mean ± SD
*Significant difference compared to preoperative value
PRK = Photorefractive keratectomy

creased visual performance after refractive surgery (6, 18, 20). Ideal corrections may come in the form of customized corneal corrections. One of the benefits of reducing higher order aberrations is to improve the patient's visual acuity. Some authors show a high correlation between corneal aberrations and visual performance (24, 25). Customized corneal ablation is a surgical procedure designed to improve the visual quality of the eye. A goal of wavefront-guided refractive surgery is to improve visual performance by minimizing the RMS error. Reducing the optical aberrations to zero is not realistic. A near-term goal of refractive surgery is to not induce any new aberrations while correcting the sphere and cylinder. Recent US Food and Drug Administration submission data using wavefront-guided flying spot laser corneal surgery using the Alcon CustomCornea showed that induced aberrations are about one half the magnitude of traditional surgery. Studies by Alcon investigators found that approximately 30% of eyes have higher order aberrations that are less than presurgical levels (Brint S. Wavefront guided custom cornea for correction of previously operated eyes: case studies. Presented at the 2002 International Society of Refractive Surgery; Orlando, FL; October 2002). Nagy and coauthors (13) reported the results of WASCA-guided PRK in 6 months follow-up. The differences between preoperative and postoperative UCVA and BSCVA were statistically significant. UCVA and BSCVA at month 3 were better than at month 1. At month 6 after surgery 80.7% of patients had UCVA 0.00 or better, and 2% had –0.10. In 71.3% of postoperative cases BSCVA was the same as preoperatively. In 20% of cases BSCVA increased by one line; in 6.7% of eyes it increased by two lines, and in 1.3% of patients it increased by three lines. Mrochen and coauthors (9) reported the results of wavefront-guided LASIK. In 41.9% of treated patients UCVA was –0.08 or better after 3 months.

It should be noted that reduction of higher order aberrations is important, because higher order aberrations of the cornea induced by refractive surgery, combined with naturally occurring aberrations, affects visual performance after surgery.

CONCLUSIONS

Wavefront-guided PRK using a WASCA workstation is safe and effective for corrections of myopia up to –6.0 D with astigmatism up to –3.75 D. This method reduced the number of higher order aberrations induced by excimer laser surgery and improved uncorrected and spectacle-corrected visual acuity when compared to conventional PRK.

No author has a financial or proprietary interest in any material or method mentioned.

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